Environmental Factors Causing Fatigue in Equipment Operators During Winter Operations

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16. Abstract

This report presents the final results of a three-part data collection effort to investigate causes of fatigue in operators during winter emergencies. Naturalistic driving and actigraph data were collected from four winter maintenance operators, and questionnaires were collected from 1,043 winter maintenance operators and 453 winter maintenance managers. More than 368 hours of valid on-road data were collected, including 338 hours (24 days) of winter emergency operations and approximately 30 hours of non-winter emergency operations. Additionally, more than 6,600 hours of actigraph data were collected from the four winter maintenance operators. An analysis of the literature review, naturalistic and actigraph data, and questionnaires resulted in the following list of cost-effective, realistic recommendations for reducing/eliminating operator fatigue: winter maintenance operator fatigue training, encouraged use of breaks/naps, fatigue education for winter maintenance managers, increased winter maintenance vehicle maintenance, investigation of winter emergency shift start/end times and shift length, an offer of shift options, involvement of winter maintenance operators in the decision-making process, and an increase in management's personal interactions with winter maintenance operators.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AMI	Ambulatory Monitoring, Inc.
ANSI	American National Standards Institute
CMV	Commercial motor vehicle
DAS	Data acquisition system
dB	decibels
FMCSA	Federal Motor Carrier Safety Administration
GPS	Global positioning system
HOS	Hours of service
Hz	hertz
ID	Identification
In.	inch
ISO	International Organization for Standards
mg	milligrams
NRT	National Response Team
ORD	Observer rating of drowsiness
PERCLOS	Percent of eye closures
PC	Personal computer
SCE	Safety-critical event
SR	Sleep-related
SV	Subject vehicle
TR	Task-related
VDOT	Virginia Department of Transportation
VTTI	Virginia Tech Transportation Institute

EXECUTIVE SUMMARY

BACKGROUND

Research has shown that fatigue impairs and degrades driving performance by changing the behavior of the driver (here, fatigue is meant to imply either activity- or sleep-related drowsiness). A number of risk factors contribute to fatigue in commercial motor vehicle (CMV) drivers, including varying work schedules; unusual work shifts, such as night driving; and long, monotonous driving conditions, such as on interstates. Previous research has shown fatigue to be the primary cause or a contributing factor in up to 31 percent of truck crashes (Federal Motor Carrier Safety Administration, 2006; Knipling and Wang, 1994).

Although the research concerning fatigue in winter maintenance drivers is sparse, much of the research relating fatigue to CMV drivers can be applied to winter maintenance personnel. For example, inconsistent and varying schedules, which have been shown to contribute to fatigue in CMV drivers, are inherent in the job of winter maintenance drivers due to the unpredictability of winter storms. Also, winter maintenance drivers are generally required to work long shifts while performing many activities in addition to driving (e.g., communicating with central office personnel or monitoring the application of de-icing agents) during winter emergencies (it should be noted that winter maintenance operators are not subject to hours-of-service [HOS] regulations). This situation can lead to the onset of task-related active fatigue. The literature review in the current report found the following factors could be used to reduce the level of fatigue in winter maintenance drivers: mitigating driver stress, scheduling practices offering more opportunities for rest/sleep, improving management's attitude towards rest and fatigue, improving the ergonomic design of the cab, increasing off-duty rest while limiting activities prior to a shift, and implementing fatigue management technologies.

PROJECT SUMMARY

The goal of the current project was to develop a series of cost-effective, realistic recommendations for reducing or eliminating fatigue in equipment operators during winter emergency operations. Three data collection efforts were performed to accomplish this goal. The first involved a literature review to identify factors that may cause driver fatigue during winter maintenance operations. The second involved the collection of naturalistic driving and actigraph data to investigate issues related to winter maintenance operator fatigue during winter operations. The third effort involved the collection of qualitative information from winter maintenance operators and management personnel to assess major facets of winter maintenance operator fatigue.

METHODS

Participants

Four winter maintenance operators from the Virginia Department of Transportation (VDOT) were recruited to participate in the naturalistic driving study. All four drivers completed three months of participation in the study (January 24, 2013, to April 29, 2013). A total of 1,043 winter maintenance operators and 453 managers from 24 Clear Roads member states completed questionnaires.

Data Collection

A diverse set of on-road driving and participant (non-driving) naturalistic data were collected during the study, including: driver input/performance measures (e.g., speed, acceleration, lane position), five camera views, actigraph measures (for sleep quantity), and a demographic questionnaire. The data acquisition system (DAS) instrumented in the winter maintenance trucks included three major components: sensors, vehicle network, and video cameras. Each component became active when the ignition system of the truck was initiated. Data collection software was developed to coordinate the data collection from those different DAS components and to integrate the data into a specific DAS output file linked to the video.

Two questionnaires were developed to assess major facets of fatigue, work and rest schedules, and how work schedules affected winter maintenance operator fatigue. The first questionnaire targeted winter maintenance operators, and a second parallel questionnaire targeted winter maintenance managers. These two surveys identified factors that contribute to winter maintenance operator fatigue; served as a baseline to measure awareness, attitudes, and behavior of the participating agencies regarding winter maintenance operator fatigue; provided a comparison of winter maintenance operators' and managers' perceptions regarding fatigue; and collected information about existing practices to mitigate fatigue-related incidents and to decrease the impact of fatigue in winter maintenance operations.

Data Reduction

A specialized software program called Hawkeye was used to support analyses for the on-road driving data. Data reduction started with identifying events of interest. Hawkeye scanned the on-road driving data set for notable actions (e.g., hard braking and quick steering maneuvers), and potential events of interest were identified for validation. Valid events were classified into one of seven safety-critical events (SCEs): crash, crash: low-hanging branch, tire strike: avoidable, tire strike: unavoidable, near-crash, crash-relevant conflict, and illegal maneuver. These events were analyzed in detail with an established coding directory.

RESULTS

Naturalistic Driving Data

Ninety-two SCEs were observed during the three months of data collection. Noteworthy results from the naturalistic driving data collection are presented below.

- Out of the 92 SCEs, 3.26 percent were crashes, 17.39 percent were crashes with low-hanging branches covered with snow/ice, 3.26 percent were avoidable curb strikes, 22.83 percent were near-crashes, and 53.26 percent were crash-relevant conflicts.
- Drivers were at least moderately drowsy during 35.9 percent of the SCEs.
- The majority of the drowsy driving SCEs (63.6 percent) occurred in the circadian low between 2:00 a.m. – 6:00 a.m.

- Fatigue was the critical reason in 28.3 percent of the SCEs.

Actigraph Data

A total of 516,867 minutes of actigraph data were collected during a three-month period. Table 1 shows a summary of the mean sleep for each participant. Overall, drivers averaged less sleep during winter emergencies versus non-winter emergencies. However, as shown in Table 1, much of the difference was likely due to Participant #1.

Table 1. Actigraph Sleep Summary (in hours)

Participant #	Daily Sleep	Daily Sleep during Non-Winter Emergency	Sleep 24 Hours Prior to Winter Emergency	Sleep during Consecutive Winter Emergency Shifts	Sleep 24 Hours Prior to SCE
1	8.05	8.63	6.31	7.48	4.55
2	10.04	10.66	8.58	8.71	8.83
3	8.12	8.10	8.26	8.32	8.02
4	8.64	8.53	8.31	8.73	7.81
Average	**8.71**	**8.98**	**7.87**	**8.31**	**7.30**

Questionnaire Data

Data from both questionnaires provided valuable insight into the perceptions and opinions of winter maintenance operators and managers regarding fatigue in winter maintenance operations. Below are some of the key results.

- The majority of winter maintenance operators and managers indicated fatigue had a “moderate impact” on winter maintenance operations. Winter maintenance operators were more likely than managers to report greater impacts of fatigue, and younger winter maintenance operators were more likely to report lower impacts of fatigue compared to older winter maintenance operators.
- Most winter maintenance operators and managers reported that fatigue was “sometimes” experienced while operating a snow plow during winter emergencies. However, managers indicated fatigue was experienced more frequently by winter maintenance operators than winter maintenance operators’ self-reports. Additionally, winter maintenance operators that experienced fatigue while operating a snow plow were more likely to report greater impacts of fatigue.
- Managers indicated that winter maintenance operators had more frequent lapses in concentration while operating a snow plow during a winter emergency when compared to the winter maintenance operators’ self-reports.

- Vibration, seat type, noise, heavy traffic, lights, too much technology, and nighttime operations were all reported to be important sources of fatigue by winter maintenance operators and managers.
- Managers were more likely than winter maintenance operators to indicate that winter maintenance operators prefer driving to taking a break.
- In general, winter maintenance operators and managers indicated adequate knowledge concerning effective strategies to combat fatigue. However, winter maintenance operators reported limited use of those strategies shown to be most effective in reducing fatigue (e.g., taking breaks, moving one's body, and naps).

CONCLUSIONS

The main objective of the current project was to develop a series of cost-effective, realistic recommendations for reducing or eliminating fatigue impacting equipment operators during winter emergency operations. The research team used three data collection efforts to accomplish this objective: literature review, naturalistic driving and actigraph data, and winter maintenance operator and manager questionnaires.

Most of the literature came from CMV studies. Although the current study did not focus on CMV drivers, winter maintenance operators are occupational drivers and may experience many of the same negative effects as CMV drivers. This research found fatigue to be the critical reason in 28.3 percent of the SCEs. This is consistent with the results obtained by Knipling and Wang (1994). However, a closer inspection of the data revealed that one participant accounted for all of the fatigue-related SCEs. In other words, three of the four participants in the current study did not have any fatigue-related SCEs, while Participant #1 was at least moderately drowsy during 63.5 percent of the SCEs. Also, four winter maintenance operators compose a very small sample. Therefore, these data should not be used to make any general comparisons, nor are the participant winter maintenance operators and their data representative of the population of winter maintenance operators. Instead, the study data illustrate the feasibility of conducting a naturalistic driving study during winter maintenance operations and the need for a larger naturalistic study with winter maintenance operators to more accurately assess fatigue.

Questionnaire results showed that winter maintenance operators and managers were familiar with the adverse effects of fatigue in winter maintenance operations. In general, winter maintenance operators and managers agreed on the sources of fatigue, the impact of fatigue on safety, and the use and effectiveness of fatigue countermeasures. However, winter maintenance operators reported limited use of the strategies shown to be the most effective in reducing fatigue (e.g., taking breaks, moving one's body, naps).

The following list of cost-effective, realistic recommendations for reducing or eliminating winter maintenance operator fatigue were derived from the literature review, naturalistic and actigraph data, and the winter maintenance operator and manager questionnaires (listed in no specific order).

- **Encourage use of breaks/naps:** Management should continue to encourage winter maintenance drivers to take breaks/naps when fatigued/tired. Results from the questionnaires revealed there was little emphasis on the use of body movement and naps to reduce fatigue.

- **Encourage winter maintenance operator fatigue reporting:** A system, possibly confidential, should be developed to encourage and reinforce winter maintenance operators' self-reports of fatigue. Questionnaire results showed that managers underestimated the impact of fatigue in winter maintenance operators. This may be due to winter maintenance operators underreporting fatigue and fatigue-related incidents.
- **Increased vehicle maintenance:** Winter maintenance operators and managers suggested increased vehicle maintenance as a method to reduce unnecessary truck vibrations and noise. Updated equipment (e.g., rubber blades) was frequently reported as a method to reduce vibrations and noise. Care should be taken to ensure that components used to reduce fatigue, such as those that reduce outside noise and minimize whole-body vibrations, are kept in a good state of repair.
- **Investigate winter emergency shift start/end times (including shift length):** Research shows an increased risk of winter maintenance operator fatigue during circadian lows (between 2:00 a.m. and 6:00 a.m.). Thus, staring or ending a shift during these times may be dangerous. This may also be the best time to encourage drivers to take a break. Furthermore, winter maintenance operators may be at an increased risk of fatigue at the start of a shift and after an extended period of driving. Shift start and end times should be assigned with consideration of circadian lows. As non-driving activities impact the winter maintenance operator's level of fatigue, shift length should take into consideration any possible non-driving responsibilities.
- **Offer shift options:** Winter maintenance operators' rest periods preceding their shifts should be taken into account when scheduling shifts. Research shows sleep schedules that do not correspond to the circadian rhythm tend to provide inadequate amounts of rest. Therefore, if the winter maintenance operator was required to work a night shift just prior to being scheduled, this should be considered by management before requiring another night shift.
- **Involve winter maintenance operators in the decision-making process:** Managers suggested involving winter maintenance operators in the decision-making process. Winter maintenance operators have first-hand knowledge of the impact of fatigue and often have thoughtful suggestions about operational improvements. Additionally, involving winter maintenance operators in the decision-making process will help develop an effective safety culture that minimizes operator fatigue.
- **Increase personal interactions with winter maintenance operators:** Managers suggested increased personal interactions with winter maintenance operators as a method to reduce fatigue. This interaction will help managers identify fatigued winter maintenance operators and additional methods to combat fatigue. Such interaction will also help develop an effective safety culture that minimizes winter maintenance operators' fatigue.
- **Free Resources:** There are several education and training resources available to assist safety managers in dealing with fatigue and implementing some of the recommendations described above. The first is the North American Fatigue Management Program (NAFMP, www.nafmp.com). The NAFMP is designed to address the issue of driver fatigue using a

comprehensive approach on corporate culture, fatigue education, sleep disorders screening and treatment, driver and trip scheduling, and fatigue management technologies. Also, the Commercial Motor Vehicle Driving Safety (http://cmvdrivingsafety.org/) website has a training module on driver drowsiness and fatigue.

1. LITERATURE REVIEW

Research has shown that fatigue impairs and degrades driving performance by changing the behavior of the driver. A number of risk factors contribute to fatigue in commercial motor vehicle (CMV) drivers, including varying work schedules; unusual work shifts, such as night driving; and long, monotonous driving conditions, such as on interstates. The Large Truck Crash Causation Study conducted by the Federal Motor Carrier Safety Administration (FMCSA) reported that approximately 4 percent of truck crashes were primarily caused by the driver sleeping at the wheel, and 13 percent involved driver fatigue as an associated factor (FMCSA, 2006). Also, fatigue was the primary factor in 31 percent of 182 truck crashes that were fatal to the driver and were investigated in 1990 by the National Transportation Safety Board (Knipling and Wang, 1994).

Fatigue in the work environment has been assessed among many different disciplines, especially in the case when long hours occur within complex work environments. Along with CMV drivers, disaster mitigation workers, medical residencies, and air traffic controllers are some of the other professions in which extensive research pertaining to fatigue has been conducted (Nunes et al., 2012; The National Response Team [NRT], 2009; West et al., 2009). In many cases, the results of the research within the different disciplines can be generalized to other professions that include complex work environments and long working hours.

The terms "fatigue" and "drowsiness" are often used interchangeably in discussions of their impact on drivers. However, the causes of fatigue and drowsiness are fundamentally different, although their symptoms are generally the same. Fatigue is a physiological state that results in many symptoms, such as drowsiness and a reduction in task-related effort (Matthews et al., 2011). Drowsiness can be a result of fatigue, but it can also be due to other factors, such as a lull in the body's natural circadian rhythm or poor sleep quantity or quality (Ferguson et al., 2012). Lal and Craig (2001) defined fatigue as the transitory period between wakefulness and sleep that, if not addressed, would lead to a state of sleep. Fatigue has been shown to adversely impact people in the following ways: changes in performance, impaired logical reasoning and decision making, reduced situational awareness, and poor assessment of risk or failure to appreciate the consequences of certain actions (Baulk et al., 2008; Desmond and Hancock, 2001; Lyznicki et al., 1998). Although fatigue and drowsiness are scientifically different, this paper will use the word "fatigue" hereafter to refer to a person's propensity to feel sleepy, regardless of its genesis.

Studies use various methods to assess driver fatigue, but some of the most common methods are driving simulators, crash data from police accident reports (i.e., crash data and driving logs), and naturalistic driving studies. Hanowski et al. (2008) described a study that used naturalistic data in which unobtrusive data collection equipment installed in the vehicle took measures while the driver performed his or her normal driving tasks over a period of time. By contrast, driving simulators are generally seen as a safe and controlled way to study risky driving behaviors (Rossi et al., 2011).

In general, research has identified two types of fatigue in drivers: task-related (TR) and sleep-related (SR) fatigue. TR fatigue is associated with the tasks of driving, as well as the attention and focus required for the given driving conditions (May and Baldwin, 2009). For example, driving in a high-stress environment while completing work-related tasks may lead to TR fatigue. SR fatigue is related to the time of day (circadian rhythms) and other SR factors (May and Baldwin, 2009).

An example would be a driver beginning to drive after an inadequate rest period or continuing to drive without a restorative period of sleep. Haworth et al. (1988) discuss fatigue as a neurological phenomenon stemming from levels of arousal, and an optimal level of arousal experienced by a driver minimizes fatigue. In this case, overarousal of the senses would be similar to active fatigue, as presented by May and Baldwin (2009), such as sustained driving under demanding conditions. Underarousal of the senses is comparable to the passive TR fatigue, as presented by May and Baldwin (2009), such as driving during monotonous and underdemanding conditions.

Error! Reference source not found. summarizes the two types of fatigue (SR and TR fatigue, which can be divided into active and passive). The current research has categorized several factors expected to contribute to each type of fatigue: the impact of trucks (e.g., the in-cab environment and technologies existing in modern work vehicles), sleep deprivation, winter conditions (e.g., ice and snow on the roads), cold temperatures, traffic, scheduling and shift policies, and equipment (e.g., fatigue management technologies).

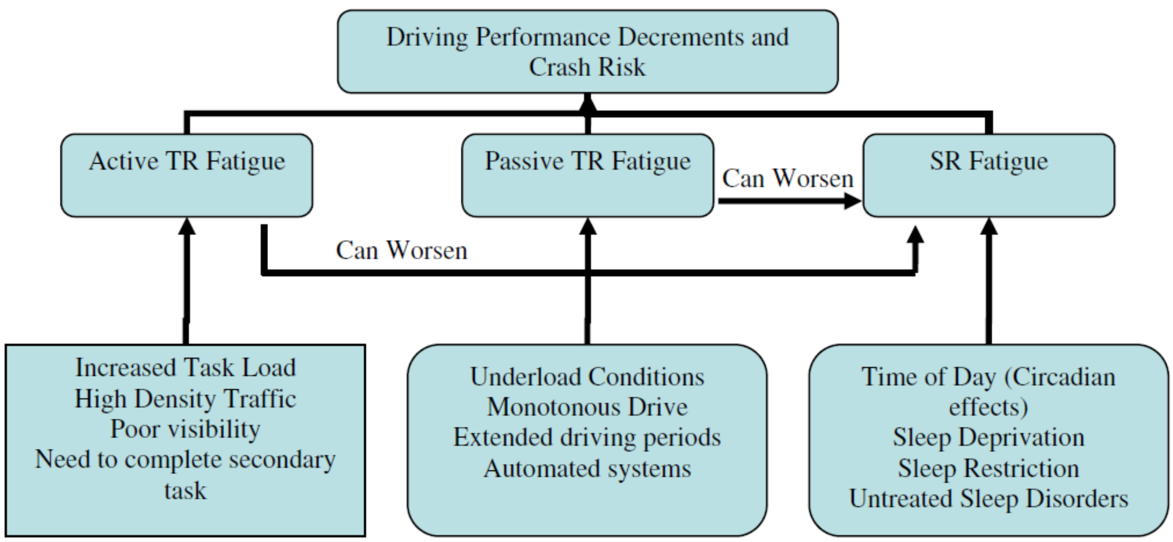

Figure 1. Two Types of Fatigue (May and Baldwin, 2009)

1.1 POTENTIAL IMPACT OF FATIGUE

Fatigue has been shown to adversely impact people in the following ways: changes in performance, impaired logical reasoning and decision making, reduced situational awareness, and poor assessment of risk or failure to appreciate the consequences of certain actions (Baulk et al., 2008; Bloomfield et al., 2009; Desmond and Hancock, 2001; Lyznicki et al., 1998). Completing a task while in a fatigued state has been shown to lead to increased medical errors among resident physicians (West et al., 2009), and fatigue significantly impacts the efforts of disaster response teams (NRT, 2009). In each of the cases where fatigue has been recognized as a significant factor in the degradation of the safety and quality of the work environment, mitigation efforts are being made to reduce the effects of fatigue. In many cases, the mitigation efforts stemming from research efforts include modifying the work schedule to include breaks (Baulk et al., 2008; Blanco et al., 2011), scheduling naps in the work schedule (Bonnefond et al., 2001; Jovanis et al., 2011), changing the work environments (e.g., the design of the truck cab; Boggs and Ahmadian, 2007;

Paschold and Mayton, 2011), and accounting for the complexity of the work tasks when scheduling shift lengths (Nunes et al., 2012; NRT, 2009).

1.2 IMPACT OF TRUCKS

Noise, body posture, and vibration transferred from the truck to the driver are some of the factors that are controlled by the ergonomic design of the truck and cab, and they can directly impact driver stress, fatigue, and performance (Boggs and Ahmadian, 2007; Paschold and Mayton, 2011). Many modern CMVs are designed to mitigate fatiguing factors by using vibration isolation systems or by using materials that reduce noise coming from the outside environment. However, the mitigating impact of some components, such as foam seat cushions, decreases with age.

Whole-body vibrations experienced by CMV drivers have been shown to directly and adversely impact driver fatigue (Paschold and Mayton, 2011). Vibrations of a certain frequency can cause muscle contractions, which lead to fatigue and reduced motor performance. Furthermore, particular body parts and internal organs vibrate at particular resonant frequencies, which amplify the vibrations and can cause discomfort or injury (Paschold and Mayton, 2011). Lower back fatigue caused by increased muscle contractions stimulated by whole-body vibrations may be exacerbated by the driver's seated position (Hansson et al., 1991).

Manufacturers of most modern CMVs have realized the importance of designing and maintaining dampening systems to sustain a particular frequency of vibration within the truck cab. For example, research has shown that the first resonant frequency of the human spine occurs at approximately 5 hertz (Hz), which increases the axial load on the spine by a factor of two or three (Wilder et al., 1994). Thus, vibrations near 5 Hz should be avoided when designing the suspension. Generally, the design of these vibration isolation systems follows the International Organization for Standardization (ISO; ISO 2631-1:1997 *Mechanical shock and vibration: Evaluation of human exposure to whole-body vibration*) or the American National Standards Institute (ANSI; ANSI S3.18:2002 *Guide for the evaluation of human exposure to whole-body vibration*). These standards specify the range of vibrations that should be designed for, how to measure the vibrations, and how to evaluate the design of the vibration isolation systems.

In addition to vibrations, the design of the vehicle seat has been directly related to driver fatigue. In a study to determine the differences between traditional foam seat design and air-cushioned seats, Boggs and Ahmadian (2007) found that drivers generally reported less fatigue across driving periods when using air-cushioned seats versus traditional foam seats. It is thought the reduction of fatigue may be due to increased resiliency of the air-cushioned seat (as opposed to foam, which becomes hard over time) and its adjustability.

Noise has also been identified as a factor that can lead to increased fatigue over time (Haworth et al., 1988). Some research has shown that noise can be a stimulant during monotonous tasks. However, fatigue that is induced by noise can be exacerbated in high-stress environments. The effect of noise has been described as a stressor, which, along with the cumulative effect of driving in a high-stress environment, induces higher levels of fatigue than either factor separately (Haworth et al., 1988). However, research has reported that effects that adversely impact driver performance have not been shown in the presence of noise levels less than 90 decibels (dB), emphasizing the impact of a controlled environment within CMV cabs (Haworth et al., 1988).

1.3 SLEEP DEPREIVATION

Sleep deprivation is a critical factor leading to driver fatigue and drowsiness. Sleep deprivation can be split into total sleep deprivation, or a period of wakefulness that extends beyond a period of average daily wakefulness; and partial sleep deprivation (sleep restriction), or a period during which some sleep is obtained but not enough to be considered restorative (Balkin et al., 2000). Sleep deprivation has been associated with fatigue in many professions, including overnight industrial workers (Bonnefond et al., 2001), air traffic controllers (Signal et al., 2009), and medical professionals (West et al., 2009). In many of these cases, sleep deprivation interacted with other factors, such as length of shift and complexity of the job environment. The current report will refer to both types as sleep deprivation. Crum and Morrow (2002) reported the most important factor influencing fatigue was whether the driver began the work week with less than adequate sleep (i.e., tired). Furthermore, scheduling policies that interfered with the driver's rest period (i.e., did not give adequate time to rest) were significant factors in driver fatigue.

As stated, driver fatigue can be sub-categorized into SR and TR fatigue based on causative factors (May and Baldwin, 2009). Some of the SR factors that contribute to fatigue are sleep deprivation, extended duration of wakefulness, and troughs in the circadian rhythm. It has been demonstrated that extended time awake, an inadequate amount of sleep, and time of day all increase fatigue among drivers (Ferguson et al., 2012). Horne and Reyner (2001) analyzed extensive crash data to separate vehicle crashes caused by SR fatigue from crashes caused by other factors. They concluded the only two significant deterrents of SR vehicle crashes were a nap or 150 to 200 milligrams (mg) of caffeine (Horne and Reyner, 2001). Activities such as turning the air conditioner on, briefly exercising, or rolling down the windows only provided momentary relief from feelings of sleepiness.

Numerous studies have shown the strong impact of the body's circadian rhythm on SR fatigue (Ferguson et al., 2012; May and Baldwin, 2009). A circadian rhythm acts as a biological clock and manifests as a lull in a person's energy level during certain points of time during a 24-hour period (Monk, 1991). The lull in the circadian rhythm corresponds to an increased propensity to sleep, and it generally occurs at two points throughout the day and night: typically, the early morning and early afternoon. On average, the greatest propensity to sleep has been reported to occur between the hours of 02:00 to 06:00 (2:00 a.m. to 6:00 a.m.) and 14:00 to 16:00 (2:00 p.m. to 4:00 p.m.; Horne and Reyner, 2001; Lyznicki et al., 1998).

Folkard (1997) reported clear temporal peaks in crash rates during the very early morning, which he referred to as "driving black times." The research indicated a clear relationship between an increase in crash rates and the corresponding time for an expected lull in the circadian rhythm. However, several other peaks in crashes were observed. These "black times" were signified by a reduction in performance across many sectors, including drivers and industrial workers. It was observed the "black times" could largely be defined by sleep propensity or circadian rhythms, but circadian rhythms were not the only factor affecting the temporal distribution of the "black times."

Folkard concluded that time spent on a task must be taken into account, along with the time of day, to describe these temporal "black times" while driving.

A study conducted at the University of Minnesota Center for Human Factors Systems Research and Design evaluated the effect of sleep deprivation on the driving habits of CMV drivers (Bloomfield et al., 2009). The study was conducted using a driving simulator. The test subjects were allowed to consume caffeine and use tobacco products during the study to simulate more realistic driving habits, although the participants were required to exit the study building to smoke tobacco products. The study concluded that the steering behavior of CMV drivers is likely to be impared if the driver is awake from 8:00 or 9:00 a.m. to the time they attempt to drive 18 or more hours later (2:00 or 3:00 a.m.; Bloomfield et al., 2009).

The common factor found throughout the studies was a significant reduction in driving performance that corresponded with the expected lulls in the circadian rhythm. In general, it was found that the only reliable method of reducing the factors of fatigue related to drowsiness is to take a break from driving (Bloomfield et al., 2009; Ferguson et al., 2012; May and Baldwin, 2009). To reduce the probability of fatigue-related incidents, this rest break can be as short as 15 minutes or as long as one hour without any activities related to driving being undertaken (Jovanis et al., 2011). A combination of caffeine consumption preceding a rest period was reported to be the ideal technique to combat fatigue.

1.4 TRAFFIC AND COMPLEXITY OF WORK TASKS

High-traffic areas can contribute to driver fatigue by requiring sustained attention to the surrounding traffic while also completing driving tasks and communicating with central office personnel. Gimeno et al. (2006) presented a discussion of two types of task-based mental fatigue: passive fatigue and active fatigue. Passive fatigue can be caused by an underload condition, or prolonged periods during which too few mental capacities are exercised. The underload condition typically occurs when the driver is very familiar with the environment, such as driving the same route with a relatively low traffic density. Rossi et al. (2011) used a driving simulator to examine the impact of driving in a monotonous environment and concluded that the fatigue produced in the underload condition is a function of the time of day, driving environment, and duration of drive time.

Winter maintenance drivers may experience active fatigue as a result of increased attention and multiple tasks required to operate a winter maintenance vehicle during a winter emergency. Active fatigue can be the result of overload, or relatively high driving demands (e.g., high traffic density, unknown driving environment, or performance of multiple tasks while driving; Gimeno et al., 2006). Liu and Wu (2009) reported that fatigue from driving in a complex road environment had a significantly negative effect on driver behavior when compared to non-fatigued driving in a complex or monotonous road environment. These results indicated that fatigued drivers encountering significant or complex traffic tend to overestimate the distance to signs and have a significantly greater number of lane crossings than non-fatigued drivers.

Some research has indicated that fatigue from driving in a low-demand environment or under low workload conditions may reduce performance more than fatigue from the overload condition

(Desmond and Hancock, 2001). This is expected because drivers in low-demand conditions fail to fully mobilize their efforts (as opposed to high-demand conditions, during which effort is very high). However, the research only analyzed the impact of completing a task in environments with various demands placed on the operator and not the impact sustained demands had on the operator's fatigue.

1.5 WORK COMPLEXITY AS A PREDICTOR OF FATIGUE

In many cases, winter maintenance drivers are subjected to complex work environments given the many tasks they must perform while driving in hazardous conditions and complex traffic scenarios. It has been shown that as the complexity of a task increases, susceptibility to fatigue also increases. A study conducted by Nunes et al. (2012) assessed fatigue in air traffic control operators as a function of shift complexity and found that respondents performed more poorly on psychomotor vigilance task tests following a complex work shift. It is important to note the most complex work shifts corresponded with night shifts; thus, the contribution to fatigue from work complexity could not be completely isolated from sleep factors. However, Nunes et al. (2012) found a strong relationship between the level of fatigue and the complexity of the work shift.

1.6 WINTER/HAZARDOUS CONDITIONS AND COLD TEMPERATURES

It is expected that active fatigue can also be present during driving in winter conditions. For example, driving on ice- or snow-covered roads requires much more attention than driving on clear roads and contributes to the driver's workload. Furthermore, high-demand driving conditions, such as driving in limited visibility (due to poor lighting and/or falling snow), can be expected in winter emergencies. These high-demand conditions lead to active fatigue, especially when combined with other fatigue-related factors, such as vehicle vibration (Gimeno et al., 2006; May and Baldwin, 2009).

Hazardous conditions (e.g., driving on snow-covered roads) are recognized to be an inherent part of winter maintenance drivers' work environments, and it is known that working in hazardous conditions contributes to the fatigue of workers. The NRT (2009) recently developed a technical assistance document focused on assisting disaster relief agencies in addressing worker fatigue during disaster relief efforts. The NRT recognized the paucity of information relating to fatigue in response personnel (i.e., personnel who respond to events that require long shifts in hazardous conditions) as the majority of the existing literature focused on shift workers and extended work hours under normal working conditions (NRT, 2009). The document developed by the NRT identifies several fatigue risk factors that are inherent in response personnel and categorizes them into: (i) work hours and rest periods, (ii) site conditions, (iii) living conditions, (iv) nature of the work being performed, (v) management and administrative support, and (vi) emotional stress (NRT, 2009). The technical assistance document recognized that each response team is unique; thus, fatigue management programs should be targeted for specific response teams (i.e., one-size-fits-all approach is likely to fail). The NRT (2009) report included a proposed four-phased approach to disaster operations, fatigue risk factors, and a step-by-step guide to developing an organizational fatigue management program (including fatigue risk management and assessment tools). The full NRT report is available at:

http://nrt.org/production/NRT/NRTWeb.nsf/allattachmentsbytitle/sa-1049tadfinal/$file/tadfinal.pdf?openelement.

In addition to active fatigue from driving in winter conditions, exposure to cold temperatures has been connected to a decrease in cognitive functioning (Pilcher et al., 2002). Research has also shown that the longer a person is exposed to cold temperatures prior to performing a task, the more adversely the person was impacted by the cold temperatures, and exposure to cold temperatures for up to an hour prior to a task significantly impacts performance (Pilcher et al., 2002). Research by Pilcher et al. (2002) indicated that the main decrements in performance during cold temperatures occurred in reasoning, memory, and learning. These results seem to suggest that winter maintenance drivers would experience a cumulative impact on fatigue when required to perform tasks outside of the truck (TR fatigue) in cold temperatures. Short-duration exposure to cold air while performing a task (as may be the case when a driver must begin a shift before the truck cab has warmed up) also had a significant impact on performance (Pilcher et al., 2002). This research also discussed the negative impact of high heat on performance; thus, a conclusion can be drawn that there is an optimal middle temperature for activities requiring sustained performance.

Research has also shown that the combination of sleep deprivation and exposure to cold temperatures significantly reduces an individual's attention capacity and working memory (Spitznagel et al., 2009). Although the impacts of sleep deprivation and cold temperatures individually impact driver performance and levels of fatigue, the combination of the two is expected to accelerate a decrease in performance. However, the research conducted on the combination of sleep deprivation and cold temperatures was conducted only on young, relatively healthy males (Spitznagel et al., 2009), limiting the generalization of the results to other populations of drivers.

1.7 SCHEDULING AND SHIFT POLICIES

Much research has tried to quantify the impact of scheduling and shift policies on the performance and safety of CMV drivers. For example, extensive research has been conducted to evaluate the impact of federal hours-of-service (HOS) legislation. It is recognized that winter maintenance drivers are not subject to HOS legislation. However, the research resulting from HOS issues is useful across a spectrum of drivers. In some cases, the research has produced conflicting results that may lead to confusion about the cumulative impact of driving and rest periods on driver fatigue. It is generally recognized that the time of day has an impact on driver fatigue: the frequency of fatigue-related traffic incidents increases between midnight and 6:00 a.m. (Desmond and Hancock, 2001).

Hanowski et al. (2008) used data from a naturalistic driving study to examine critical incidents as a function of driving hour during 11 continuous hours of driving. The research followed 98 drivers for an average of 12.38 weeks, resulting in more than 2.3 million miles of driving data (Hanowski et al., 2008). The results of the research showed a spike in critical driving incidents during the first driving hour, and no other hours were statistically significant. The results showed that the time spent on a task is a poor indicator of crashes or other traffic incidents for driving hours 1 through 11. The research presented three possible explanations for the spike in the first hour of driving: (1)

sleep inertia, (2) road type and/or traffic density, and (3) time-of-day effects. Sleep inertia describes the time the body requires to become fully alert after awakening. The time-of-day effects are attributed to the body's circadian rhythm and traffic density.

Jovanis et al. (2011) studied the increase in crash proabability with increased drive time of CMV drivers. The authors studied the driving logs of 1,564 drivers, a number of whom had reported crashes. The authors found a significantly greater probability of crashes occurring during the 11th hour of driving for less-than-truckload drivers (e.g., drivers who move loads for multiple firms on the same truck), with increasing probabilities of crashes beginning during the 6th driving hour and increasing with driving time (Jovanis et al., 2011). The authors reported that taking breaks from driving at any point during the drive time significantly reduced the probability of a crash. The authors also reported that truckload drivers (e.g., drivers who carry loads for one firm between the firm's docks) experienced an increased crash probability. However, the authors warned against drawing too many conclusions from the limited data about the impact of the 34-hour restart period.

Blanco et al. (2011) investigated the impact of non-driving activities (i.e., loading and unloading) on driver performance. The research analyzed data from a naturalistic driving study and found that, on average, the drivers spent 66 percent of the time on shift driving, 23 percent on non-driving work, and 11 percent resting (Blanco et al., 2011). The results of the study indicated that an increase in fatigue was a function of the time spent on a task and the non-driving activites of the CMV driver. In other words, CMV drivers may be able to drive safely for long periods of time. However, if they are required to load and unload, fatigue related to the time spent on a task was shown to increase.

McCartt et al. (2008) evaluated the impact of the 2004 changes in HOS legislation on drivers' schedules and reported fatigue. The legislation changed many of the driving limits, as well as the off-time requirements. The legislation also enacted the 34-hour restart period, requiring that drivers could restart the official work week only after 34 consective hours off. The research found that drivers reported significantly more driving hours after the rules changed. Drivers who reported rule violations to the researchers were also significantly more likely to report having driven while drowsy within the past week. Furthermore, driver fatigue was reported to be higher after the new rules were enacted.

When scheduling work periods, it is important to recognize that sleep quantity and quality impact the fatigue experienced by drivers. Research has shown that accumulated sleep debt has an impact on the feeling of daytime sleepiness (Dinges et al., 1997). It is generally accepted that most people need approximately eight hours of sleep to feel well rested (Van Dongen et al., 2003). The greatest quality of sleep occurs when sleep is coordinated with the circadian clock; daytime sleep is often shorter and more disrupted than nighttime sleep. Obtaining a full night's sleep can sometimes be a challenge for people working irregular or unpredictable schedules. Research has shown that eight continuous hours of sleep after a wakeful period of 26 hours should be adequate to return normal motor-skills functioning (Baulk et al., 2008).

Morrow and Crum (2004) analyzed survey data from 116 trucking firms and found that a strong safety culture has the potential to significantly reduce the occurrence of driving while fatigued. The safety culture could range from limiting the non-driving factors that could contribute to fatigue (i.e., during the loading and unloading process) to dissuading dispatchers from trying to convince drivers to continue driving after they report drowsiness (Morrow and Crum, 2004). A positive safety culture could also include programs that dis-incentivize driving after reporting fatigue. Communications with dispatchers or central office personnel were found to be critical aspects of the safety culture when trying to manage the amount of time a driver works after reporting fatigue.

The research often notes that economic pressures directly related to driving incentivize CMV drivers to drive fatigued (Lyznicki et al., 1998). CMV drivers are generally paid by the mileage driven, so an increase in drive time has a direct economic benefit for most CMV drivers. Crum and Morrow (2002) presented a truck driver fatigue model to explain the factors that contribute to driver fatigue. Some notable factors were various economic pressures (Crum and Morrow, 2002). However, most winter maintenance personnel are employed by a state department of transportation, so the majority of these employees are paid by the hour.

1.8 SCHEDULING NAPS

Whereas it was found that taking a break was the only reliable method to reduce the impact of fatigue in CMV drivers (Bloomfield et al., 2009; Ferguson et al., 2012; May and Baldwin, 2009), Bonnefond et al. (2001) took the restful period a step further to evaluate the impact of scheduling naps during the night shifts of industrial workers. Although a partial lack of data limited some of the conclusions in the study, a higher level of viligance and satisfaction was found in workers who had scheduled naps. Signal et al. (2009) evaluated the impact of scheduled naps on air traffic controllers. The results of the research indicated that sleep taken at work tends to be short and less restorative. However, Signal et al. (2009) reported increased alertness and performance in air traffic controllers as a result of the scheduled naps (Signal et al., 2009). In each of the aforementioned cases, the naps were relatively short (less than one hour).

1.9 EQUIPMENT AND FATIGUE MANAGEMENT TECHNOLOGIES

Fatigue management technologies are state-of-the-art innovations for preventing, identifying, alerting, and reducing driver fatigue and fatigue-related driving errors. These technologies generally focus on three types of measures: non-driver measures, such as fatigue modeling; driver physiological measures and psychomotor skills, such as eye tracking to detect fatigue; and vehicle kinematics or driver input, such as measuring the amount of lane drift (Balkin et al., 2011; Ji et al., 2004). There are two types of fatigue management technologies: back-office and driver, which are further subdivided into in-vehicle and out-of-vehicle technologies.

1.9.1 Fitness for Duty

A fitness-for-duty test involves technologies to measure a driver's cognitive ability before a driver begins a shift (Balkin et al., 2011). Tests of cognitive functions use an objective process and typically measure hand-eye coordination and/or reaction time, and they can be used as pre-drive monitoring. These relatively short, non-invasive tests are used as a predictor to determine whether a driver may be too fatigued for the task at hand (Horberry et al., 2001).

Technologies that measure psychomotor skills present some limitations. Technology used prior to driving must be administered by personnel in the back office, does not take into account the possible onset of fatigue at a later time during the driving shift, and may be vulnerable to drivers "beating the system" (i.e., engaging in behavior just prior to testing that temporarily mitigates the symptoms of fatigue). Technologies that measure a driver's psychomotor skills while driving create an additional task for the driver to perform, increasing the possibility of driver inattention.

Actigraphy is another fatigue measure using physiological concepts (Baulk et al., 2008; Dinges et al., 2005). This device uses predictive sleep algorithms to determine the driver's sleep quantity and quality, along with rest and activity patterns. Some devices may also incorporate circadian rhythm analyses into the algorithm. Actigraph devices provide a general indicator of sleep variability. These devices are typically wrist-worn watches and may include a light sensor, ambient temperature detection, and off-wrist detection. It is important to note that actigraph devices are predictive technologies that do not account for individual differences and require the driver to wear the device. Furthermore, actigraph devices do not provide the driver real-time alerts or data.

1.9.2 Back-office Fatigue Management Technologies

Back-office fatigue management technologies are aimed at prevention. They include in-vehicle systems designed to monitor the driver and roadway using video and kinematic sensors (Horberry et al., 2001). Some of these systems also record data from the vehicle network, such as speed, braking, and global positioning system (GPS) location. Crossing certain thresholds, such as sufficiently hard braking, triggers event markers in the video and data recording. The video and data are collected, transferred (generally by vehicle telemetry or wireless Internet), and reviewed and analyzed. This process can be handled either by a third party or within the fleet, depending on the system employed. This allows risky driving behavior to be flagged for review by the safety manager, who can coach the driver to reduce risky driving behavior in the future. Behavior-based coaching systems are for overall driving behavior, not just fatigue management (Hickman et al., 2007). Mitigating distracted driving and increasing fuel economy are just two of the other uses of this type of system.

1.9.3 In-vehicle Monitoring

In-vehicle driver fatigue management technologies are designed to identify and alert the driver to impending fatigue to reduce risky driving behaviors, performance degradation, and driver errors. Real-time driver monitoring occurs in the vehicle and uses physiological measures, psychomotor skills, vehicle kinematics, or driver input (Fletcher et al., 2005). Real-time driver monitoring is seen as the last stop-gap countermeasure that warns the driver before potential risky driving behavior or a crash could occur.

During the past few decades, considerable research has been conducted on the use of eye measures when determining fatigue. The percent closure of the driver's eyelids (PERCLOS) is typically considered one of the more effective in-vehicle measurements of driver drowsiness (Ji et al., 2004). Amplitude velocity ratio is a measure of how fast and how far the eyelid opens after closure and is another eye measurement that can be used to measure fatigue. However, physiological concepts present several potential limitations: systems that use eye measures can produce false alarms for glances to mirrors and in-cab devices, the sensitivity of camera and infrared varies under different lighting conditions, and there is driver resistance to systems that require wearing glasses.

In-vehicle fatigue management technologies are either single- or multi-channel systems. Single-channel systems, such as lane-departure warning systems, rely on one predictor of fatigue. Single-channel systems also have the potential for intermittent data loss. For example, snow-covered roads could render a lane-departure warning system ineffective. Multi-channel systems combine two or more predictors of fatigue. An example of a multi-channel system would be a lane-departure warning system with eye tracking using PERCLOS algorithms. This creates a more robust system for monitoring driver fatigue by compensating for the weaknesses of each predictor. It is expected that a multi-channel system could be created with currently available single-channel systems.

1.9.4 Crash Avoidance Systems

Crash avoidance systems are designed to warn a driver of driving behaviors that may lead to a crash, and they have applications in fatigue management. Vehicle kinematics and driver-input fatigue management technology concepts use lane tracking or steering input as the driver performance measure (Dinges et al., 2005). Lane tracking uses computer-based algorithms in conjunction with a camera, machine vision, and vehicle state to monitor lane position. These systems warn the driver, usually with an auditory alert, when he or she is deviating from the travel lane. Lane-departure warning systems tend to improve overall attention and performance even when the driver is not fatigued (Dinges et al., 2005).

Fatigue management technology systems that employ steering input as the performance measure use a computer sensor to detect the actual amount of steering input and changes in steering behavior, such as rapid lateral movements of the steering wheel (also known as drift and jerk steering). When programmed thresholds are met, the system warns the driver.

1.10 FATIGUE SURVEYS

Many studies use fatigue surveys that elicit responses directly from drivers following a driving session or study. The structure of these surveys is critical for the way the information being gathered can be used and determining which assumption can or must be made. Surveys are also a useful way to reveal factors that are important to a study but may not have been identified otherwise. This section discusses some of the components of the surveys used in various driver fatigue studies and the sample populations surveyed.

Adams-Guppy and Guppy (2003) present the results of an investigation of driver fatigue using driver questionnaires in large multi-national corporations. The questionnaire was sent to managers and drivers and contained the following sections: reported frequency of fatigue problems (e.g., *How often do you drive while tired?*), reported crash and near-miss experience, driver biography and driving history, work features (e.g., hours worked and miles driven per week), driver behavior and perceptions related to taking breaks, satisfaction and involvement with work environment, and restraint in alcohol consumption (Adams-Guppy and Guppy, 2003). One issue that was discussed was bias in the questionnaire responses. It is expected that many drivers with poor driving histories would not complete the questionnaire, resulting in questionable validity in some of the conclusions (Adams-Guppy and Guppy, 2003). However, even with the expected bias, it is thought the information gleaned from the questionnaires was adequate for determining relationships among the study variables. The results showed a relationship between self-reported fatigued driving and self-reported near-misses and crashes. No relationship was found between fatigued driving and age or years of driving experience. A relationship was shown to exist between an increased frequency of driving while tired and an increase in disagreement that breaks were encouraged by participating employers. The results also indicated a slight increase in driving while fatigued when the driver began a shift prior to 7:00 a.m. (Adams-Guppy and Guppy, 2003). Finally, an increase in fatigued driving was found in drivers who did not limit the amount of alcohol they consumed the night prior to driving.

Gander et al. (2006) reported the results of a three-page questionnaire designed to assess driver fatigue in truck crashes. The questionnaire was designed to collect driver age and gender, sleep habits and sleepiness (e.g., information about feeling refreshed after sleep, as well as neck circumference data), sleep and duty history for 72 hours prior to the crash, how long it had been since the driver had two ideal successive nights of sleep (for sleep recovery opportunity), and information about the crash (Gander et al., 2006). The research revealed that the questionnaire-based method identified fatigue-induced crashes at a significantly higher rate than the standard method, which involved the attending police officer simply checking a box for fatigue during the crash investigation. However, one drawback to the surveys was the retrospective and subjective nature of gathering the information a significant amount of time after the crash occurred (Gander et al., 2006). The results showed the three measures that contributed most to the differences between fatigued and non-fatigued crashes were the duration of the most recent sleep, number of hours slept during the 24-hour period prior to the crash, and whether the driver had a split-sleep pattern during the 24 hours prior to the crash. The majority of the crashes (86.3 percent) occurred on roads familiar to the driver.

2. METHODS

The goal of the current project was to develop a series of cost-effective, realistic recommendations for reducing or eliminating fatigue impacting equipment operators during winter emergency operations. Although there is a distinction between TR and SR fatigue, this project addressed both. From this point forward, the term "fatigue" is used interchangeably to indicate both TR and SR fatigue. In addition to the literature review above, two data collection efforts were performed to accomplish the project goal. The first involved the collection of naturalistic driving data to investigate issues related to winter maintenance operator fatigue during winter emergencies. This first effort should be viewed as a feasibility study as only four winter maintenance operators participated in the study. The second effort involved the collection of qualitative information from winter maintenance operators and management personnel to assess major facets of snow plow operator fatigue. These two efforts are described below.

2.1 NATURALISTIC DRIVING DATA

Four winter maintenance operators from the Virginia Department of Transportation (VDOT) were recruited to participate in the current study. All four drivers completed three months of participation in the study (beginning on January 24, 2013, and ending on April 29, 2013). Participants' typical shifts during non-winter emergencies began at 7:00 a.m. and ended at 4:00 p.m. These shifts usually involved drivers working as a team, with two drivers per vehicle. There were two shifts during winter emergencies. The day shifts started at 7:00 a.m. and ended at 7:00 p.m.; the night shifts began at 7:00 p.m. and ended at 7:00 a.m. During winter emergencies, participants traveled solo for the duration of their shifts. Participants #1 and #2 performed the night shifts during winter emergencies, and participants #3 and #4 performed the day shifts. These participants rarely operated an instrumented vehicle during non-winter emergencies; thus, comparisons between winter emergencies and regular operations was not possible with the driving data.

2.1.1 Test Vehicles

VDOT provided two vehicles from its operations for use during the study (see Figure 2 and Figure 3). These two vehicles were selected by VDOT management based on the participants' work vehicles.

Figure 2. 2001 GMC C7500 4x4

Figure 3. 2001 International Tandem Model 2674 6x4

2.1.2 Data Acquisition System

The data acquisition system (DAS) allowed for the continuous collection of driver and roadway video, as well as parametric data pertaining to the vehicle across an extended period of time. This allowed driver behavior and vehicle status in the instances occurring prior to and during a safety-critical event (SCE) to be examined. The DAS used in the current project was designed, developed, and enhanced during the last decade by the Virginia Tech Transportation Institute (VTTI). Previous versions of the system were used in several other on-road naturalistic driving studies (Blanco et al., in press; Dingus et al., 2006; Hanowski et al., 2008). The main DAS unit and its components are described below.

2.1.2.1 Main DAS Unit

The main DAS unit comprised a Pentium-based computer that was mounted behind the driver seat of the truck (Figure 4). The DAS received and stored data from a network of sensors distributed throughout the vehicle. The sensors used in the study included an accelerometer for longitudinal and lateral acceleration, a video-based lane-tracking system that measured lane-keeping behavior, a GPS sensor for location, and continuous video recordings of the driver and roadway. Each of the sensor subsystems within the instrumented vehicle was independent with respect to the others, resulting in containment of sensor failures to the single sensor itself. Data were stored on an external hard drive that was locked in place to prevent tampering. This hard drive could store several weeks of driving data before requiring replacement. The DAS was constructed to automatically start when the truck's ignition was turned on. Each of the DAS sensors is described below.

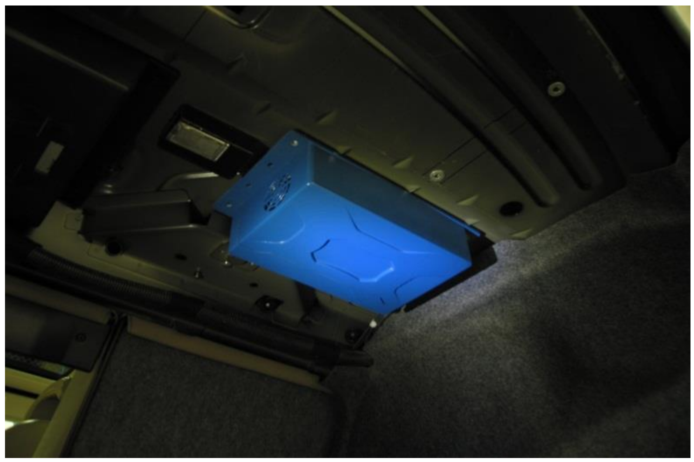

Figure 4. The Main DAS Unit Installed behind the Driver's Seat

2.1.2.2 Video Cameras

Five digital video cameras were used to record continuous video of the driver and the driving environment. Three cameras were used to record video of the roadway, including: (i) a view of the forward roadway (Figure 5), (ii) a backwards-facing view of the left side of the snow plow (Figure 6), and (iii) a backwards-facing view of the right side of the snow plow. Additionally, two cameras were used to record video of the driver, including a center-facing view of the driver's face (Figure 5) and an over-the-shoulder view of the driver, steering wheel, and dashboard (Figure 7). These five camera views were multiplexed into a single image (Figure 8). The top left frame shows the forward camera view, the top right frame shows the driver's face camera, the bottom left shows the left/right backwards-facing camera views in a split-quadrant format, and the bottom right shows the over-the-shoulder camera view. A timestamp (mpeg frame number) was included in the video data. The frame number was used to time-synchronize the video (in mpeg format) and the truck/performance data (in .dat format).

Figure 5. Example of a Forward Roadway and Driver Face Cameras

Figure 6. Example of the Backwards-facing Side Camera Mounted on the Outside Rearview Mirror

Figure 7. Example of the Dome Camera Mounted on Roof of Cab (left) and View from Behind the Dome Camera (right) providing an Over-the-shoulder View of the Driver, Steering wheel, and Dashboard

Figure 8. Five Camera Images Multiplexed into a Single Image

2.1.2.3 GPS

A GPS device was mounted on top of the truck to provide data about the truck's location. The sensor was a complete eight-channel parallel tracking GPS receiver designed to operate at the L1 frequency. Data output included measures of latitude, longitude, altitude, horizontal and vertical velocity, heading, status/strength of satellite signal acquisition, and time and date data. The receiver was able to acquire a position fix with minimal delay after power cycling.

2.1.2.4 Lane Tracker

A VTTI-developed lane tracker called "Road Scout" was included in the DAS. The Road Scout comprised a single analog black-and-white camera, a personal computer (PC) with a frame grabber card, and an interface-to-vehicle network for obtaining ground speed (the grabbed video frames were not stored but were processed algorithmically in real time to calculate the vehicle position relative to road lane markings). Once installed, Road Scout's software automatically calibrated itself to determine camera position; thus, no elaborate calibration procedure was required. The following variables were reported by Road Scout:

- Distance from center of truck to left and right lane markings (estimated maximum error < 6 inches [in.], average error < 2 in.).
- Angular offset between truck centerline and road centerline (estimated maximum error < 1 degree).
- Approximate road curvature.
- Confidence in reported values for each marking found.
- Marking characteristics, such as dashed versus solid and double versus single.
- Status information, such as in-lane or solid line crossing.

Road Scout uses machine vision, and most of the data were collected during winter emergencies; thus, most of the lane lines were covered by snow. As such, Road Scout was not able to reliably track line crossings.

2.1.2.5 Yaw Rate Sensor

A yaw rate (gyro) sensor was installed in the main DAS unit to provide a measure of steering instability (i.e., jerky steering movements).

2.1.2.6 X/Y Accelerometer

Accelerometers instrumented in the truck were used to measure longitudinal (x) and lateral (y) accelerations.

2.1.2.7 Vehicle Network

The vehicle network refers to a from-the-factory onboard data collection system. The format of messages and data collected by onboard microprocessors was defined by SAE J1587 (Society of Automotive Engineers, 2002). These microprocessors were installed on the vehicle at the truck manufacturing facility and not by VTTI researchers. Depending on the truck model, year, and manufacturer, there were several data network protocols or standards that were used, including those defined by J1587 (Society of Automotive Engineers, 1993).

2.2 ACTIGRAPH DEVICE

Each study participant was instructed to wear an actigraph device (see Figure 9) on the wrist of his/her non-dominant hand. The Octagon BASIC actigraph device developed by Ambulatory Monitoring, Inc. (AMI) was used in this study. An actigraph unit is a "wrist watch"-type activity-monitoring device used to assess a participant's sleep quantity and quality. The device was the approximate size and shape of a wrist watch, though somewhat bulkier and heavier. The actigraph device collected data about the motion of the person wearing the device and stored the data as a function of time. The device was self-contained and made no electrical contact with the person wearing it.

Figure 9. AMI's Octagon BASIC Actigraph Device

2.3 WINTER MAINTENANCE OPERATOR AND MANAGER QUESTIONNAIRE

Two parallel questionnaires were developed to assess major facets of fatigue, work and rest schedules, and how work schedules related to winter maintenance operator fatigue. The first questionnaire targeted winter maintenance operators, and a second parallel questionnaire targeted winter maintenance managers. The winter maintenance operator questionnaire shown in Appendix A was designed to capture opinions and perceptions about:

- Work hours (e.g., per day, per week, normal shift, overtime, emergency situations, and breaks),
- Type of equipment used (including other types of equipment operated when not performing winter maintenance activities),
- Freedom to refuse work due to fatigue,
- Rest periods,
- Fatigue awareness,

- Percentage of winter maintenance operators that work overtime under normal and emergency situations,
- Medical issues, and
- Fatigue management strategies used.

The winter maintenance manager questionnaire shown in

Appendix B was designed to capture opinions and perceptions about:

- Characteristics of the workforce,
- Type of equipment used,
- Typical work hours,
- Scheduling,
- Requirements to ensure that winter maintenance operators take rest periods,
- Percentage of winter maintenance operators that work overtime under normal and emergency situations,
- Fatigue awareness training,
- Medical issues,
- The impact of work scheduling practices on operational safety,
- Existing monitoring practices of driver fatigue, and
- Fatigue management strategies used.

2.3.1 Questionnaire Distribution

VTTI worked with Clear Roads member states to recruit winter maintenance operators and safety managers. Links to both surveys were provided to each Clear Roads member state. Each member state subsequently distributed the appropriate link to its winter maintenance operators and managers. Completed questionnaire responses were automatically entered into a secure online database. All responses were anonymous; there was no link between personally identifiable information and questionnaire responses. Additionally, paper-based versions of the questionnaires were made available for those individuals without reliable access to the Internet. Paper-based questionnaires were returned to VTTI, where a researcher entered the responses into the secure database.

2.3.2 Questionnaire Content Analysis

The approach used to analyze open-ended questions was an adaption of a framework analysis developed during the 1980s at the National Centre for Social Research in Britain (Ritchie et al., 2003). This methodology includes the following steps:

1. Determining Analysis Focus: For each of the questions, key themes were identified.
2. Familiarization: Each of the open-ended responses was read by a researcher to become familiar with the data set.
3. Identifying Thematic Framework: A review of the data set was conducted, and a list of key subthemes for each theme was identified.
4. Indexing: The themes and subthemes were arranged in a logical order to create an index. The index was systematically applied to the data set, and the relevant comments were identified and highlighted.

5. Charting: All of the indexed comments were arranged into spreadsheets based on key themes and were sorted by subtheme.
6. Interpretation: The themes and subthemes were used to better understand participant perspectives.

2.4 PROCEDURES

The procedures used to collect and reduce the naturalistic, actigraph, and questionnaire data are described below.

2.4.1 Vehicle Instrumentation

Each winter maintenance truck was instrumented at VTTI. The DAS was installed without any permanent modifications. To achieve this, VTTI researchers developed customized brackets for the sensors and equipment of the DAS to make use of existing mounting holes in the frame of each vehicle. The brackets were designed individually based on mirror style, vehicle cab, or dashboard. Each installation was customized according to the make, model, and year of the winter maintenance truck.

Installation of DAS components was completed by VTTI researchers in five to six hours. The winter maintenance trucks were chosen by VDOT management based on reliability and accessibility of the trucks to the participants. Sensors were mounted in the appropriate locations inside and outside the winter maintenance truck. All cables attached to the sensors were routed to the main DAS unit. All sensors were mounted as discreetly as possible, and all cables were installed beneath ceiling panels, under floors and carpeting, and beneath plastic molding and compartments to make as little change to the winter maintenance truck as possible.

Once the initial installation and operational check were completed, data information was entered and verified for VDOT, location, individual truck identification (ID), and driver ID of interest. The participants were asked to adjust their seats for normal driving, and the DAS cameras were adjusted to the proper orientation for each driver. These checks and adjustments were also performed each time researchers met with the participants.

2.4.2 Vehicle Data Collection

A VTTI researcher visited the VDOT facility bi-weekly to inspect the DAS for proper operation and to retrieve the collected data. If any equipment was damaged, the researcher scheduled the vehicle to be brought to VTTI for necessary repairs. During each visit, the researcher also replaced the hard drives with empty hard drives to ensure there was sufficient storage for the subsequent data collection interval.

Once the hard drives were returned to VTTI, the data were downloaded to a secure server. Each file on the hard drive was inspected to verify the appropriate driver was operating the instrumented vehicle. Non-participating drivers would sometimes drive the instrumented winter maintenance truck during regular operations or participant absences. These files were deleted upon discovery as these drivers did not agree to participate in the study. The researchers ensured that none of the non-participating drivers were included in the study.

2.4.3 Participant Data Collection

A participant orientation was held at VDOT by the VTTI researchers. During the orientation meeting, a member of the VTTI team explained the purpose of the study, the methods to be employed during the study, the rights of research participants, and participant expectations; answered any questions; and requested that participants read and sign an informed consent form (

Appendix C) to voluntarily participate in the proposed research. After signing the informed consent form, participants completed a brief demographic questionnaire (

Appendix D).

Immediately following vehicle instrumentation and prior to driving, an actigraph device was initialized by VTTI researchers and given to the participant to wear on his/her non-dominant wrist (see

Appendix E for a description of the actigraph device initialization procedures). If the standard watch band did not fit properly or the participant found it uncomfortable, the band was replaced with a Velcro band that offered a wider circumference and reduced the degree of contact between the actigraph device and the skin. Participants were asked to wear the actigraph device 24 hours a day, seven days per week for the duration of their time in the study. Participants were instructed to remove the actigraph device only when showering, washing dishes, swimming, or performing any other task during which the device may become submerged in water. To minimize data loss, participants were asked to replace the device on their wrist as soon as possible after performing such activities.

A member of the VTTI research team met with each participant once a month to download the data from the actigraph device (Figure 10). Once the data were downloaded, the files were viewed using “Action4” software to verify the participant was wearing the actigraph device as instructed. The Action4 graph contained a plot of motion (y-axis) versus time (x-axis). Flat lines in the data graph (highlighted in Figure 11) corresponded to time periods when the participant removed the actigraph device from his or her wrist. If the data indicated the participant had removed the actigraph device for an extended period of time or a large aggregate sum of time, VTTI researchers reminded the participant to wear the unit as much as possible with the exception of time periods when it could potentially be submerged in water.

Figure 10. Downloading Data from Actigraph Device

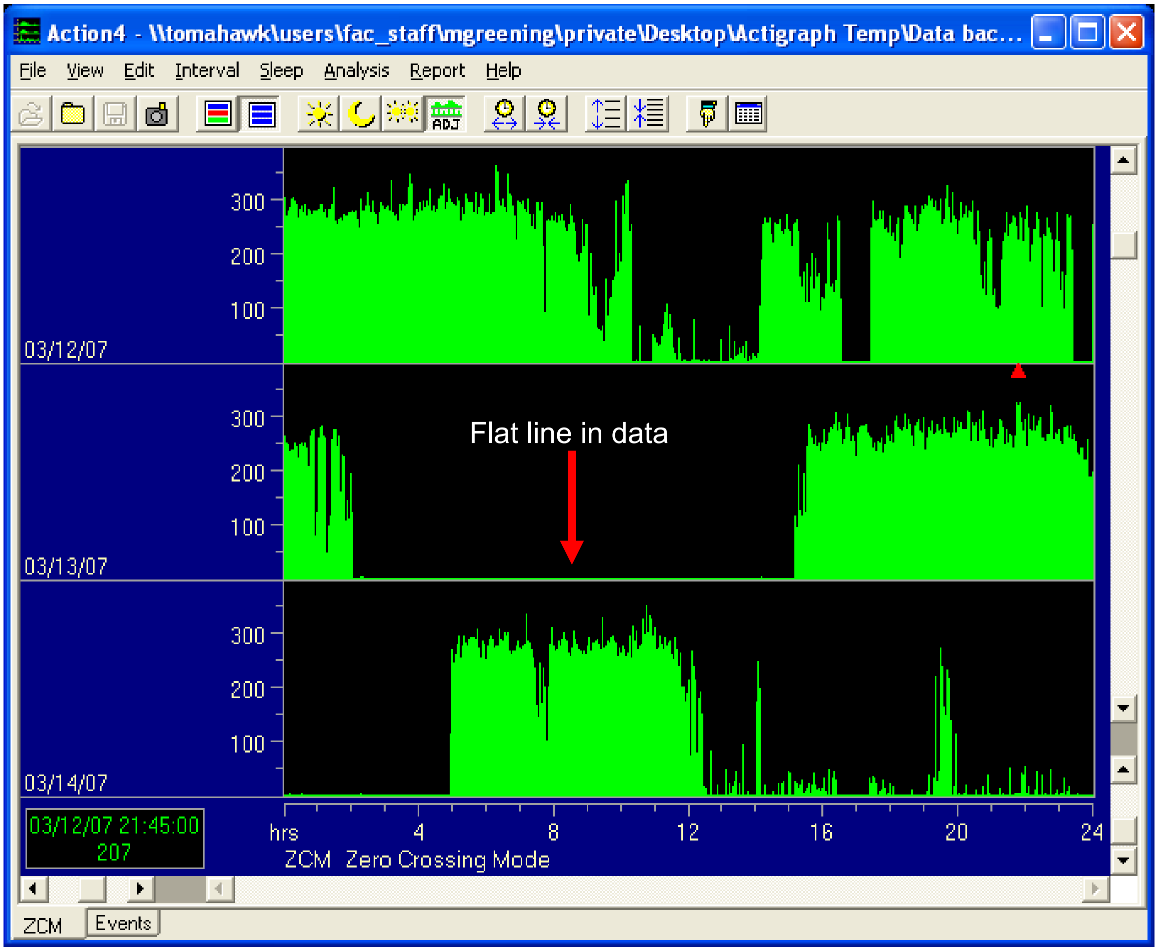

Figure 11. Action4 Software Displaying Collected Motion Logger Data from an Actigraph Device; Flat Line Indicated Device was Removed

Once participants completed three months of data collection, VTTI researchers scheduled a final meeting. This meeting allowed researchers to collect the actigraph devices and participant contact information. The researcher thanked the participant for his/her time and notified VDOT that the participant had completed the study. The following day, each participant was mailed compensation for his/her time in the study. Compensation was $100 per month, plus a $100 bonus for completing the study.

2.4.4 DAS Removal

Upon completion of the study, a time was scheduled with VDOT for the removal of all DAS components from each winter maintenance truck. The removal of DAS components was completed by VTTI personnel in approximately three hours. The intent of the removal was to restore the winter maintenance truck to its original condition. VTTI researchers coordinated with VDOT to perform an acceptance inspection of the winter maintenance truck and to verify that operation and configuration matched the original pre-study specifications. All equipment installed by VTTI personnel during installation of the DAS was recovered and returned to VTTI.

2.5 DATA REDUCTION

The VTTI-developed Hawkeye software was used to support the data reduction of SCEs. An SCE occurred when there were one or more vehicles involved in a conflict and at least one of those vehicles had to perform an evasive maneuver. There were three main steps involved in the data reduction process. The first step was to run event-trigger algorithms on all the data to flag potential SCEs. The second step was to validate the event triggers by visually inspecting the video data pertaining to them. The final step was to record the attributes that pertain to the events. Each of these steps is described below.

2.5.1 Trigger Algorithms

The first step in the data reduction process was to identify events of interest, including crashes, near-crashes, and crash-relevant conflicts (i.e., SCEs). Each of these events may or may not have involved an interaction with another vehicle. Hawkeye was used to find events of interest by scanning the data set for notable actions, including hard brakes and quick steering maneuvers. To identify these actions, threshold values ("triggers") were developed. Table 2 displays the two triggers and their event signatures.

Table 2. Triggers and Trigger Values Used to Identify SCEs

Trigger Type	Definition	Description
Longitudinal Acceleration	Hard braking or sudden acceleration	Acceleration or deceleration greater than or equal to |0.20 *g*|. Speed greater than or equal to 1 mph (1.6 km/h).
Swerve	A sudden "jerk" of the steering wheel to return the truck to its original position in the lane.	Swerve value greater than or equal to 2 degrees. Speed greater than or equal to 15 mph (24.14 km/h)

These event signatures, or trigger types, were selected based on data collected during the 100-Car Naturalistic Driving Study (Dingus et al., 2006). They have been refined to reflect heavy-vehicle kinematics and were shown to be effective in the Drowsy Driver Warning System Field Operational Test (Hanowski et al., 2008) and the Naturalistic Truck Driving Study (Blanco et al., in press). The swerve trigger was further refined for this study when a limited number of swerve triggers were found initially.

2.5.2 Trigger Validation

The Hawkeye software scanned the data set and flagged potential events of interest with a trigger for review. A 75-second epoch was created for each trigger (i.e., an epoch comprising one minute prior to the trigger and 15 seconds after the trigger). The result of the automatic scan was a data set that included valid and invalid triggers.

Valid triggers were those where recorded dynamic motion values actually occurred and were verifiable in the video and other sensor data (also identified by an analyst). One or more valid triggers could be included in an SCE. Invalid triggers were those where sensor readings were spurious, due to a transient spike or some other anomaly (e.g., false positive). The validity of all triggers was determined through video review. Triggers determined to be invalid were not analyzed further. Valid triggers continued to be analyzed and classified as conflicts or non-conflicts. Conflicts were valid triggers that also represented a traffic conflict (e.g., crash). Non-conflicts were triggers that did not create safety-significant traffic events, even though their trigger values were valid ("true trigger"). Non-conflicts were analogous to nuisance alarms, where the threshold value for that particular trigger was set ineffectually. Examples of valid triggers that were non-conflicts included hard braking by a driver in the absence of a specific crash threat or a high swerve value from a lane change not resulting in any loss of control, lane departure, or proximity to other vehicles/objects. Although such situations reflect at-risk driving habits and styles, they did not always result in an SCE.

To determine the validity of the trigger, data analysts observed the recorded video and data plots of the various sensor measures associated with each 75-second epoch. The vehicle sensor measures—each represented in different pop-up windows in Hawkeye—are shown in Figure 12.

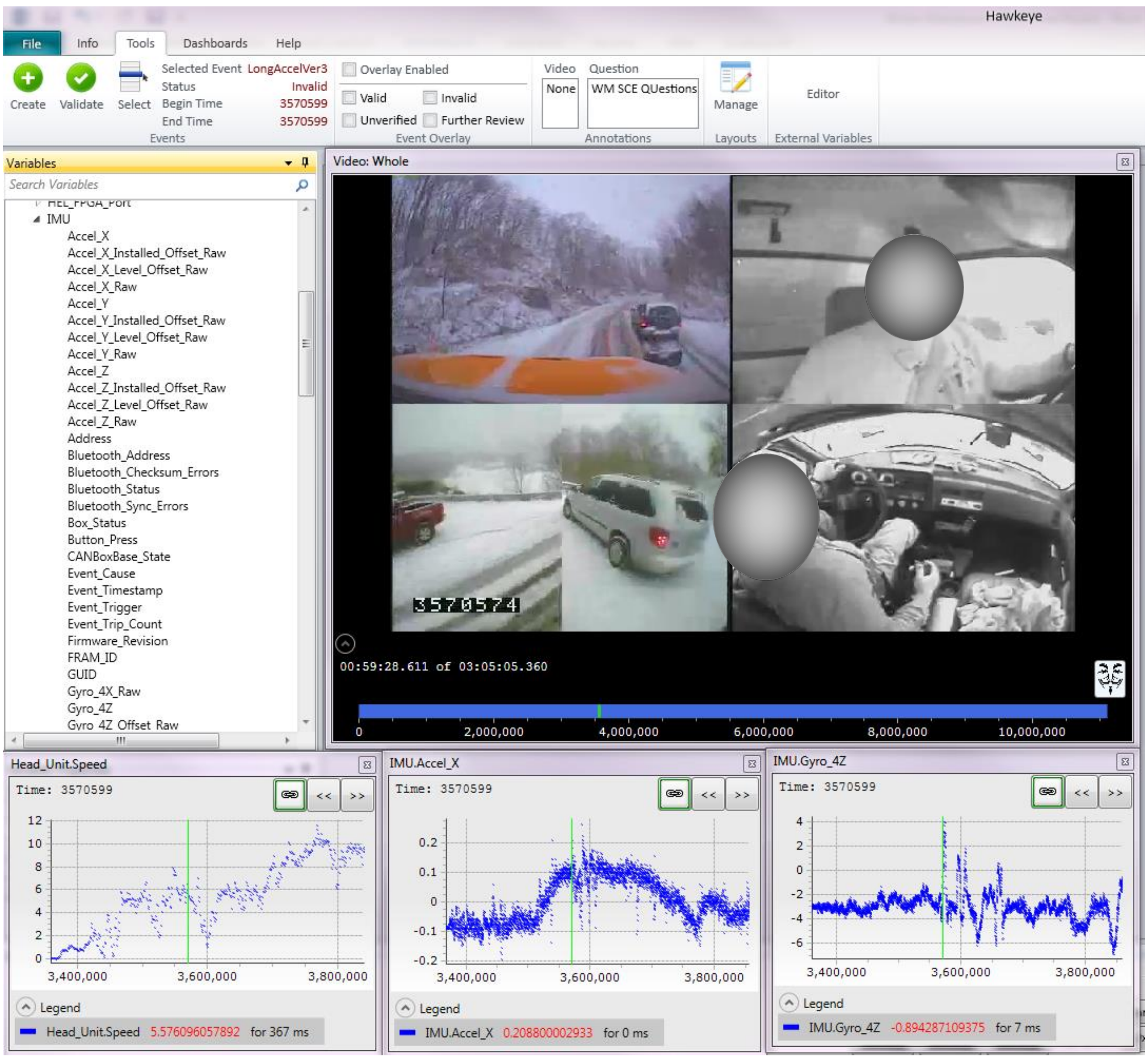

Figure 12. Pop-up Windows for Vehicle Sensors in Hawkeye

The lower the trigger values were set, the more false-positive triggers, non-conflict triggers, and less severe conflicts (i.e., crash-relevant conflicts) were identified. The trade-off was that lower trigger values resulted in relatively few missed valid events. The goal of setting the lower, optimum trigger value was to maximize the number of valid events (e.g., crashes and near-crashes) without having an unmanageable number of false-positive triggers, non-conflict triggers, and low-severity conflict events. The training manual for the trigger validation process is shown in Appendix F.

Figure 13 shows an example of a valid trigger for longitudinal acceleration. In this example, the IMU_Accel_X plot shows a green highlighted trigger at the same time the acceleration value reached -0.484 *g*, indicating a sharp deceleration of the vehicle. For this example, the longitudinal acceleration trigger was set at |0.20 *g*|; therefore, a trigger was created anytime the software detected a longitudinal acceleration with a magnitude equal to or greater than |0.20 *g*|. Looking closely at the top left quadrant of the video screen capture in Figure 13, a vehicle can be seen in front of the snow plow. At this point, the automobile starts to brake, and the winter maintenance operator needs to brake hard to avoid striking the automobile.

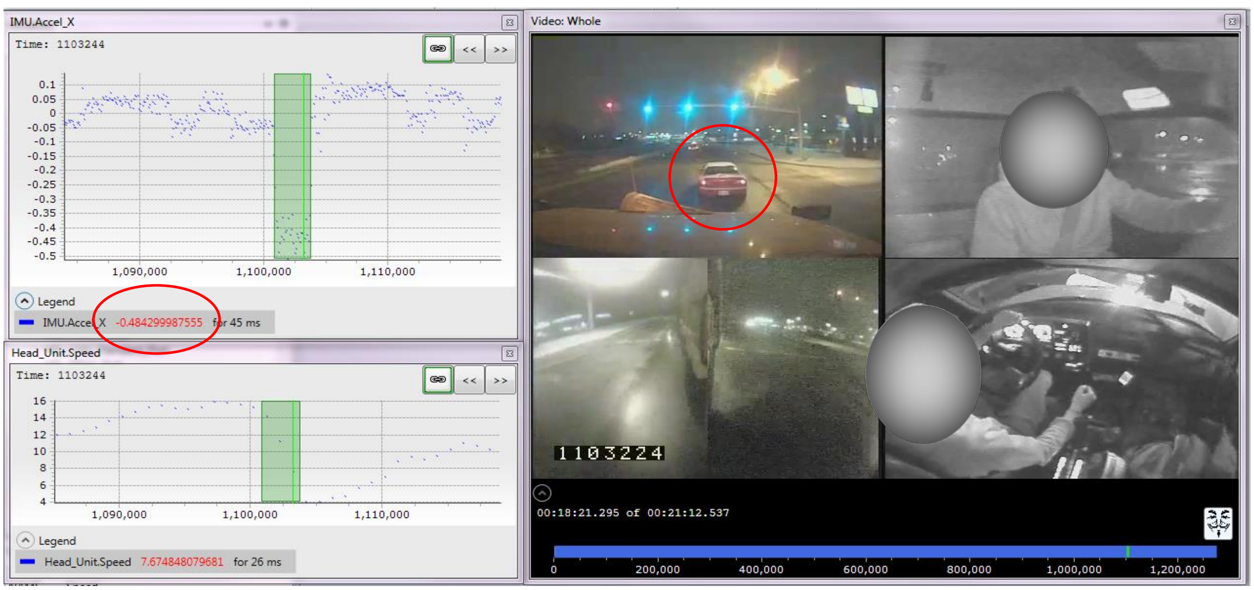

Figure 13. Example of a Validated Trigger where the Longitudinal Acceleration was of Greater Magnitude than the Pre-set Value of |0.20 g|

Figure 14 shows an example of a non-conflict that had a valid swerve (quick steering) trigger. During this event, the participant was negotiating a curve. The IMU_Gryo_4Z plot shows a grey highlighted trigger at the same time the yaw rate reached -4.065 (the value for this trigger was set at |2.0 g|). As shown in the top left quadrant of the video screen capture in Figure 14, there were no vehicles/objects in front or to the side of the instrumented truck; the driver was simply negotiating a curve.

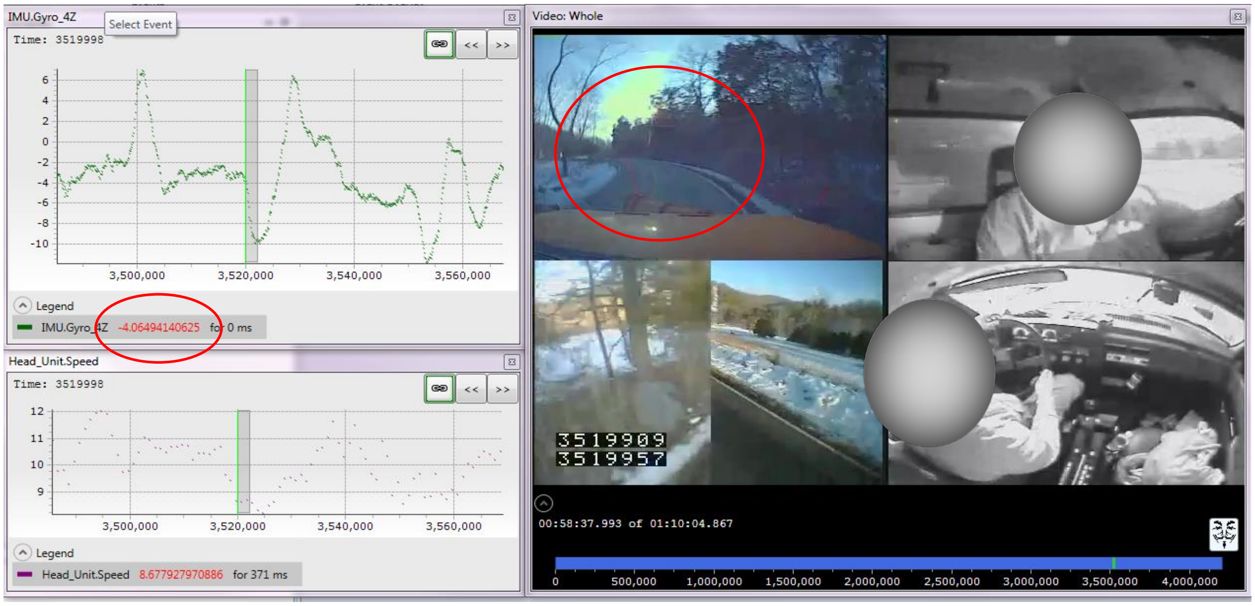

Figure 14. Example of a Non-conflict Event (with a Valid Trigger) where the Driver's Swerve (Quick Steering) was -4.065 (trigger was set to l2.0 gl)

An expert analyst reviewed all valid triggers to determine if they were to be used in the analysis. Furthermore, an expert analyst reviewed 33 percent of all triggers to assess reliability. Reliability for validation of triggers and conflict triggers was 99.60 percent. Discrepancies were resolved by a third party expert (usually the principal investigator).

2.5.3 Classify Valid, Conflict Events to an SCE Type

The valid, conflict triggers were classified into one of seven SCEs: (i) crash, (ii) crash: low-hanging branch, (iii) curb strike: avoidable, (iv) curb strike: unavoidable, (v) near-crash, (vi) crash-relevant conflict, and (vii) illegal maneuver. Descriptions for each event type are listed in Table 3.

Table 3. Description of Each SCE Type

Event Type	Description
Crash	Any conflict with an object, either moving or fixed, at any speed (with the exception of low-hanging tree branches and curbs).
Crash: Low-hanging Branch	Any contact with a low-hanging tree branch at any speed. The most likely cause for these events in the current study are tree branches covered with snow and ice.
Curb Strike: Avoidable	Any contact with a curb or median where it is apparent that the driver could have performed a maneuver to avoid the contact.
Curb Strike: Unavoidable	Any contact with a curb or median where it is apparent that the driver could not have performed a maneuver to avoid the contact. The most likely cause for these events is poor roadway design.
Near-crash	Any circumstance that requires a rapid, evasive maneuver (e.g., hard braking, steering) by the subject vehicle (SV) or any other vehicle, pedestrian, cyclist, or animal to avoid a crash.
Crash-relevant Conflict	Any circumstance that requires a crash-avoidance response on the part of the SV or any other vehicle, pedestrian, cyclist, or animal that was less severe than a rapid evasive maneuver (as defined above) but greater in severity than a normal maneuver. A crash avoidance response can be braking, steering, accelerating, or any combination of control inputs.
Illegal Maneuver	Any circumstance where either the SV or the other vehicle performs an illegal maneuver, such as passing another vehicle across the double yellow line or on a shoulder. For many of these cases, neither driver performs an evasive action.

2.5.4 Applying the Data Directory

A data directory was used to reduce and analyze all SCEs. This data directory was originally used by Hickman et al. (in press) in a preliminary analysis of the Drowsy Driver Warning System Field Operational Test data. The same data directory was also used in Blanco et al. (in press). The Hawkeye software presented the data analyst with a series of variables consisting either of a blank space for entry of specific comments or pull-down menus that allowed the analyst to select the most applicable option. The analyst coded variables, such as pre-event movement, critical reason for the conflict, distraction(s), road condition, weather condition, and if the event occurred during a winter emergency (see Appendix G for the full data directory). To ensure accuracy, an expert data analyst reviewed all valid SCEs to verify they were valid and then applied the data directory.

2.5.5 Analysis of Actigraph Data

Actigraph data collected were used to measure sleep quantity for the participating drivers. Several steps were taken to prepare the data for analysis. For each actigraph file, the following steps were taken to assess sleep quantity (see Appendix H for detailed steps):

1. Identify and mark any "bad data" episodes (e.g., driver takes actigraph device off to shower),
2. Convert data into minute-by-minute files,
3. Import all data into actigraphy database, and

4. Implement algorithm to identify sleep periods.

3. RESULTS

This chapter is divided into three major sections: (i) naturalistic driving data, (ii) actigraph data, and (iii) questionnaire data. The first section describes the results obtained from vehicle sensors during the naturalistic driving portion of the study. The second section describes the data collected from the actigraph devices. The third section describes the results from the winter maintenance operator and manager questionnaires.

3.1 NATURALISTIC DATA RESULTS

Select results from the naturalistic data collection are presented below. Additional results are located in

Appendix I.

3.1.1 Participant Demographics

Four winter maintenance operators participated in the study. Three of these drivers were male and one was female. Limited participant demographic information is presented to protect the anonymity of the participating drivers.

Table 4 shows when and how frequently each instrumented snow plow was dispatched for winter emergencies. As shown, the GMC truck was dispatched for 24 days, and the International Tandem truck was dispatched for 15 days (due to vehicle maintenance).

Table 4. Winter Emergency Dates

Date	2001 GMC C7500 4x4		2001 International Tandem Model 2674 6x4	
	Dispatched?	Shift	Dispatched?	Shift
1/25/13	X	AM/PM	Not Instrumented	-
1/26/13	X	AM/PM	Not Instrumented	-
1/28/13	X	AM/PM	Not Instrumented	-
2/1/13	X	AM/PM	X	AM/PM
2/2/13	X	AM/PM	X	AM/PM
2/3/13	X	AM/PM	X	PM
2/5/13	X	PM	X	AM/PM
2/7/13	X	PM	X	AM/PM
2/8/13	X	AM/PM	X	AM
2/15/13	X	PM	X	PM
2/19/13	X	AM/PM	Out of Service	-
2/21/13	X	AM	Out of Service	-
2/22/13	X	PM	Out of Service	-
2/26/13	X	AM	Out of Service	-
2/27/13	X	AM/PM	X	AM/PM
2/28/13	X	AM	X	AM
3/5/13	X	AM/PM	Out of Service	-
3/6/13	X	AM	Out of Service	-
3/22/13	X	AM/PM	X	AM/PM
3/23/13	X	AM/PM	X	AM/PM
3/24/13	X	AM/PM	X	AM/PM
3/25/13	X	AM/PM	X	AM/PM
4/4/13	X	AM/PM	X	AM/PM
4/5/13	X	AM/PM	X	AM/PM
Total Days	**24**	**-**	**15**	**-**

Data were collected during winter emergencies and regular hours (as indicated above, data collection during regular working hours was limited). Table 5 shows the amount of vehicle sensor data collected during winter emergencies and non-winter emergencies, the number of acceleration triggers, the number of deceleration triggers, and the number of swerve triggers.

Table 5. Video Data and Triggers Recorded During Data Collection

Participant #	Winter Emergency Video (hr:min:sec)	Non-winter Emergency Video (hr:min:sec)	Total Video (hr:min:sec)	Acceleration Triggers	Deceleration Triggers	Swerve Triggers
1	102:07:35	2:00:44	104:08:19	820	1,449	2,822
2	106:52:25	5:00:13	111:52:38	1,626	890	6,505
3	65:44:34	12:49:02	78:33:36	1,349	1,238	4,796
4	64:13:13	10:05:21	74:18:34	646	1,167	2,717
Total	**338:57:47**	**29:55:20**	**368:53:07**	**4,441**	**4,744**	**16,840**

3.1.2 SCE Classification

A total of 92 SCEs were identified from the four participating drivers (Table 6). Of these 92 SCEs, three were due to acceleration (3.26 percent), six were due to deceleration (6.52 percent), and 83 were due to swerves (90.22 percent). As shown in Table 6, Participant #1 accounted for 54.52 percent of all SCEs.

Table 6. Number of SCEs

Participant #	Total SCEs	Acceleration SCEs	Deceleration SCEs	Swerve SCEs
1	52	2	5	45
2	12	1	0	11
3	16	0	0	16
4	12	0	1	11
Total	**92**	**3**	**6**	**83**

Table 7 shows the distribution of the SCE severity. Out of the 92 SCEs, 3.3 percent were crashes, 17.4 percent were crashes with low-hanging branches covered with snow/ice, 3.3 percent were avoidable curb strikes, 22.8 percent were near-crashes, and 53.3 percent were crash-relevant conflicts.

Table 7. SCE Severity

Crash Severity	Number (%)
Crash	3 (3.26%)
Crash: Low-hanging Branch	16 (17.39%)
Curb Strike: Avoidable	3 (3.26%)
Near-crash	21 (22.83%)
Crash-relevant Conflict	49 (53.26%)
Total	**92 (100%)**

Of the 92 SCEs, 90 (97.8 percent) occurred during a winter emergency. The two SCEs that did not occur during a winter emergency were classified as crash-relevant conflicts. The high percentage of SCEs occurring during winter emergencies is likely the result of the limited amount of data captured during non-winter emergencies (only 8.11 percent of all naturalistic driving data were collected during non-winter emergencies).

Figure 15 shows the percentage of SCEs by the hour of the day. As shown, the majority of SCEs (56.5 percent) occurred between 12:00 a.m. and 6:00 a.m.

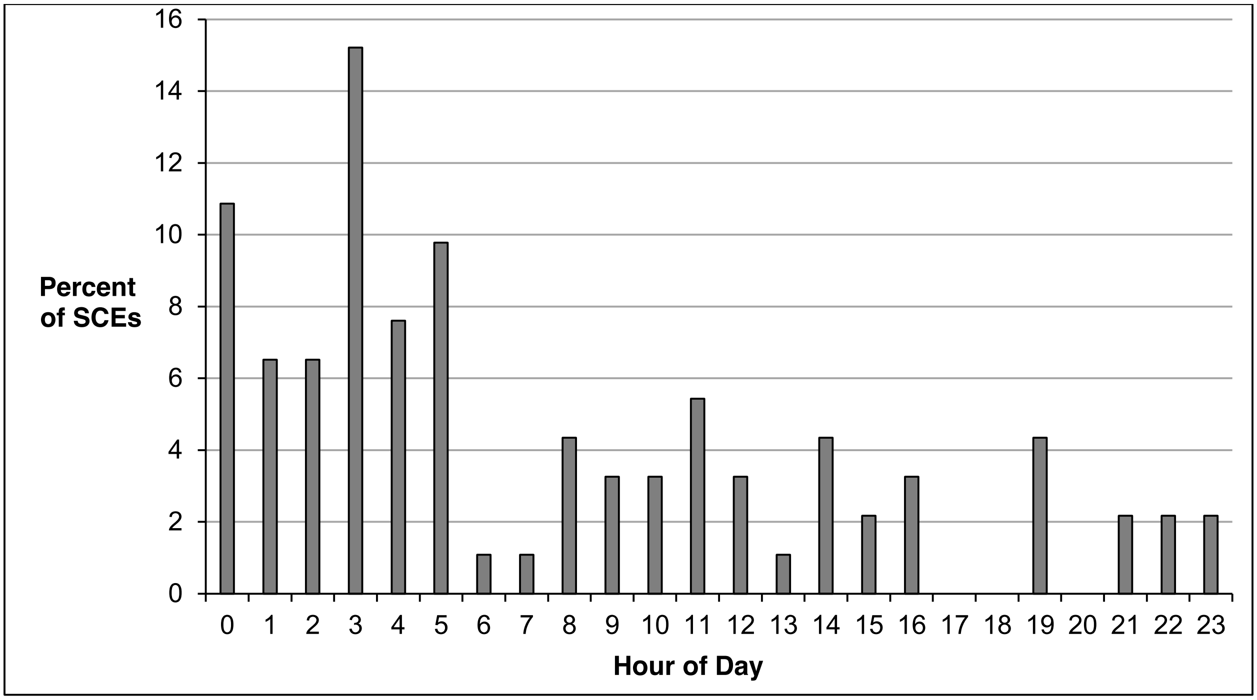

Figure 15. SCEs by Hour of Day

Figure 16 shows the percentage of SCEs occurring by the number of hours into the participants' work shift. As shown, the majority of SCEs occurred when the participant was between five and eight hours into his/her shift.

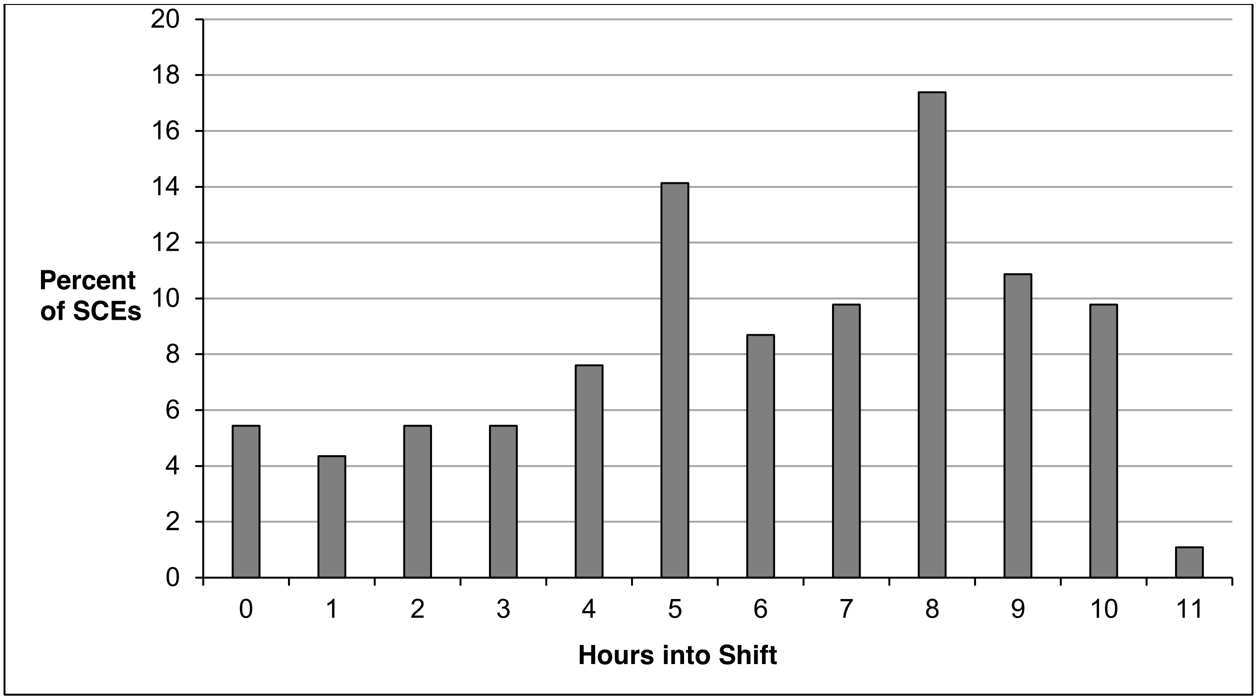

Figure 16. SCEs by Number of Hours into Shift

3.1.2.1 Contributing Factors

The contributing factor describes the researcher's assessment of why the SCE occurred. Figure 17 shows the distribution of contributing factors assigned to the SCEs. The majority of contributing factors were inattention/distraction (59.8 percent), driving on the wrong side of the road (14.1 percent), and other (18.5 percent).

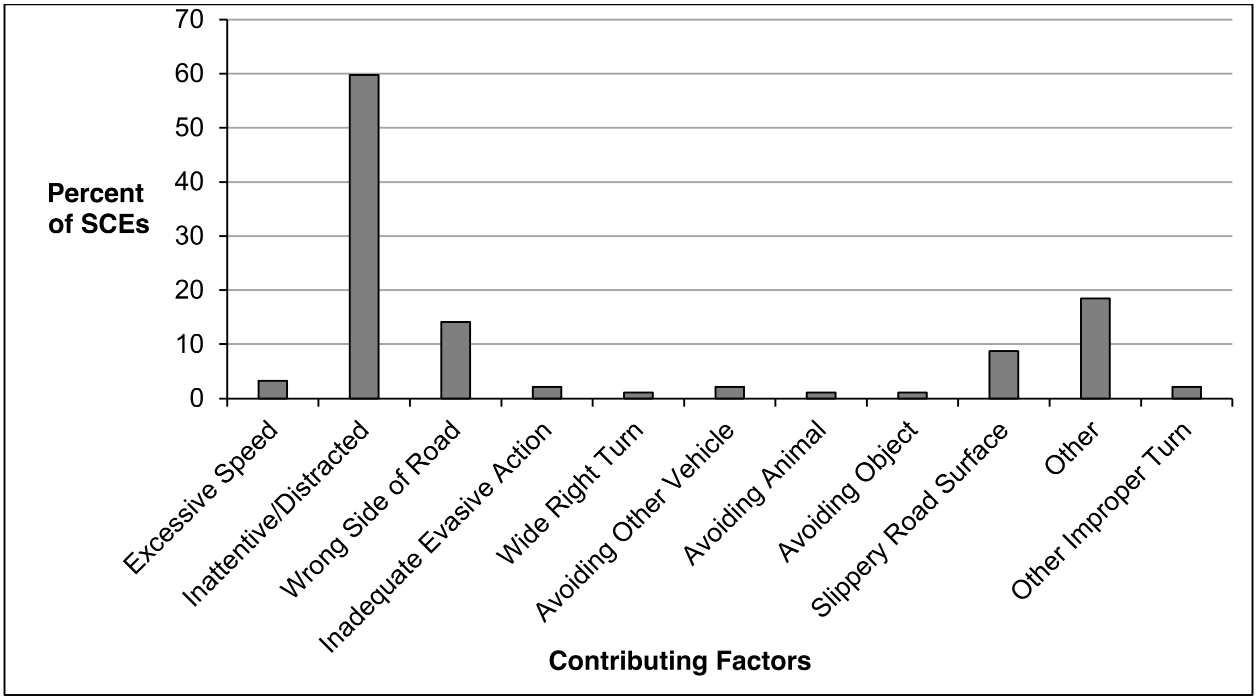

Figure 17. SCEs by Contributing Factors

3.1.2.2 Observer Rating of Drowsiness

An experienced data analyst reviewed each SCE to determine if it was possible to assess the driver's level of fatigue/drowsiness, also known as observer rating of drowsiness (ORD). An ORD of "0" means the driver was wide awake, and an ORD of 100 means the driver was asleep. A data analyst was able to complete an ORD for 83.7 percent of the SCEs. In the remaining SCEs, the data analyst was not able to clearly see the driver's eyes.

Table 8 shows the percent of SCEs where the driver was identified as drowsy (ORD ≥ 40). As shown, Participant #1 accounted for all the SCEs where the driver was identified as drowsy.

Table 8. Number of Drowsy Driving SCEs by Participant

Participant #	Total Number of SCEs	Total Number of SCEs with ORD ≥ 40	Percent of SCEs Where Driver was Drowsy
1	52	33	63.5%
2	12	N/A	N/A
3	16	0	0%
4	12	0	0%
Total	**92**	**33**	**35.9%**

3.1.2.3 Crash/Incident Type

Figure 18 shows the number of vehicles involved in an SCE. As shown, the majority of SCEs were single vehicle, including objects and animals (90.2 percent).

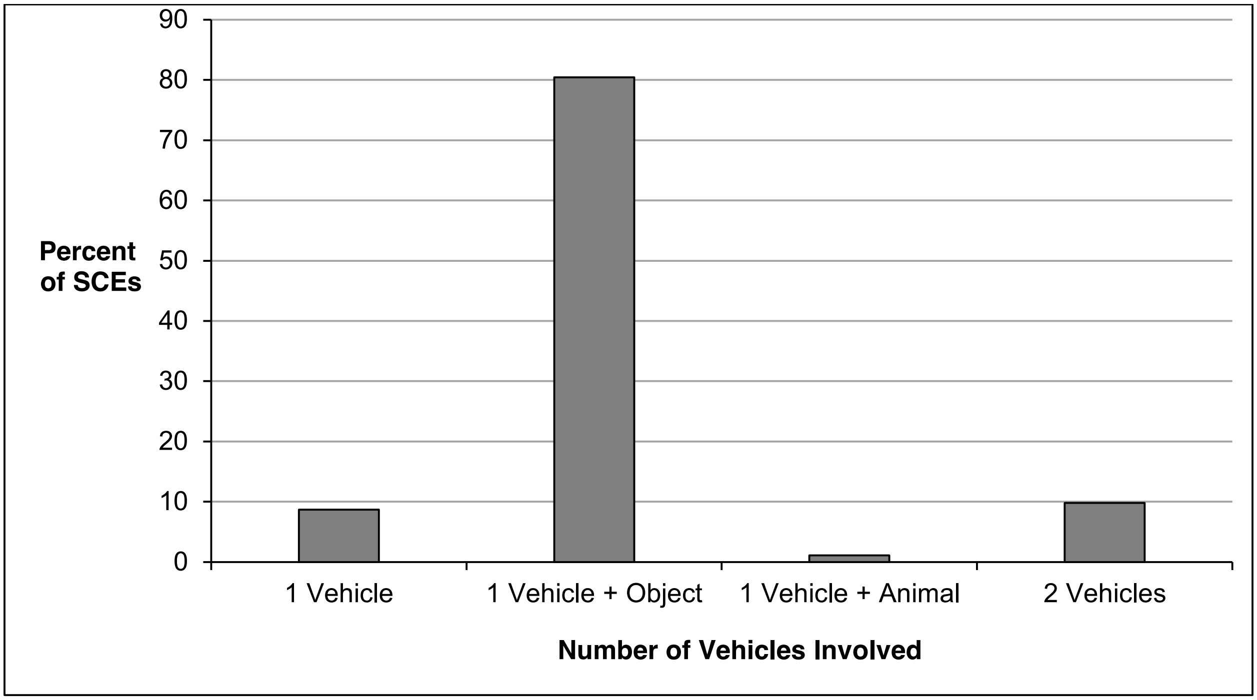

Figure 18. Percent of SCEs by Number of Vehicles Involved

Table 9 shows the frequency of Vehicle 1 (i.e., the instrumented truck) crash types. Crash types categorize the collisions of vehicles involved in crashes. However, since most of the SCEs were not crashes but rather near-crashes or other traffic conflicts, data analysts were instructed to code the crash type variable as if a crash occurred. This required a judgmental extrapolation of the SCE. Data analysts were instructed to ask themselves the question, "If a crash had occurred, what type of crash would it have been?" A visual representation of each crash type can be seen in the data directory in Appendix G. As shown in Table 9, the majority of SCEs were roadside or lane departures (65.22 percent). Right roadside (or lane) departures accounted for 46.7 percent of the SCEs, and left roadside (or lane) departures accounted for 12.0 percent. The other common crash type was forward impact with a stationary object (21.7 percent).

Table 9. Vehicle 1 Crash Types by SCE Severity

Vehicle 1 Crash Type	Crashes	Crashes: Low Hanging Branch	Curb Strike: Avoidable	Near-Crash	Crash-Relevant Conflict	Total SCEs
Right Roadside (or Lane) Departure – Drive Off Road	1	1	0	15	26	**43**
Right Roadside (or Lane) Departure – Control/Traction Loss	0	0	0	2	4	**6**
Left Roadside (or Lane) Departure – Drive Off Road	0	0	2	1	8	**11**
Forward Impact - Stationary Object	2	15	1	1	1	**20**
Forward Impact - Pedestrian/Animal	0	0	0	0	1	**1**
Forward Impact – Parked Vehicle	0	0	0	0	1	**1**
Forward Impact – End Departure	0	0	0	1	0	**1**
Rear-end	0	0	0	1	0	**1**
Same Roadway, Same Direction – Sideswipe Angle	0	0	0	0	2	**2**
Same Roadway, Opposite Direction – Avoid Collision with Vehicle	0	0	0	0	1	**1**
Same Roadway, Opposite Direction – Sideswipe Angle	0	0	0	0	4	**4**
Vehicle Turning – Turn into Same Direction	0	0	0	0	1	**1**
Total	**3**	**16**	**3**	**21**	**49**	**92**

Table 10 shows the number of Vehicle 1 incident types. The incident types were similar to crash types in that they referred to the vehicle's actions during each SCE. However, rather than being designed to describe the collision between two vehicles or a pedestrian/object (as described by the crash type), the incident types were developed to describe SCEs, such as near-crashes and crash-relevant conflicts (Hanowski et al., 2004). As shown in Table 10, the majority of SCEs involved a conflict with an animal/object either on or beside the roadway (63.0 percent).

Table 10. Vehicle 1 Incident Types by SCE Severity

Vehicle 1 Incident Type	Crashes	Crashes: Low Hanging Branch	Curb Strike: Avoidable	Near-Crash	Crash-Relevant Conflict	Total SCEs
Improper U-turn	0	0	1	0	0	**1**
Lane Drift	0	0	0	0	2	**2**
Late Braking (and/or Steering) for Stopped/Stopping Traffic	0	0	0	1	0	**1**
Lateral Deviation of Through Vehicle	0	0	0	0	5	**5**
Conflict with Animal/Pedestrian/Cyclist/Object in Roadway	2	0	0	1	3	**6**
Conflict with Animal/Pedestrian/Cyclist/Object on Side of Roadway	1	1	2	17	31	**52**
Other Single Vehicle Event	0	0	0	2	7	**9**
Conflict with Through Traffic	0	0	0	0	1	**1**
Other	0	15	0	0	0	**15**
Total	**3**	**16**	**3**	**21**	**49**	**92**

3.1.2.4 Critical Reason

Table 11 shows the Vehicle 1 critical reasons. The critical reason was the primary reason for the SCE occurring (Thieriez et al., 2002). Only one critical reason was coded for each SCE (i.e., either coded for Vehicle 1 or Vehicle 2, but not both). The critical reason was coded for Vehicle 1 in 91 out of the 92 SCEs. Table 11 only shows the critical reasons coded for Vehicle 1. The most frequent critical reasons were related to drowsiness/fatigue/sleep (28.3 percent), external distraction (19.6 percent), and object in roadway (19.6 percent).

Table 11. Vehicle 1 Critical Reasons by SCE Severity

Vehicle 1 Critical Reason	Crashes	Crashes: Low Hanging Branch	Curb Strike: Avoidable	Near-Crash	Crash-Relevant Conflict	Total SCEs
Critical Reason Not Coded to this Vehicle	0	0	0	0	1	**1**
DRIVER-RELATED FACTOR – Critical Non-performance Errors:						
Sleep (i.e., Actual Sleep)	1	0	0	2	2	**5**
Drowsiness, Fatigue, or Other Reduced Alertness (Not Asleep)	0	0	0	6	15	**21**
DRIVER-RELATED FACTOR – Recognition Errors						
Inattention (i.e., Daydreaming)	0	0	0	2	1	**3**
Internal Distraction	0	0	0	3	4	**7**
External Distraction	1	1	0	4	12	**18**
Inadequate Surveillance	0	0	2	0	2	**4**
Other Driver-related Recognition Error	0	0	0	0	1	**1**
Unknown Driver-related Recognition Error	0	0	0	0	1	**1**
DRIVER-RELATED FACTOR – Performance Errors						
Overcompensation	0	0	0	1	2	**3**
Poor Directional Control	0	0	1	0	0	**1**
ENVIRONMENT-RELATED FACTOR – Highway-related						
View Obstructions by Roadway Design	0	0	0	0	2	**2**
Slick Roads	0	0	0	2	4	**6**

ENVIRONMENT-RELATED FACTOR – Other						
Animal in Roadway (No Driver Error)	0	0	0	0	1	**1**
Object in Roadway (No Driver Error)	1	15	0	1	1	**18**
Total	**3**	**16**	**3**	**21**	**49**	**92**

3.1.2.5 Potential Distractions

Table 12 shows the number of potential distractions for each SCE occurring in Vehicle 1. Data analysts were instructed to code up to four potential distractions observed during a six-second epoch (i.e., five seconds prior to the start of the trigger and one second after the trigger). Potential distractions were coded regardless of their apparent relevance to the event. If there were more than four potential distractions, data analysts were instructed to select the ones that occurred closest in time to the trigger.

Data analysts coded 116 potential distractions in 62 SCEs. The most frequent potential distractions exhibited by participating drivers were *look at outside vehicle, person, animal, object* (27.6 percent), *look at left-side mirror* (15.5 percent), *look at right-side mirror* (12.1 percent), and *use chewing tobacco* (12.1 percent).

Table 12. Vehicle 1 Potential Distractions by SCE Severity

Vehicle 1 Crash Type	Crashes	Crashes: Low Hanging Branch	Curb Strike: Avoidable	Near-Crash	Crash-Relevant Conflict	Total SCEs
INTERNAL DISTRACTION: Person or Object						
Talk/sing/dance with no indication of passenger	0	0	1	2	3	**6**
Look at internal object	0	0	0	2	2	**4**
Reach for object in vehicle	0	0	0	2	3	**5**
Look back behind seat	0	0	0	0	1	**1**
INTERNAL DISTRACTION: Electronic Devices						
Talk or listen to CB microphone	0	0	0	1	0	**1**
Interact with dispatching device	0	0	0	1	1	**2**
INTERNAL DISTRACTION: Smoking-related						
Use chewing tobacco	0	1	0	2	11	**14**
INTERNAL DISTRACTION: Grooming						
Other personal hygiene	0	1	0	0	3	**4**
Adjust in seat	0	0	0	1	3	**4**
INTERNAL DISTRACTION: Vehicle-related						
Adjust instrument panel	0	1	0	0	1	**2**
EXTERNAL DISTRACTION						
Look at outside vehicle, person, animal, object	1	6	1	7	17	**32**

DRIVING-RELATED INATTENTION TO FORWARD ROADWAY						
Look at left-side mirror	1	1	1	2	13	**18**
Look at right-side mirror	0	5	0	4	5	**14**
Check speedometer	0	0	0	1	1	**2**
OTHER						
Other	0	3	1	1	2	**7**
Total	**2**	**18**	**4**	**26**	**66**	**116**

3.2 ACTIGRAPH DATA

Although each participant was instructed to wear the actigraph device at all times (with the exception of when the device may become submerged in water), there were instances when the device was removed for an extended period of time. For example, the watch band broke on three actigraph devices; thus, the participants did not wear the actigraph until it was replaced. Furthermore, in some situations the actigraph did not record the participant's activity level (e.g., the actigraph may provide false readings when it is pressed against another object for an extended period of time). A researcher reviewed all actigraph data to identify the "bad" data. "Bad" data were defined as 20 consecutive minutes with zero activity/movement (even in sleep there is minor activity that is measured by the actigraph). Table 13 displays the actigraph data. Participants wore the actigraphs for a total of 516,867 minutes; 53,612 of those minutes were coded as "bad" (10.37 percent).

Table 13. Total Actigraph Data Minutes Collected, Total Number of Bad Minutes, and Percent of Bad Minutes

Participant #	Total Minutes Worn	Total Bad Minutes	Percent Bad Minutes
1	128,729	19,123	14.86 %
2	129,065	15,244	11.81 %
3	129,029	12,289	9.52 %
4	130,044	6,956	5.35 %
Total	**516,867**	**53,612**	**10.37 %**

Table 14 shows the average sleep for each participant during the study. A complete night of actigraph data was defined as no more than 20 consecutive minutes of "bad" data. A night was excluded if that night had more than 20 consecutive minutes of "bad" data. As shown in Table 14, participants averaged 8.71 hours of sleep per day (N = 343 days; SD = 2.41 hours), 8.98 hours of sleep per day during non-winter emergencies (N = 256 days; SD = 1.56 hours), 7.87 hours of sleep 24 hours prior to a winter emergency (N = 34 days; SD = 1.60 hours), 8.31 hours of sleep during consecutive winter emergency shifts (N = 37 days; SD = 1.43 hours), and 7.30 hours of sleep 24 hours prior to an SCE (N = 92 days; SD = 1.89 hours).

Table 14. Sleep Summary (in hours)

Participant #	Daily Sleep	Daily Sleep during Non-winter Emergency	Sleep 24 Hours Prior to a Winter Emergency	Sleep during Consecutive Winter Emergency Shifts	Sleep 24 Hours Prior to SCE
1	8.05	8.63	6.31	7.48	4.55
2	10.04	10.66	8.58	8.71	8.83
3	8.12	8.10	8.26	8.32	8.02
4	8.64	8.53	8.31	8.73	7.81
Average	**8.71**	**8.98**	**7.87**	**8.31**	**7.30**

3.3 QUESTIONNAIRE RESULTS

The two parallel questionnaires in the current study targeted winter maintenance operators and managers of winter maintenance operations. The noteworthy questionnaire results are presented here; additional winter maintenance operator and manager questionnaire results are included in Appendix J and Appendix K, respectively.

3.3.1 Questionnaire Participant Demographics

A total of 1,043 winter maintenance operators and 453 managers from 24 states completed the questionnaires. The states highlighted in Figure 19 participated in the questionnaire data collection effort.

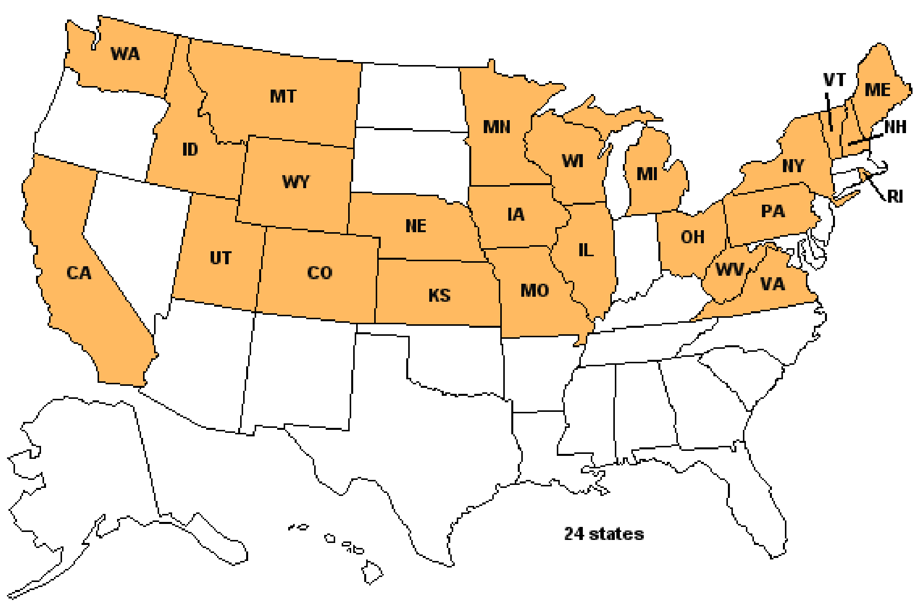

Figure 19. Participating States

3.3.1.1 Winter Maintenance Operator Demographics

Figure 20 shows the distribution of winter maintenance operators' places of employment. As shown, the majority of winter maintenance operators (95 percent) were employed at state DOTs.

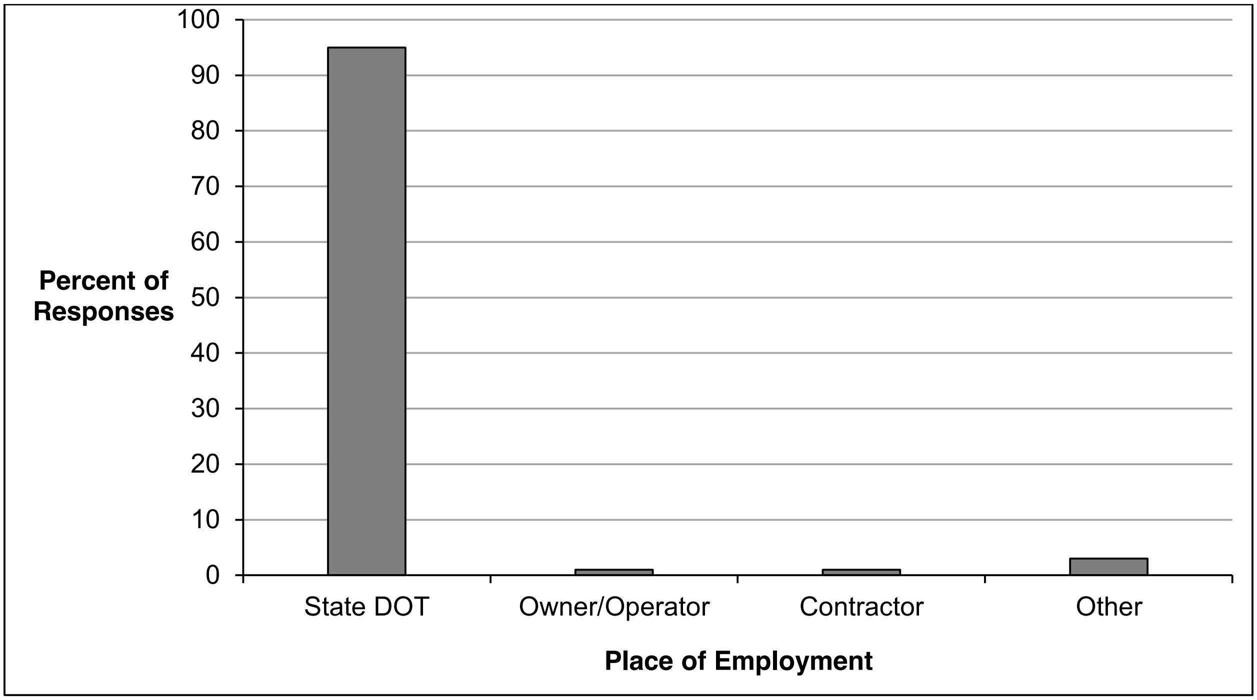

Figure 20. Winter Maintenance Operators' Places of Employment

Figure 21 shows the age distribution for winter maintenance operators. As shown, the majority of operators (55 percent) were between 45 and 65 years of age.

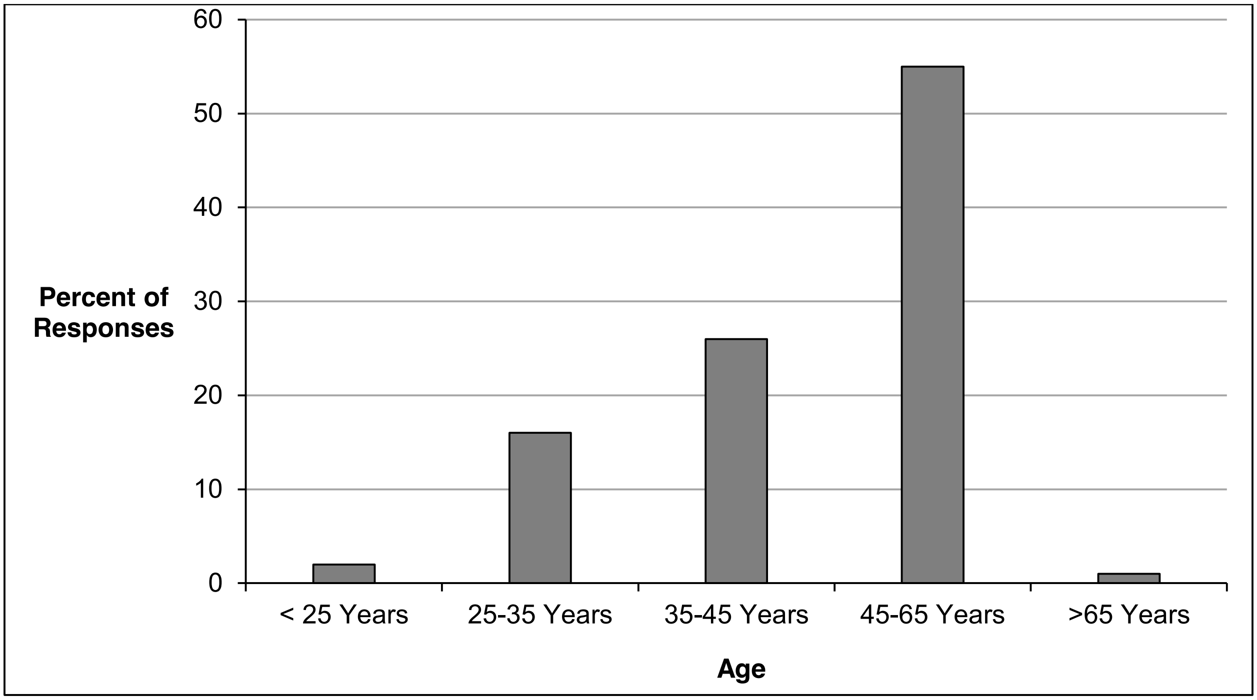

Figure 21. Age Distribution for Winter Maintenance Operators

Figure 22 shows the number of years the winter maintenance operators worked in winter maintenance operations. The majority of winter maintenance operators (31 percent) had more than 15 years of experience in winter maintenance operations.

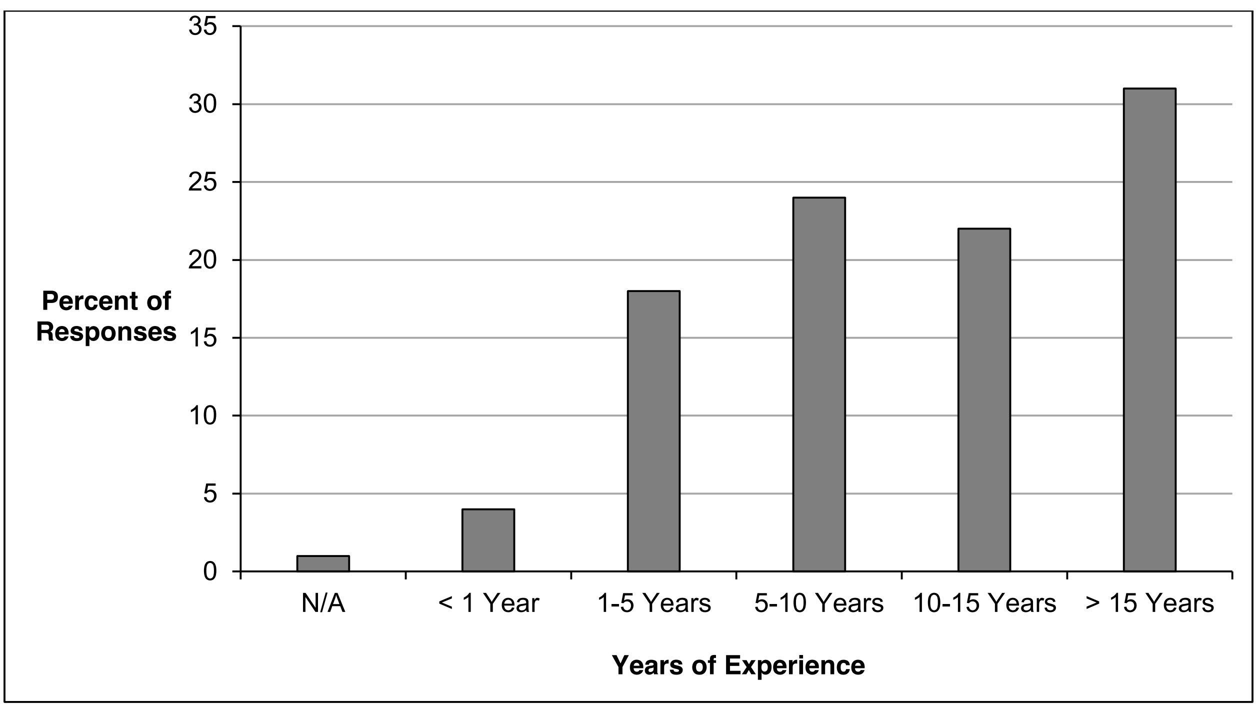

Figure 22. Winter Maintenance Operators' Experience in Winter Operations

3.3.1.2 Manager Demographics

Figure 23 shows the distribution of managers' current positions. The majority (65 percent) of the manager respondents were supervisors.

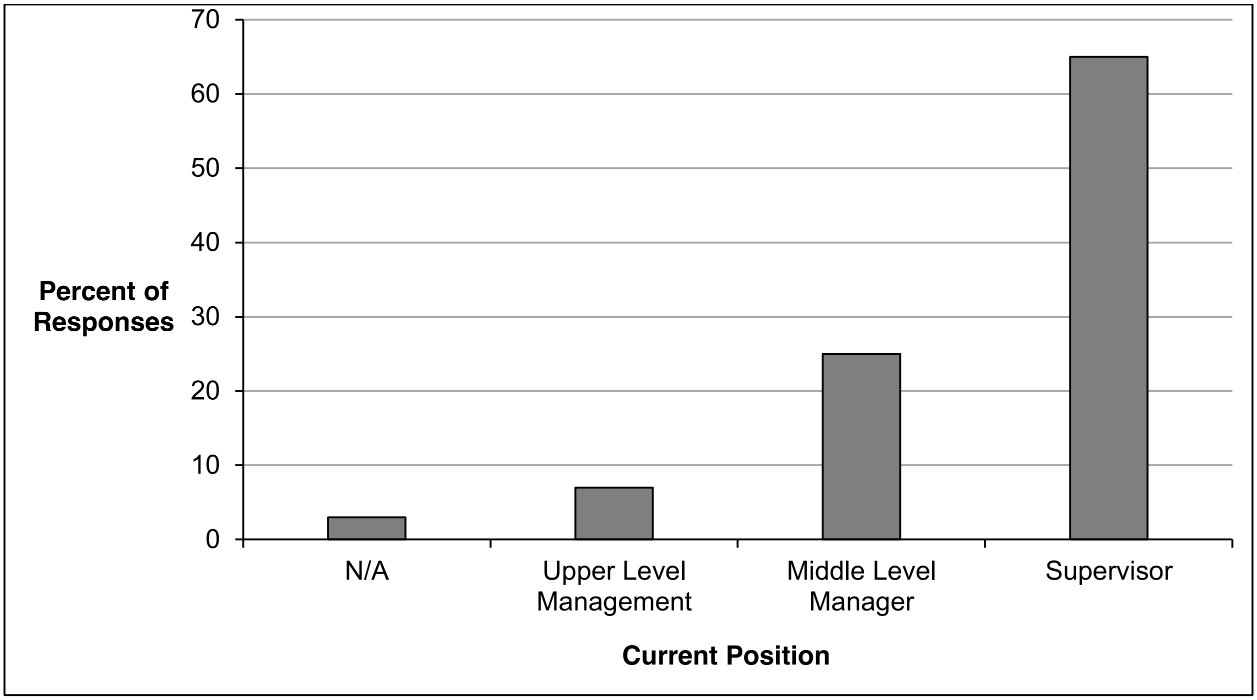

Figure 23. Managers' Current Positions

Figure 24 shows the age distribution of managers. The majority of managers (72 percent) were between the ages of 45 and 65.

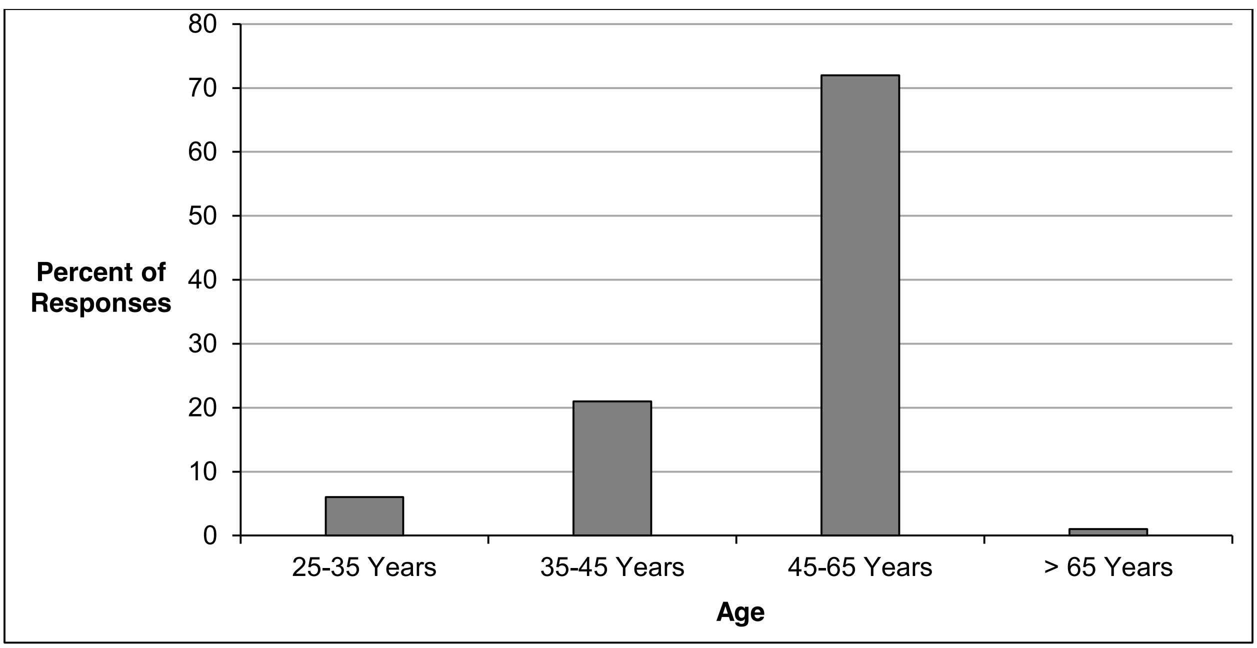

Figure 24. Age Distribution for Managers

Figure 25 shows how many years the managers have worked in winter maintenance operations. The majority of managers (68 percent) had more than 15 years of experience in winter maintenance operations.

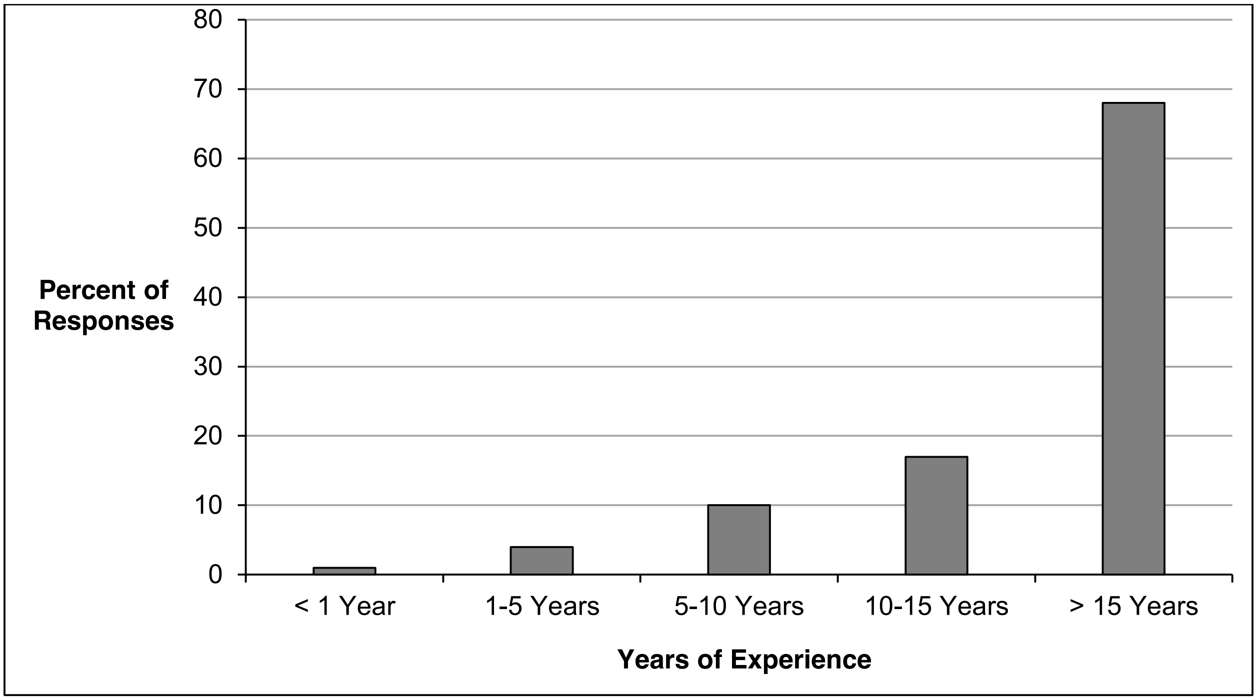

Figure 25. Managers' Experience in Winter Maintenance Operations

3.3.2 Noteworthy Questionnaire Results

The following section presents the noteworthy results from the questionnaires, including comparisons of winter maintenance operators' and managers' responses. Chi-square tests were performed on each question to determine if the distribution of responses between the winter maintenance operators and managers was significantly different.

3.3.2.1 Impact of Fatigue

Figure 26 shows the distribution of winter maintenance operators' and managers' responses to the following question: "To what degree do you think fatigue impacts the operation of a snow plow during winter emergencies?" The majority of winter maintenance operators and managers reported fatigue had a "moderate impact" on the operation of a snow plow during winter emergencies. However, the distribution of winter maintenance operators' and managers' responses was found to be significantly different ($\chi^2 = 34.18$, $p < 0.01$). As shown in Figure 26, winter maintenance operators reported fatigue impacts the operation of snow plows during winter emergencies to a greater degree than the managers.

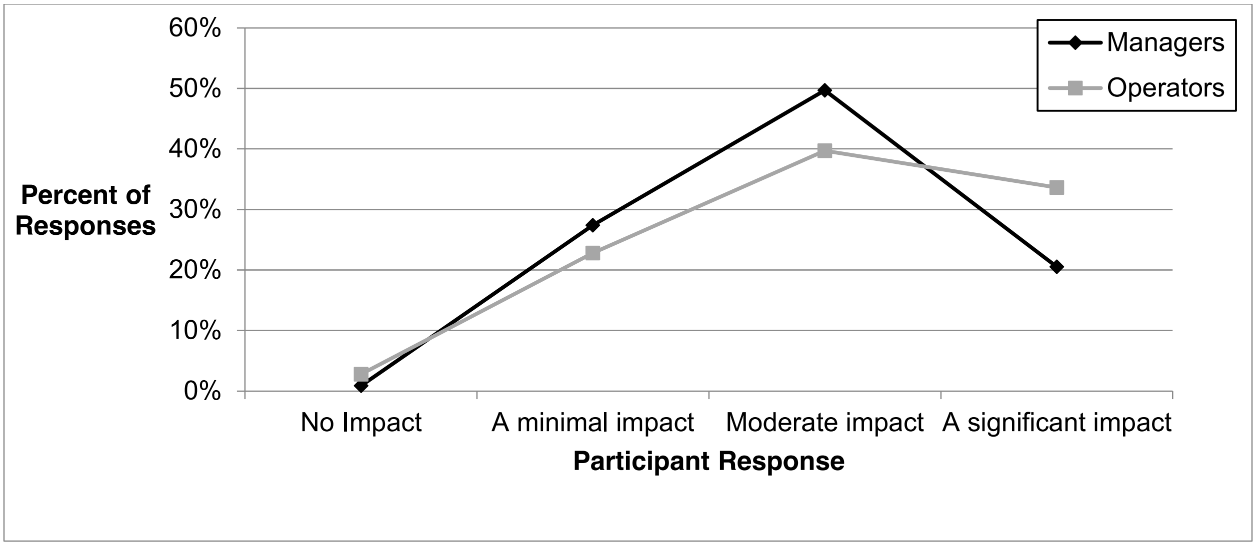

Figure 26. Impact of Fatigue on the Operation of a Snow Plow during Winter Emergencies

The winter maintenance operators' responses regarding the impact of fatigue on winter maintenance operations were correlated with the age of winter maintenance operators ($\chi^2 = 25.46$, $p < 0.05$). Older winter maintenance operators (more than 45 years old) believed fatigue had a greater impact on winter maintenance operations compared to their younger counterparts.

3.3.2.2 Frequency of Fatigue

Figure 27 shows the distribution of winter maintenance operators' and managers' responses to how frequently winter maintenance operators experience fatigue while operating a snow plow during winter emergencies. The majority of winter maintenance operators and managers indicated that winter maintenance operators "sometimes" experience fatigue while operating a snow plow during winter emergencies. However, the distribution of winter maintenance operators' and managers' responses was found to be significantly different ($\chi^2 = 96.65$, $p < 0.01$). As shown in Figure 27, managers believed winter maintenance operators experienced fatigue more frequently while operating a snow plow during a winter emergency than did winter maintenance operators.

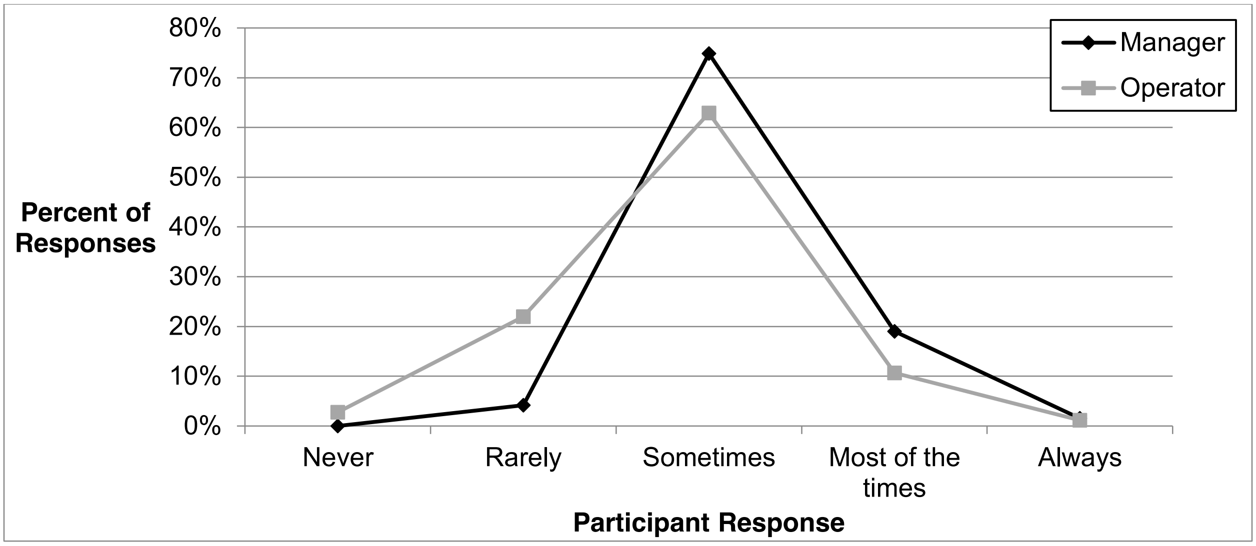

Figure 27. Frequency of Fatigue While Operating a Snow Plow during Winter Emergencies

How frequently winter maintenance operators experienced fatigue when operating a snow plow during winter emergencies was correlated with their opinions regarding the impact of fatigue ($\chi^2 = 416.43$, $p < 0.05$). The more a winter maintenance operator reported experiencing fatigue while operating a snow plow, the more he/she believed fatigue had an impact on snow plow operations during winter emergencies.

3.3.2.3 Lapse in Concentration

Figure 28 shows the distribution of winter maintenance operators' and managers' responses to how frequently winter maintenance operators experience lapses in concentration while operating a snow plow during winter emergencies. The majority of winter maintenance operators indicated they "rarely" experienced a lapse in concentration while operating a snow plow during winter emergencies. The majority of managers reported that winter maintenance operators "sometimes" experienced a lapse in concentration while operating a snow plow during winter emergencies. This difference in the distribution of winter maintenance operators' and managers' responses was significantly different ($\chi^2 = 137.08$, $p < 0.01$).

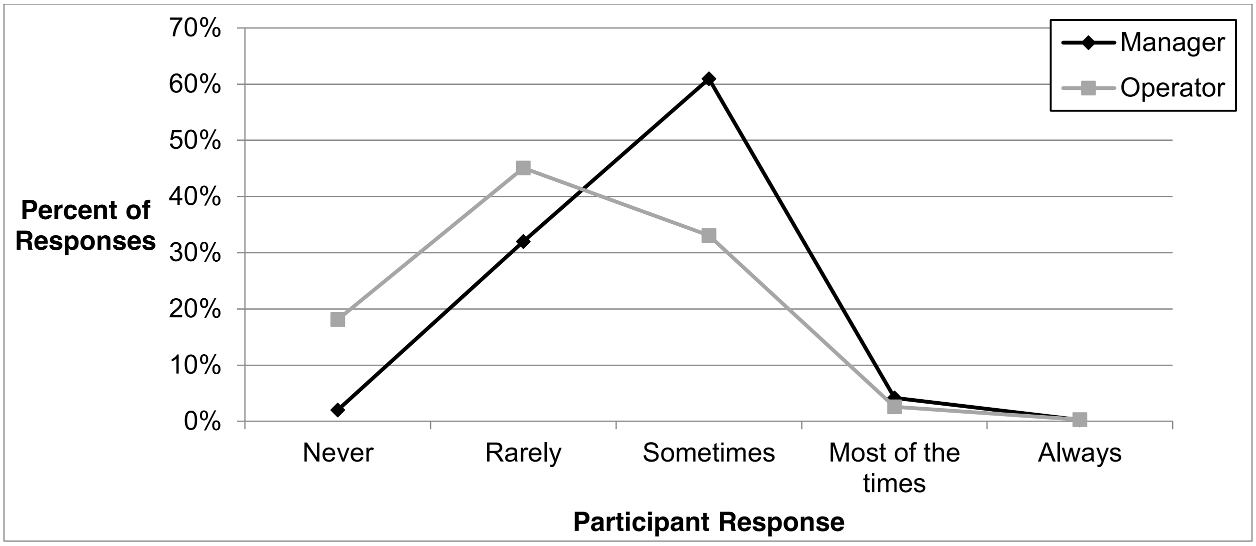

Figure 28. Frequency of "Lapses in Attention" While Operating a Snow Plow during Winter Emergencies

How often a winter maintenance operator reported a lapse of concentration was correlated with the winter maintenance operator's responses regarding the impact of fatigue on winter operations ($\chi^2 = 14.30$, $p = 0.03$). The more a winter maintenance operator reported experiencing a lapse in concentration while operating a snow plow, the more he/she considered fatigue to impact winter maintenance operations.

3.3.2.4 Fatigue While Driving Home

Figure 29 shows the distribution of winter maintenance operators' and managers' responses to how frequently winter maintenance operators feel extremely tired while driving home after completing a winter emergency shift. The majority of winter maintenance operators indicated they "sometimes" feel extremely tired while driving home after a winter emergency shift. The majority of managers reported that "most of the time" winter maintenance operators feel extremely tired while driving home after a winter emergency shift. The difference in the distribution of winter maintenance operators' and managers' responses was found to be significantly different ($\chi^2 = 101.26$, $p < 0.01$).

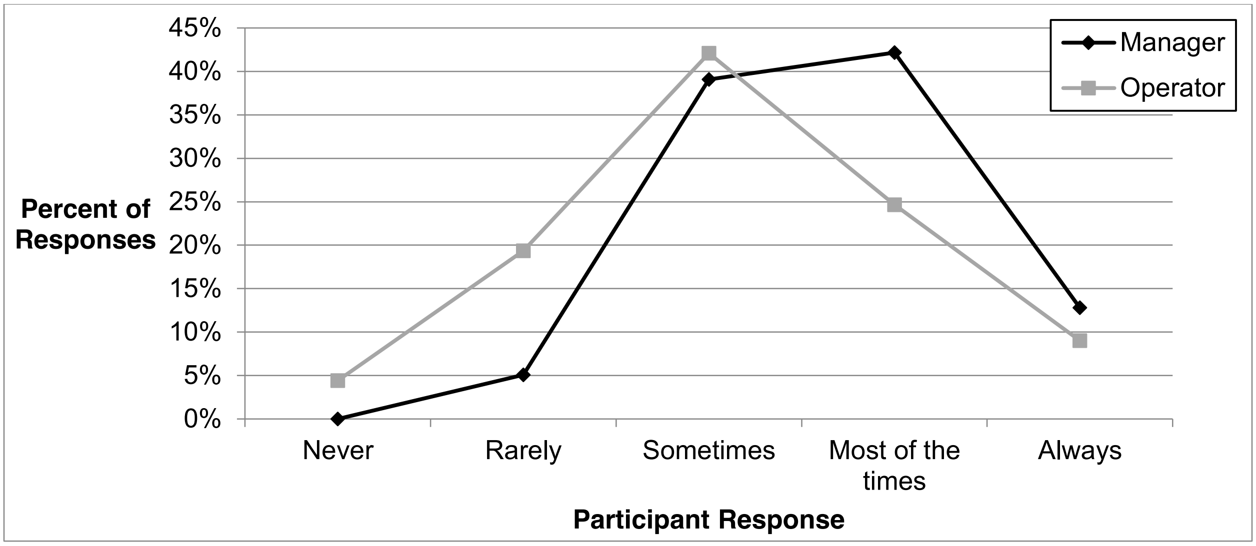

Figure 29. Responses to the Question, "How Often Do Operators Feel Extremely Tired when Driving Home After Completing a Shift during a Winter Emergency?"

How often a winter maintenance operator reported being extremely tired when driving home after a winter emergency was correlated to the winter maintenance operator's opinions regarding the impact of fatigue ($\chi^2 = 259.41$, $p < 0.05$). The more frequently a winter maintenance operator reported feeling tired while driving home after a winter emergency, the more he/she considered fatigue to impact winter operations.

3.3.2.5 Sources of Fatigue

Figure 30 compares winter maintenance operators' and managers' opinions regarding the importance of the type of seat as a source of fatigue during a winter emergency. The majority of winter maintenance operators indicated the type of seat was an "extremely important" source of fatigue. However, the majority of managers indicated the type of seat was "very important" as a source of fatigue. The distribution of responses between winter maintenance operators and managers was found to be significantly different ($\chi^2 = 53.62$, $p < 0.01$).

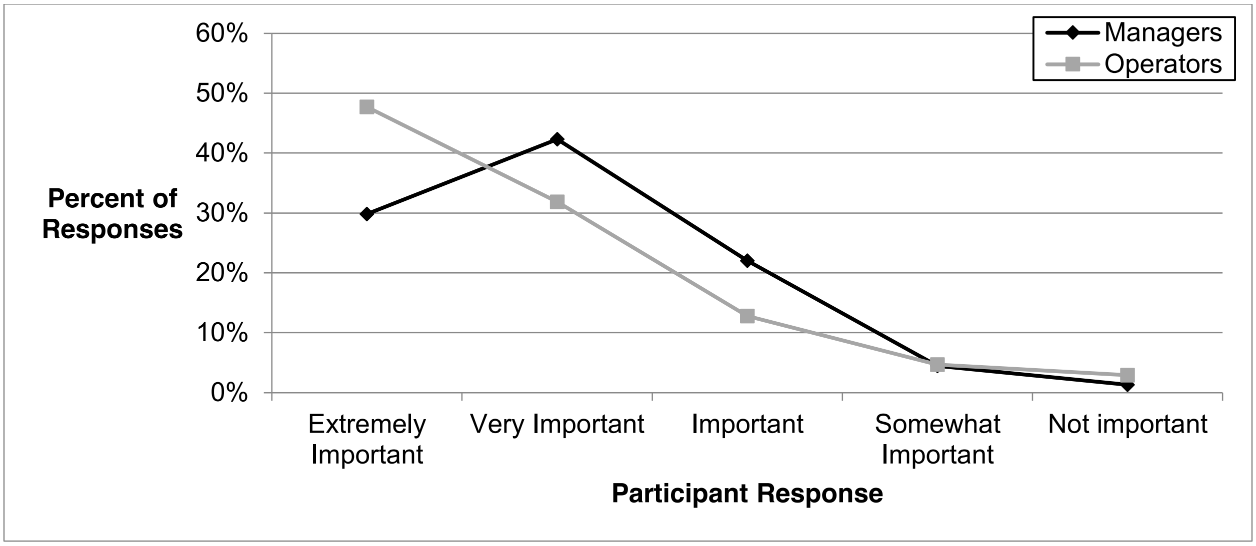

Figure 30. Importance of Seat Type as a Source of Fatigue during Winter Emergencies

Figure 31 compares winter maintenance operators' and managers' opinions regarding the importance of noise as a source of fatigue during a winter emergency. The majority of winter maintenance operators indicated that noise was a "very important" source of fatigue. However, the majority of managers indicated that noise was an "important" source of fatigue. The distribution of responses between winter maintenance operators and managers was found to be significantly different ($\chi^2 = 58.40$, $p < 0.01$).

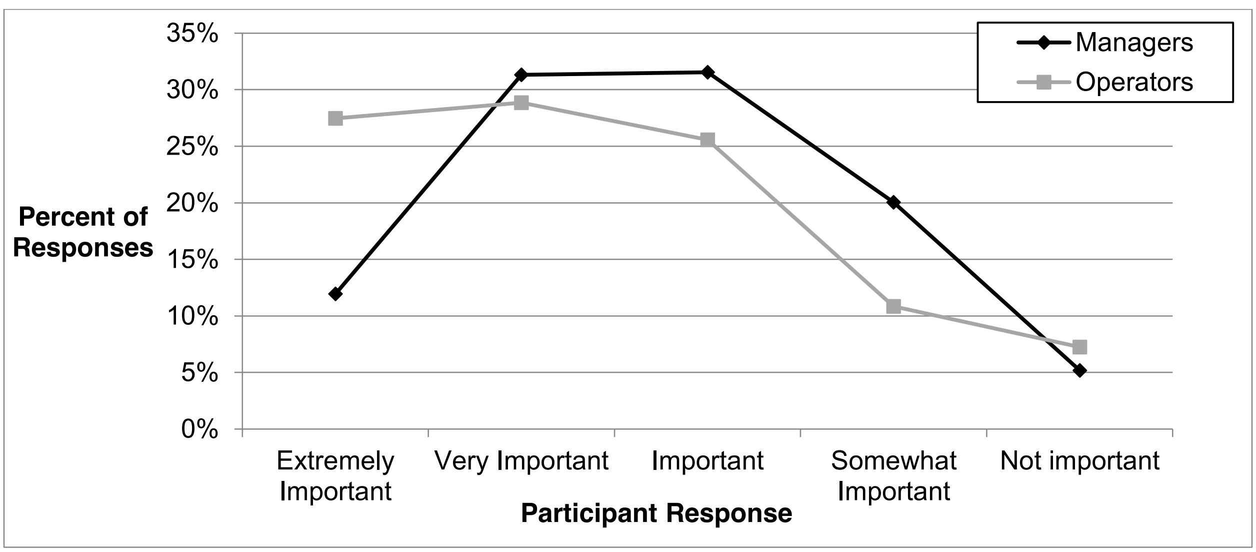

Figure 31. Importance of Noise as a Source of Fatigue during Winter Emergencies

Figure 32 compares winter maintenance operators' and managers' opinions regarding a lack of technology on the snow plow (e.g., route maps automatically updated via a wireless signal, automatic/drop tire chains, automatic transmissions, and air-ride seats) as a source of fatigue during a winter emergency. The majority of winter maintenance operators indicated that a lack of technology inside the snow plow was an "important" source of fatigue. The majority of managers indicated that a lack of technology inside the snow plow was a "somewhat important" source of fatigue. The distribution of responses between winter maintenance operators and managers was found to be significantly different ($\chi^2 = 33.72$, $p < 0.01$).

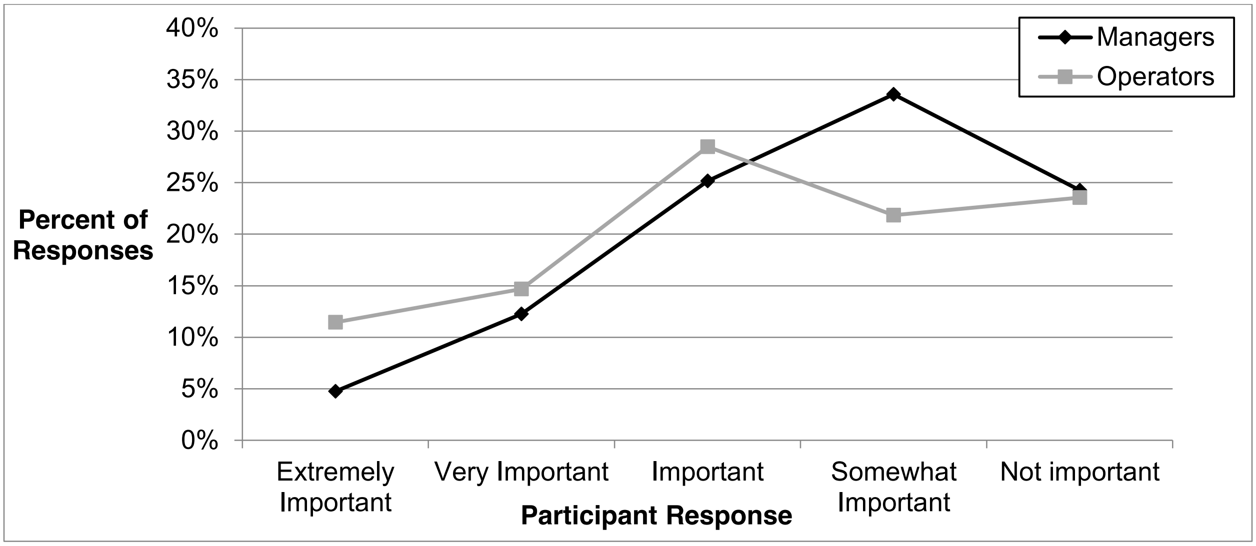

Figure 32. Importance of a Lack of Technology on Truck as a Source of Fatigue during Winter Emergencies

3.3.2.6 Pressure to Work More than Comfortable

Figure 33 shows the distribution of winter maintenance operators' and managers' responses to the following statement: "Snow plow operators feel they are pressured to work more than they feel comfortable/reasonable during a winter emergency." The majority of winter maintenance operators "disagreed" that they felt pressured to work more than they felt comfortable/reasonable, and managers "agreed" that winter maintenance operators felt pressured to work more than they felt comfortable/reasonable. Managers were significantly more likely than winter maintenance operators to report that winter maintenance operators felt pressured to work more than they felt comfortable/reasonable ($\chi^2 = 49.76$, $p < 0.01$).

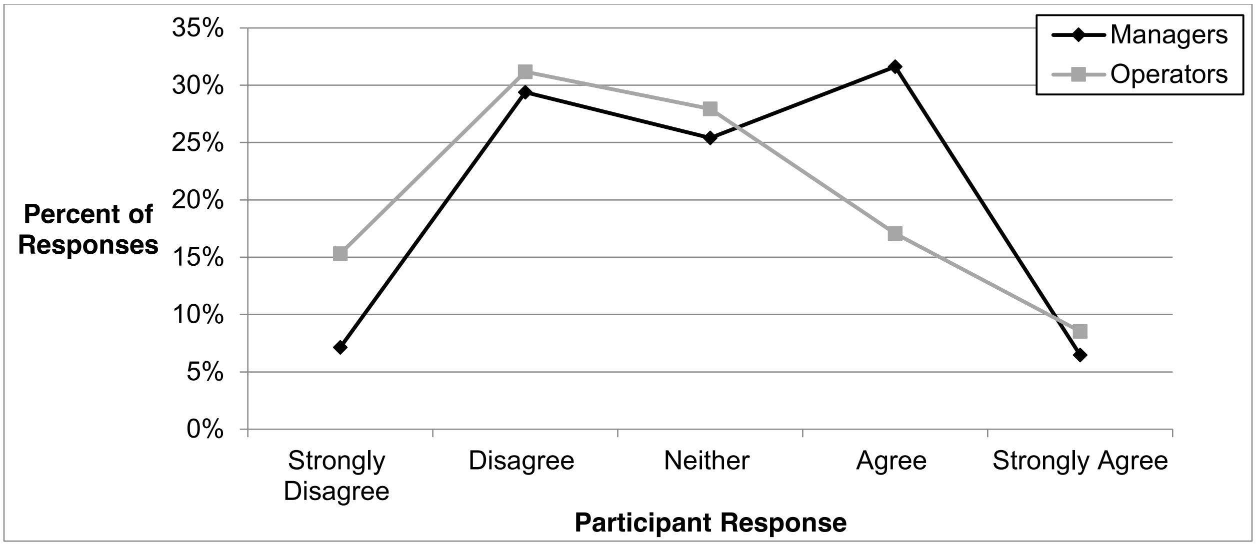

Figure 33. Responses to the Statement, "Snow Plow Operators Feel they are Pressured to Work More than They Feel Comfortable/Reasonable during a Winter Emergency."

3.3.2.7 Strategies to Combat Fatigue

Figure 34 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of a break from driving when winter maintenance operators get tired or fatigued. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 185.08$, $p < 0.01$). As shown in Figure 34, winter maintenance operators indicated that taking breaks was an effective method to reducing fatigue, but they only "sometimes" used breaks to reduce fatigue.

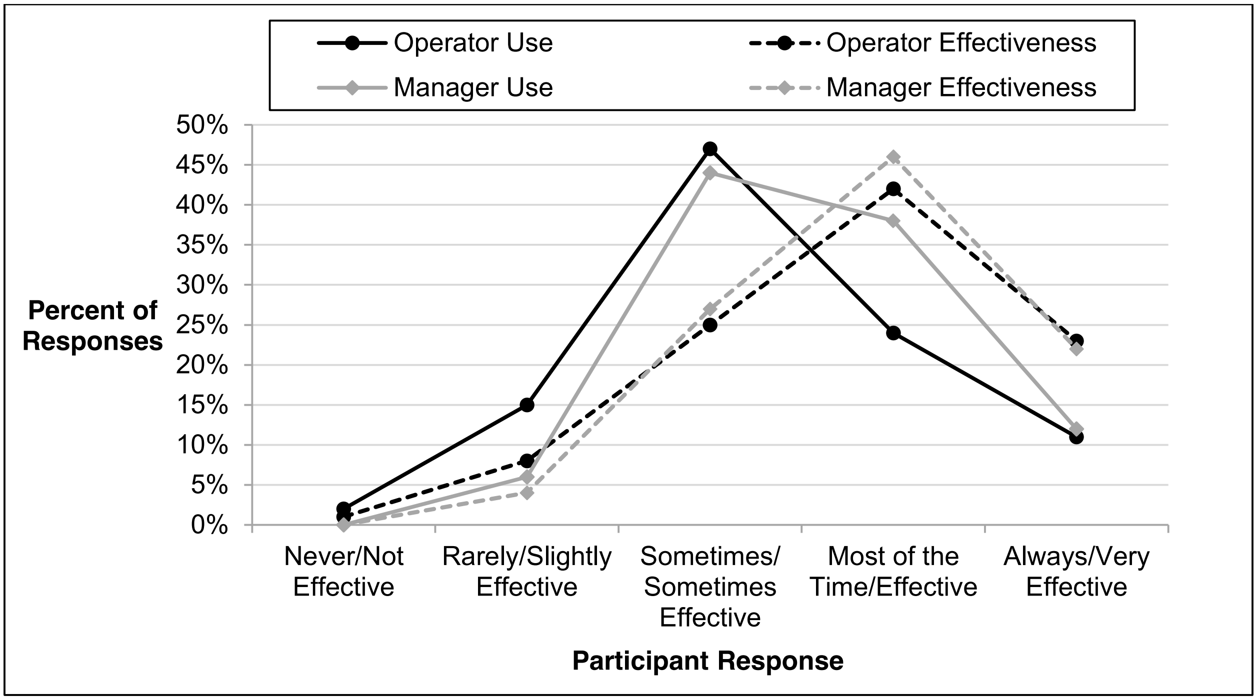

Figure 34. Use and Effectiveness of Breaks in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of breaks was significantly different ($\chi^2 = 40.50$, $p < 0.01$). Similar to winter maintenance operators, managers indicated that taking breaks was an effective method to reducing fatigue, but they believed winter maintenance operators only "sometimes" used breaks to reduce fatigue.

Figure 35 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of body movement in reducing fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 98.09$, $p < 0.01$). As shown in Figure 35, winter maintenance operators indicated that body movement was an effective method to reducing fatigue, but they only "sometimes" used body movement to reduce fatigue.

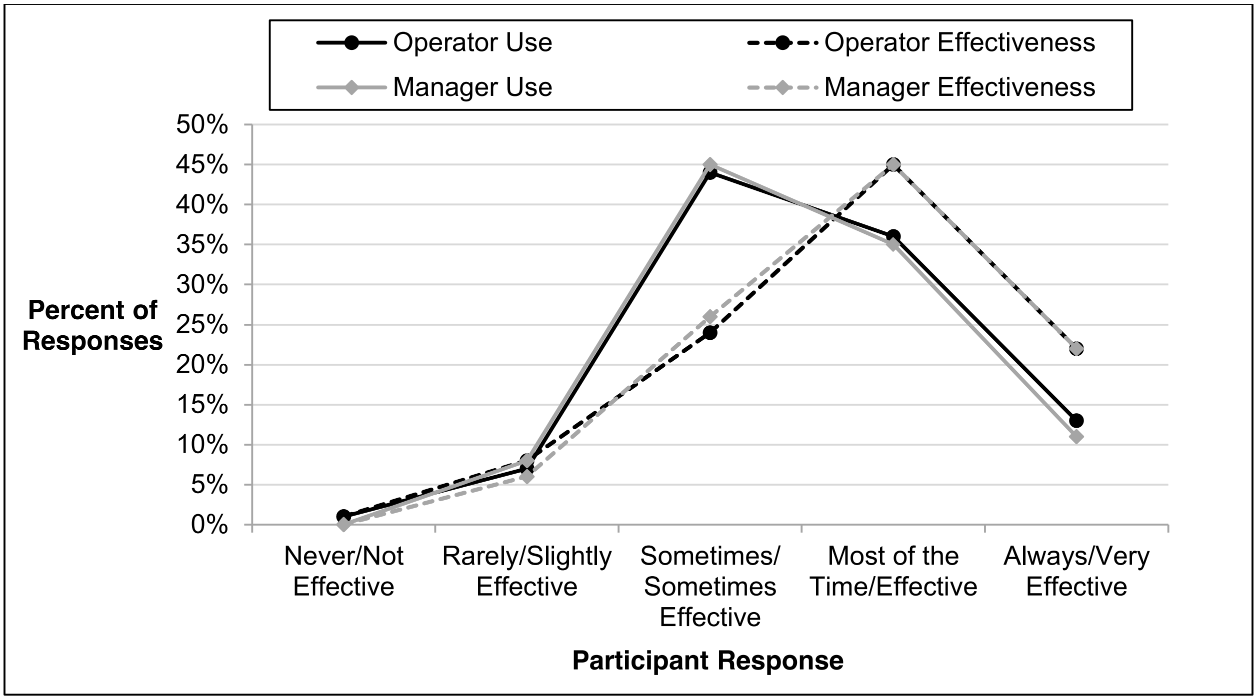

Figure 35. Use and Effectiveness of Body Movement in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of body movement was significantly different ($\chi^2 = 45.19$, $p < 0.01$). Similar to winter maintenance operators, managers indicated that body movement was an effective method to reducing fatigue, but they believed winter maintenance operators only "sometimes" used body movement to reduce fatigue.

Figure 36 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of a conversation on a cell phone or CB radio in reducing fatigue. The majority of winter maintenance operators indicated that they "never" or "rarely" had a cell phone/CB conversation when they were tired or fatigued, and the cell phone/CB conversation was not effective in reducing fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 34.35$, $p < 0.01$).

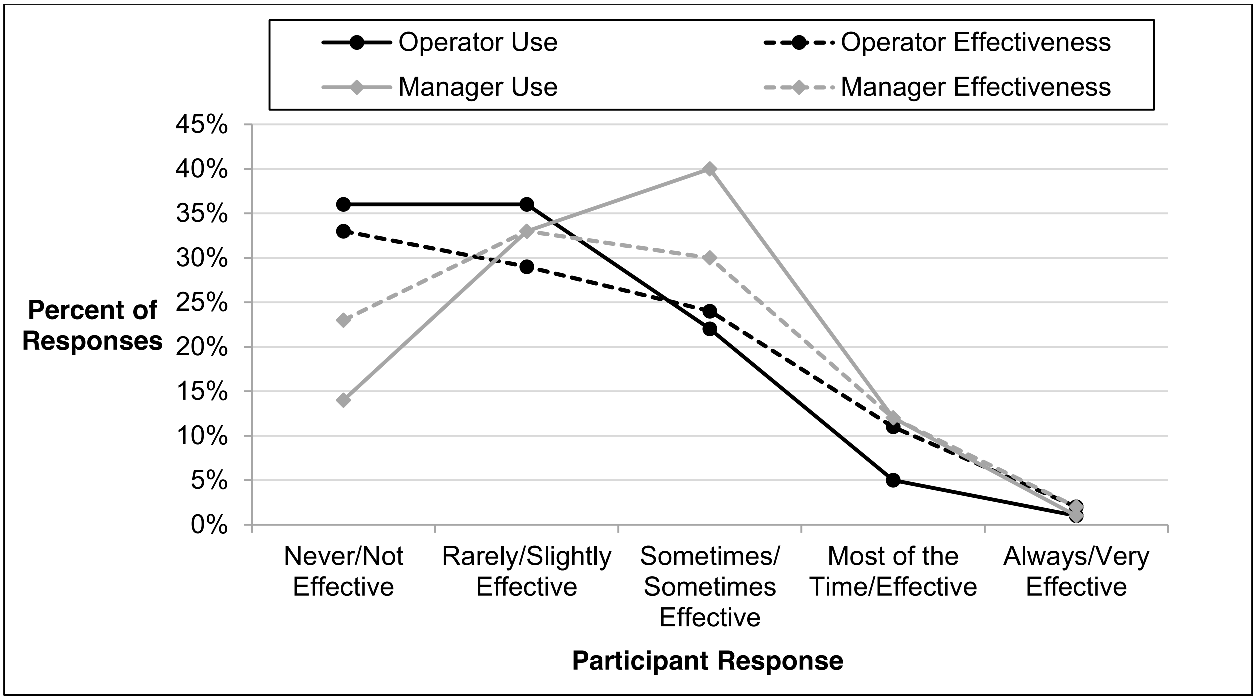

Figure 36. Use and Effectiveness of Cell Phone or CB Radio Conversations in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of cell phone/CB radio conversations was significantly different ($\chi^2 = 45.19$, $p < 0.01$). Unlike winter maintenance operators, managers indicated that cell phone/CB radio conversations were a "slightly effective" method in reducing fatigue and winter maintenance operators "sometimes" used cell phone/CB radio conversations to reduce fatigue.

Figure 37 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of taking a quick nap in reducing fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 441.58$, $p < 0.01$). As shown in Figure 37, winter maintenance operators indicated that a short nap was an effective method in reducing fatigue most of the time, but they only rarely took a short nap to reduce fatigue.

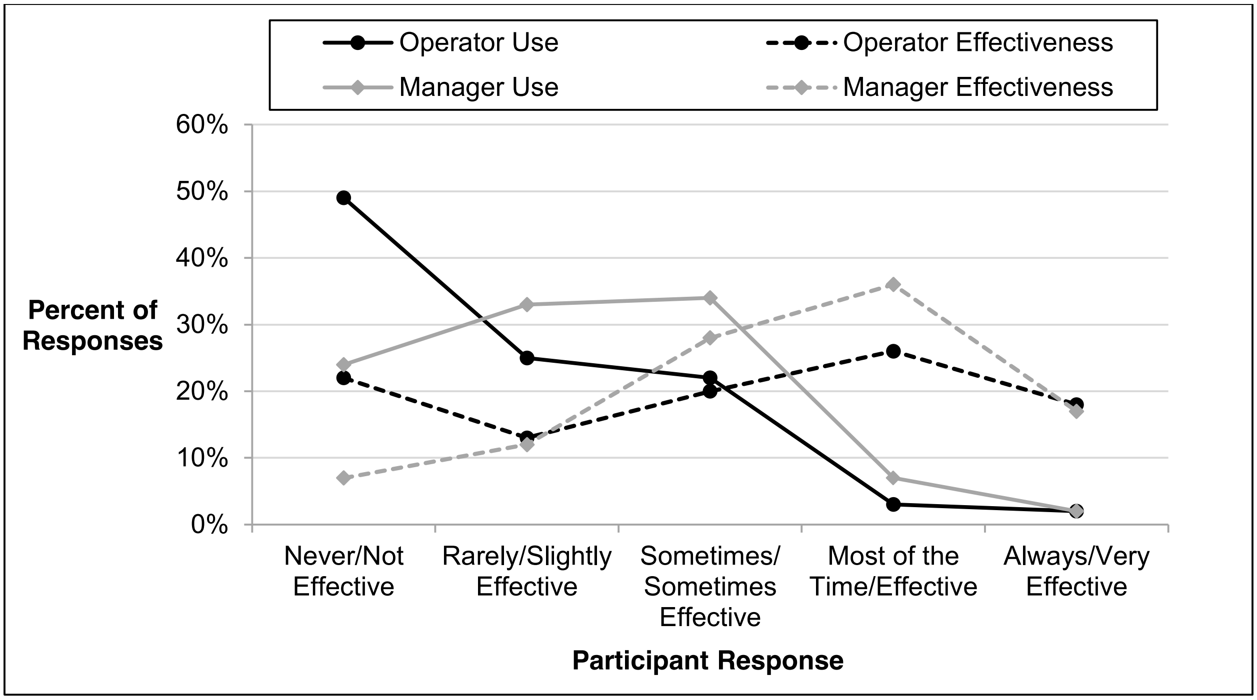

Figure 37. Use and Effectiveness of a Quick Nap in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of a quick nap was significantly different ($\chi^2 = 228.26$, $p < 0.01$). Similar to winter maintenance operators, managers indicated a quick nap was an effective method in reducing fatigue most of time. Unlike winter maintenance operators, they believed winter maintenance operators took a short nap "sometimes" to reduce fatigue.

Figure 38 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of over-the-counter stimulants in reducing fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 73.75$, $p < 0.01$). The majority of winter maintenance operators indicated that they never used an over-the-counter stimulant when they felt tired/fatigued and an over-the-counter stimulant was not effective in reducing fatigue.

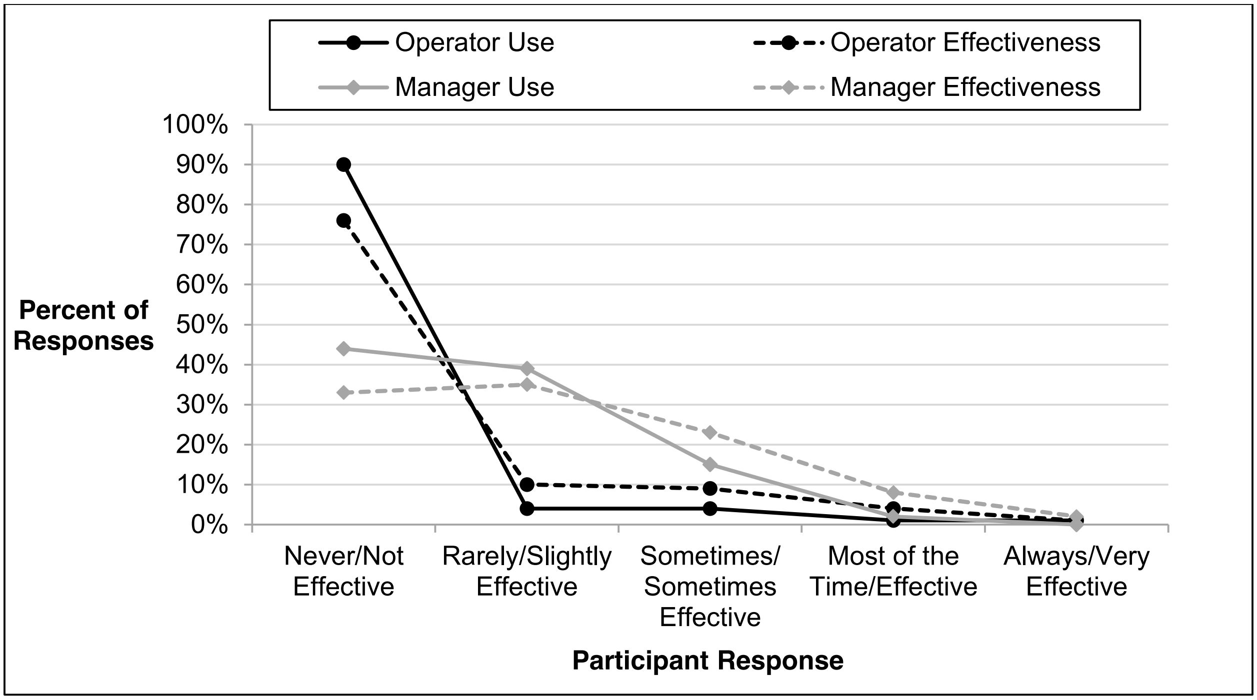

Figure 38. Use and Effectiveness of Over-the-counter Stimulants in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of over-the-counter stimulants was significantly different ($\chi^2 = 35.11$, $p < 0.01$). Similar to winter maintenance operators, managers believed winter maintenance operators never or rarely used over-the-counter stimulants to reduce fatigue. Unlike winter maintenance operators, the majority of managers believed the stimulants were slightly effective in reducing fatigue.

Figure 39 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of drinking caffeine to reduce fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 49.16$, $p < 0.01$). As shown in Figure 39, winter maintenance operators indicated that drinking caffeine was "sometimes" an effective method to reducing fatigue but they drank caffeine to reduce fatigue "most of the time."

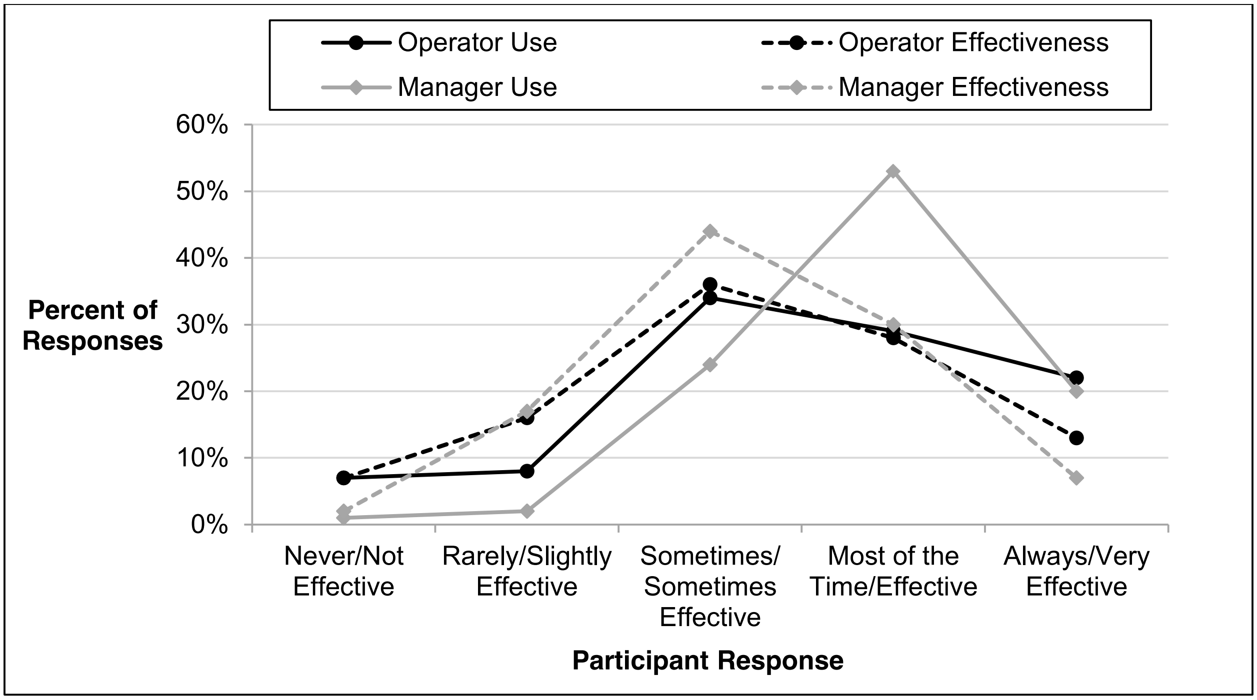

Figure 39. Use and Effectiveness of Caffeine in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of caffeine was significantly different ($\chi^2 = 137.20$, $p < 0.01$). Similar to winter maintenance operators, managers believed that drinking caffeine was "sometimes" an effective method to reducing fatigue and winter maintenance operators drank caffeine to reduce fatigue "most of the time."

Figure 40 compares winter maintenance operators' and manager's responses regarding usage and effectiveness of listening to the radio/music in reducing fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 147.99$, $p < 0.01$). As shown in Figure 40, the majority of winter maintenance operators indicated that listening to the radio/music was "sometimes" an effective method to reducing fatigue but they used the radio/music to reduce fatigue "most of the time" or "always."

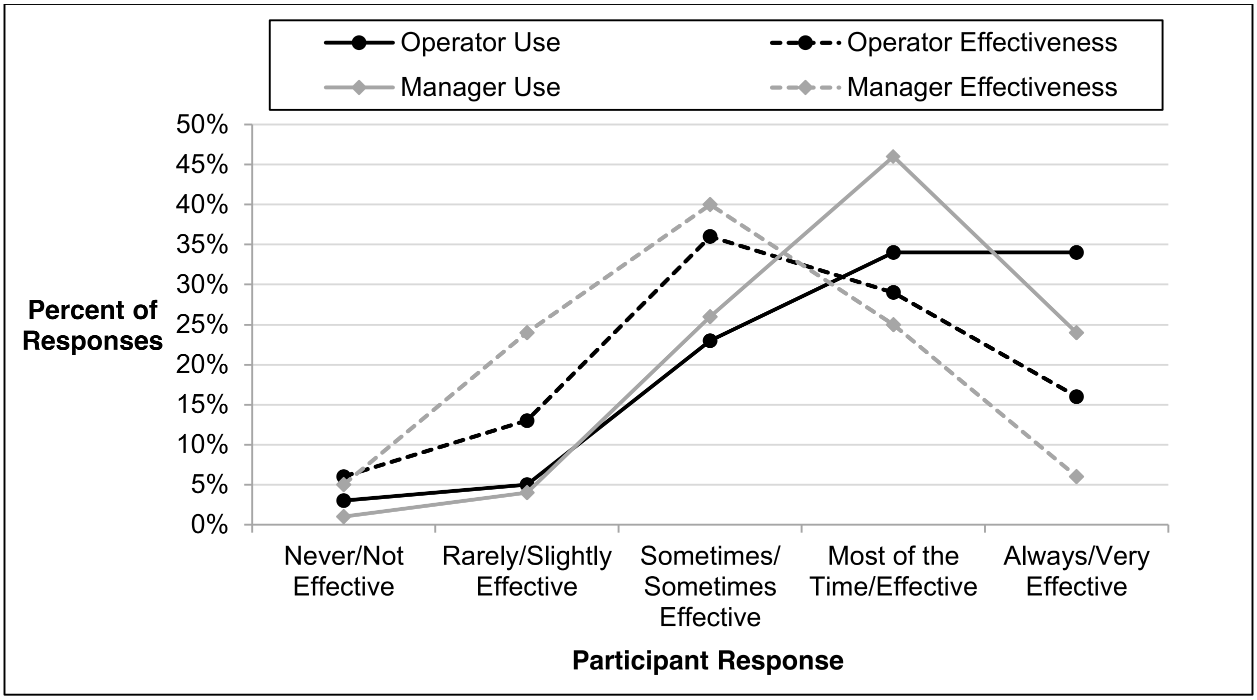

Figure 40. Use and Effectiveness of Listening to the Radio/Music in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of radio/music was significantly different ($\chi^2 = 169.25$, $p < 0.01$). Similar to winter maintenance operators, managers believed that listening to the radio/music was "sometimes" an effective method to reducing fatigue but winter maintenance operators listened to the radio/music to reduce fatigue "most of the time."

Figure 41 compares winter maintenance operators' and managers' responses regarding usage and effectiveness of continuing to drive in reducing fatigue. The distribution of winter maintenance operators' responses to use and effectiveness was significantly different ($\chi^2 = 509.65$, $p < 0.01$). As shown in Figure 41, the majority of winter maintenance operators indicated that continuing to drive was "never" an effective method to reducing fatigue, but the majority of winter maintenance operators reported they do continue to drive "sometimes."

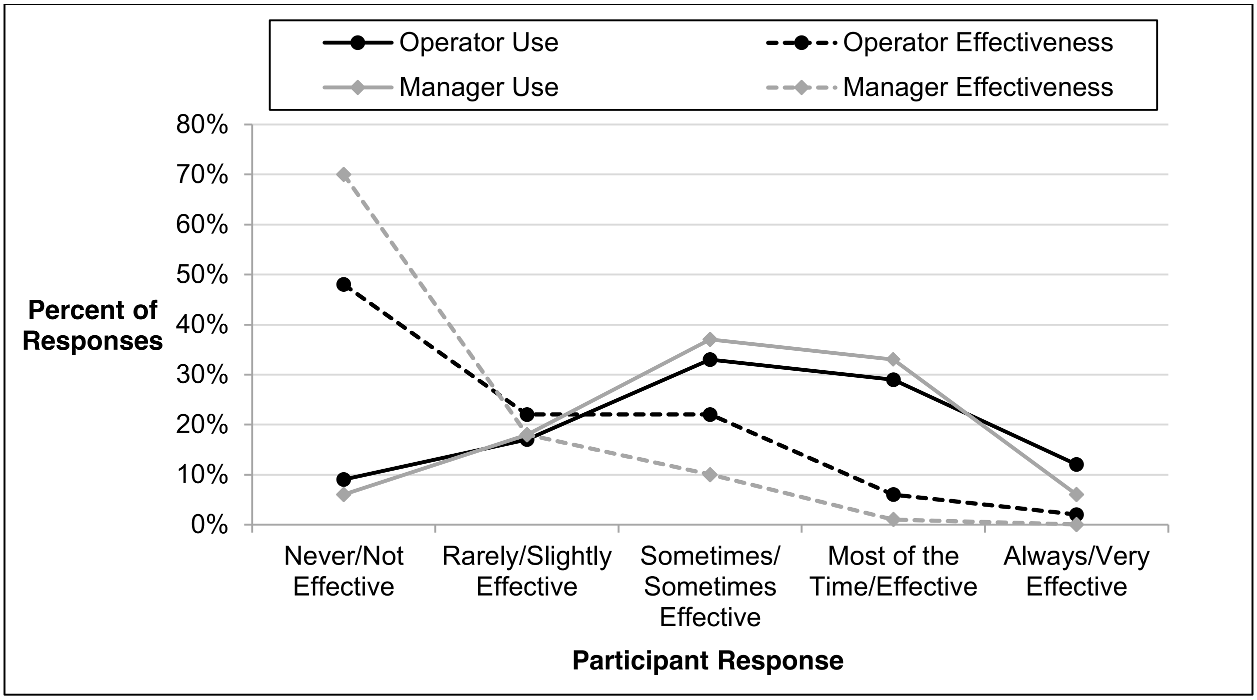

Figure 41. Use and Effectiveness of Continuing to Drive in Reducing Fatigue

The distribution of managers' responses to the use and effectiveness of continuing to drive was significantly different ($\chi^2 = 441.86$, $p < 0.01$). Similar to winter maintenance operators, managers believed continuing to drive was "never" an effective method in reducing fatigue, but they believed winter maintenance operators continued to drive to reduce fatigue "sometimes" or "most of the time."

3.3.2.8 Managers' Suggestions to Improve Winter Maintenance Operations

Managers were asked for suggestions to improve the safety of winter maintenance operations. A total of 349 managers offered suggestions. These suggestions were categorized into the following themes: shift-, equipment-, management-, traveling public-, road-, and staff-related, as well as other. The distribution of responses is shown in Figure 42.

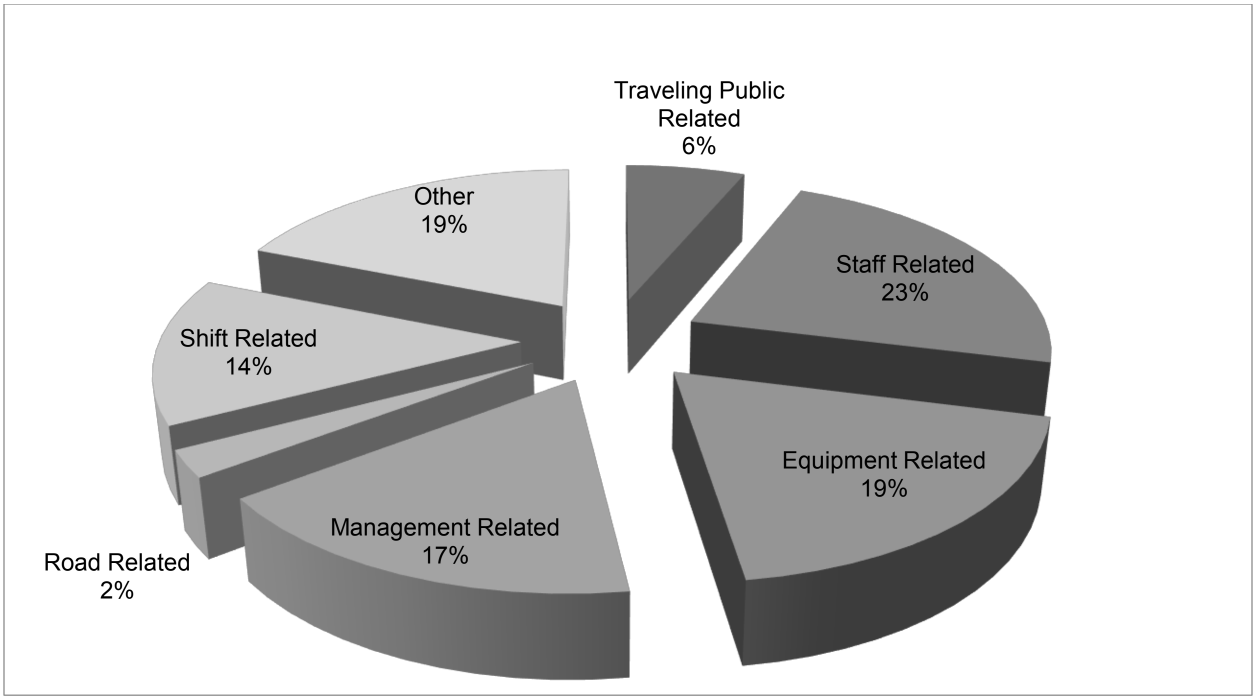

Figure 42. Managers' Suggestions to Improve Winter Maintenance Operations

As shown in Figure 42, the majority of suggestions were staff-related. Figure 43 shows the distribution of specific staff-related suggestions/comments. Most of the specific staff-related suggestions concerned the need for additional winter maintenance operators (83 percent).

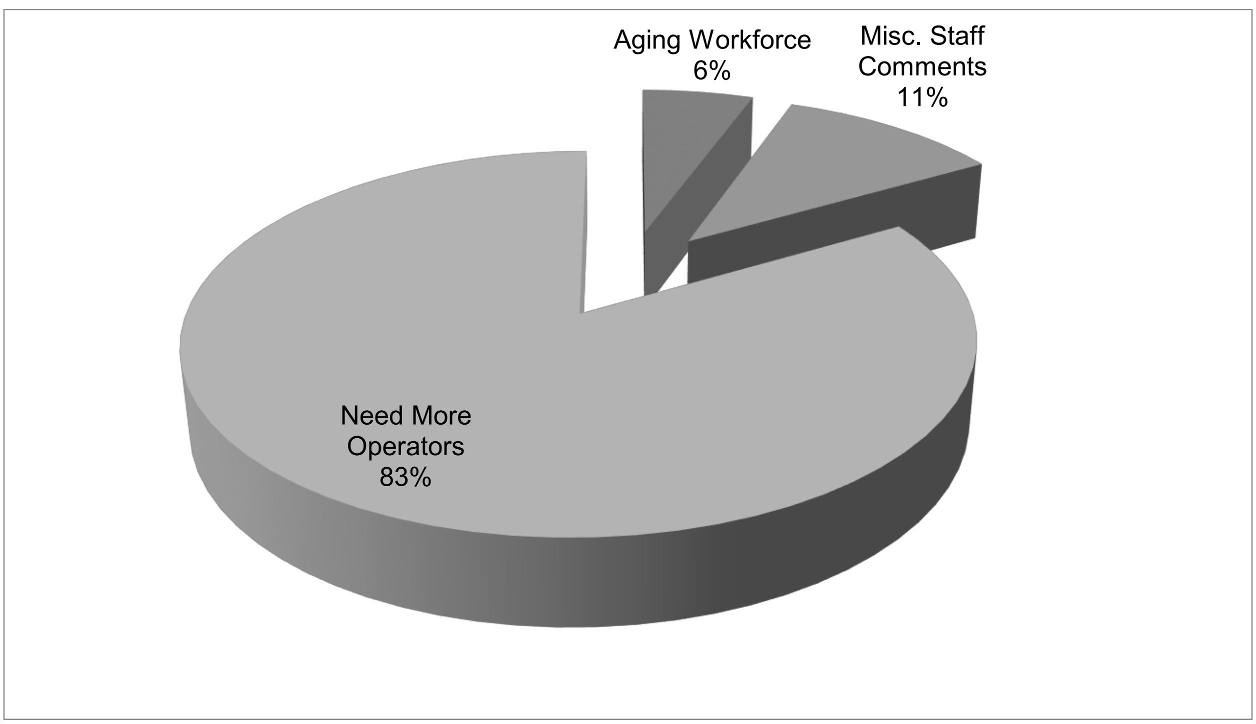

Figure 43. Staff-related Suggestions to Improve Winter Maintenance Operations

Figure 44 shows the distribution of managers' specific equipment-related suggestions/comments. The majority of specific suggestions were related to updating the snow plow's lighting (e.g., better lights to illuminate the roadway in winter weather conditions; 33 percent), updating other winter maintenance equipment (e.g., replace old/broken equipment; 30 percent), and purchasing additional snow removal equipment (20 percent).

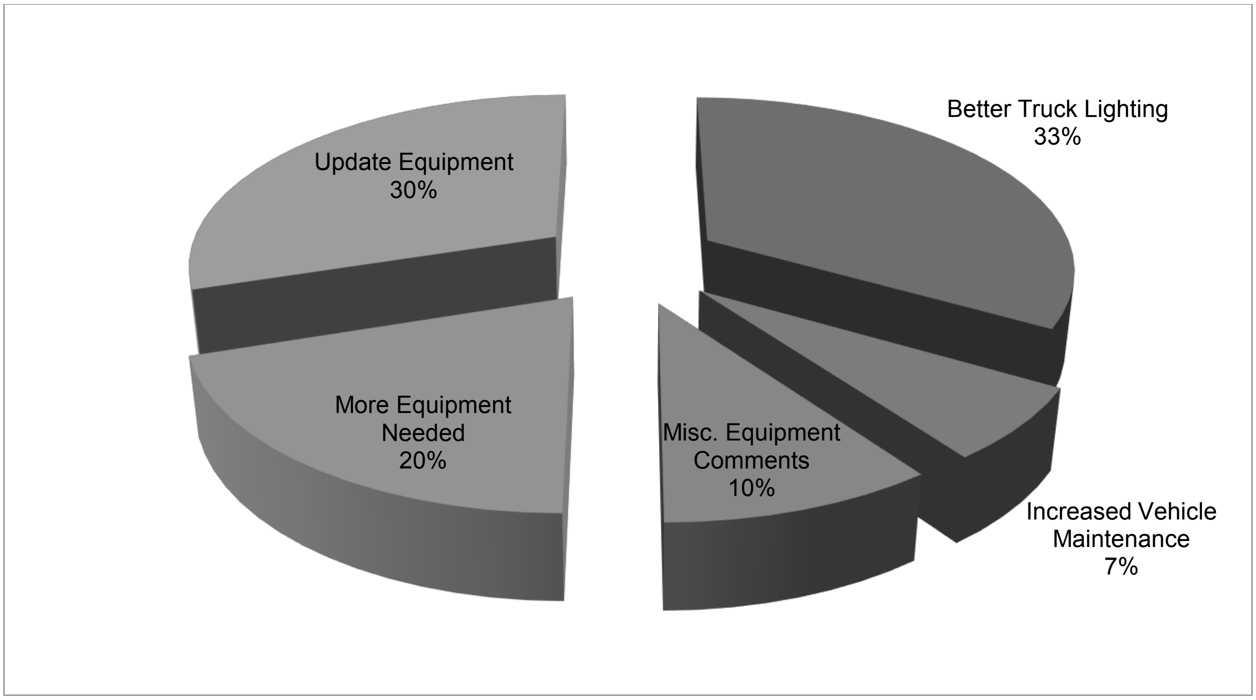

Figure 44. Equipment-related Suggestions to Improve Winter Maintenance Operations

Figure 45 shows the distribution of specific management-related suggestions. The majority of specific comments were related to offering additional fatigue awareness training (37 percent), encouraging winter maintenance operators to take breaks/rest while plowing during winter emergencies (22 percent), and involving winter maintenance operators in the decision-making process (15 percent).

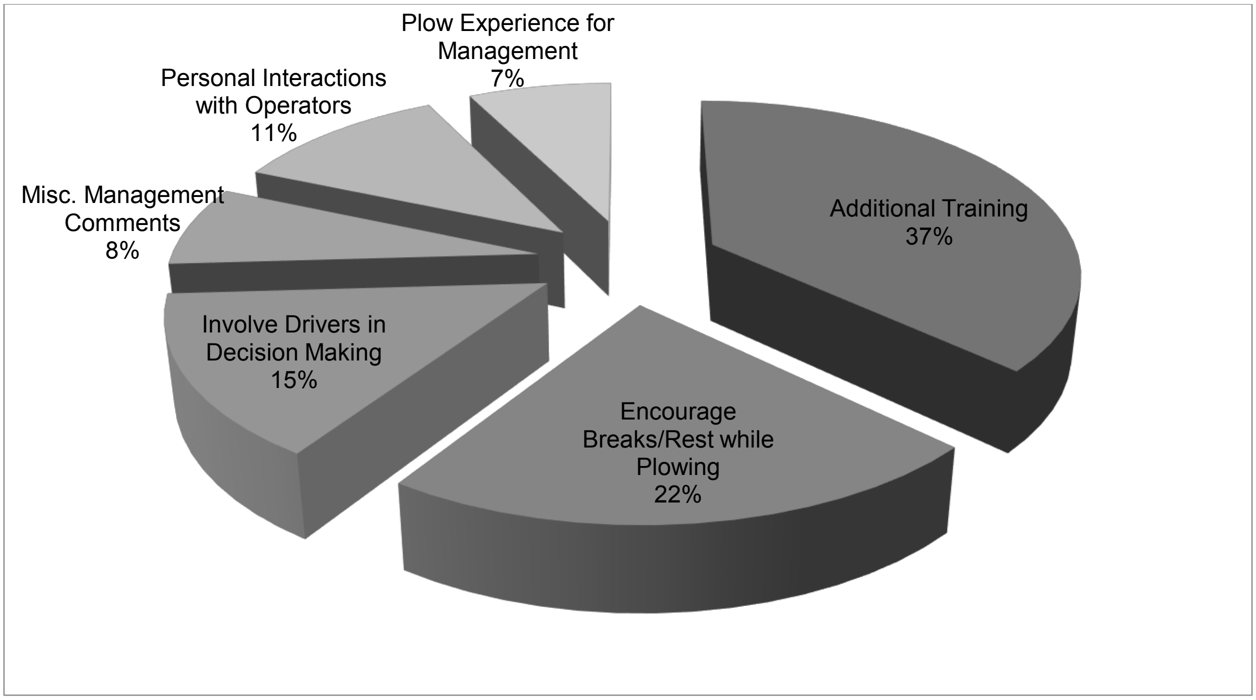

Figure 45. Management-related Suggestions to Improve Winter Maintenance Operations

Figure 46 shows the distribution of specific shift-related suggestions/comments. The majority of specific suggestions involved reducing the amount of/eliminating night plowing (19 percent) and changing shift start/end times (18 percent).

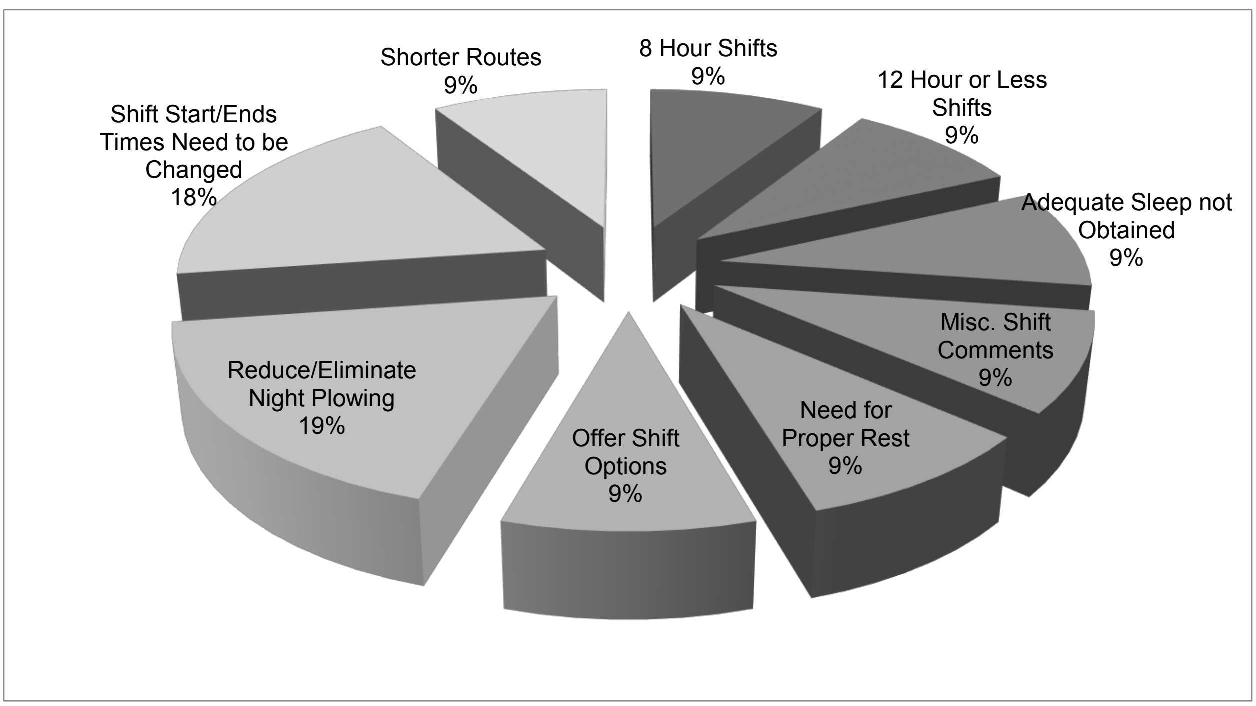

Figure 46. Shift-related Suggestions to Improve Winter Maintenance Operations

4. DISCUSSION

The main objective of the current project was to develop a series of cost-effective, realistic recommendations for reducing or eliminating fatigue in equipment operators during winter emergency operations. Three data collection efforts were performed to accomplish this goal. The first involved a literature review of published scientific documents to investigate issues related to winter maintenance operator fatigue during winter operations. The second involved a pilot test of the feasibility of collecting naturalistic driving data in winter maintenance trucks. The third effort involved the collection of new information from winter maintenance operators and management personnel to assess major facets of winter maintenance operator fatigue.

VTTI completed the naturalistic data collection effort during April 2013, and the questionnaire data collection effort was completed during June 2013. The following list provides an overview of the data collected:

- More than 368 driving hours of valid, on-road data
  - 24 days of winter emergency operations resulted in the collection of more than 338 hours of winter emergency operations data
  - Approximately 30 hours of data were collected during non-winter emergencies
- 92 SCEs identified in the naturalistic driving data
  - 3 Crashes
  - 16 Crashes: Low-hanging Branch
  - 3 Curb Strikes: Avoidable
  - 21 Near-crashes
  - 49 Crash-relevant Conflicts
- Approximately 6,600 hours of actigraph data
- Approximately 1,500 questionnaires completed from 24 different states
  - 1,043 winter maintenance operators
  - 453 managers

4.1 CONCLUSIONS

4.1.1 Literature Review

Although the research concerning fatigue in winter maintenance drivers is sparse, much of the research relating fatigue to CMV drivers can be applied to winter maintenance personnel. For example, inconsistent and varying schedules, which have been shown to contribute to fatigue in CMV drivers, are inherent in the job of winter maintenance operators due to the unpredictability of winter storms. Also, winter maintenance operators are generally required to work long shifts while performing many activities in addition to driving (e.g., communicating with central office personnel or monitoring the application of de-icing agents) during winter emergencies (it should be noted that winter maintenance operators are not subject to HOS regulations). This situation can lead to the onset of TR active fatigue. Based on the literature review, below are a number of conclusions and recommendations that should be applied to reduce the level of fatigue in winter maintenance operators.

- Research has shown that driving in high-stress environments while completing multiple tasks leads to the onset of fatigue. Those who schedule winter maintenance operators' work should consider the route (e.g., rural area with minimal traffic versus urban area with high traffic density), as well as the number of required non-driving activities.
- Scheduling and shift policies should consider the onset of SR fatigue, which has been shown to occur around the same times as the lulls in the circadian rhythm: 02:00 to 06:00 (2:00 a.m. to 6:00 a.m.) and 14:00 to 16:00 (2:00 p.m. to 4:00 p.m.). In this case, activities to mitigate the onset of SR fatigue, such as caffeine consumption preceding a rest period, should be built into the drivers' schedules.
- A relationship was found between the winter maintenance operators' perceptions of management's attitude towards rest and fatigued driving, with an increase in reported fatigued driving when drivers perceived an environment that marginalized breaks. An important step in mitigating fatigued driving is to ensure management takes a proactive approach in promoting breaks and rest periods.
- Winter maintenance operators' rest periods preceding their shifts should be taken into account when scheduling. Some research showed that the most significant factor leading to the onset of fatigue was beginning the work week tired. Furthermore, the research showed that sleep schedules that do not correspond to the circadian rhythm do not tend to provide adequate amounts of rest. Therefore, if the winter maintenance operator was required to work a night shift just prior to being scheduled, this should considered by management before requiring another night shift.
- The ergonomic design of the cab of the truck is important to minimizing fatigue. Care should be taken to ensure that components used to reduce fatigue, such as those that reduce outside noise and minimize whole-body vibrations, are kept in a good state of repair.
- The combination of inadequate sleep with cold temperature exacerbates the onset of fatigue, particularly when work is performed in cold weather prior to completing other tasks. Warming the cab of the truck prior to the beginning of a driver's shift ensures the winter maintenance operator does not have to perform a number of tasks in cold temperature and mitigates the onset of fatigue.
- Performing non-driving activities (e.g., loading the truck, etc.) prior to driving impacts the level of fatigue and should be taken into account when determining the length of the winter maintenance operator's scheduled work period. For example, a winter maintenance operator who must conduct a physically demanding activity prior to driving should have less required drive time than a winter maintenance operator whose only responsibility is driving.
- Finally, various fatigue management technologies measure operator behaviors and vehicle dynamics to detect the onset of fatigue and to prevent fatigued driving (by detecting fatigue before a shift begins). This literature review outlined and categorized a number of fatigue management technologies that work to prevent, identify, alert, and reduce driver fatigue

and fatigue-related driving errors. Any one of these fatigue management technologies or a combination should be implemented into a fatigue management program to help mitigate fatigue in winter maintenance operators.

4.1.2 On-road, Naturalistic Data Collection

This data collection effort served as a pilot test of the feasibility of collecting naturalistic driving data in snow plows. Numerous data were collected with vehicle sensors from two instrumented snow plows driven by four winter maintenance operators. Although the instrumented vehicle data are useful in demonstrating the feasibility of collecting naturalistic data in winter maintenance trucks, it was not possible to make generalizations based on such a small sample. Furthermore, limited data were collected during non-winter emergencies; thus, differences between winter emergencies and non-winter emergencies could not be assessed.

Ninety-two SCEs were observed during the three months of data collection. However, Participant #1 accounted for 54.2 percent of the SCEs. Noteworthy results from the naturalistic data collection are presented below.

- The majority of SCEs (97.8 percent) occurred during a winter emergency.
- Most of the SCEs (65.2 percent) involved a lane/roadway departure.
- The majority of SCEs (56.5 percent) occurred between 12:00 a.m. and 6:00 a.m.
- Driver inattention/distraction was a contributing factor in 59.8 percent of the SCEs. However, Participant #1 accounted for all drowsy driving SCEs. Nearly sixty-four percent of Participant #1's SCEs included drowsy driving.
- Almost all the drowsy driving SCEs (97.0 percent) occurred between 12:00 a.m. and 6:00 a.m.
- Fatigue was the critical reason in 28.3 percent of the SCEs.

Previous research found fatigue-related crashes among CMV drivers were prevalent given drivers' extended work hours and shifts that start at various times of the day and night. Among the four drivers in this project, fatigue was the critical reason in 35.9 percent of the SCEs. This is consistent with the results obtained by Knipling and Wang (1994). However, a closer inspection of the data revealed that one driver accounted for all of the fatigue-related SCEs. In other words, three of the four drivers did not have any fatigue-related SCEs, and one driver was at least moderately drowsy in 63.5 percent of his/her SCEs.

Another noteworthy finding in this project was a possible time-on-task effect. The percent of SCEs increased as the number of hours into a shift increased (and then sharply decreased at the end of the shift). In other words, more SCEs occurred when a driver had been on duty for nine hours compared to when a driver had been on duty for two hours. This may suggest winter maintenance operators became more fatigued the longer their shifts lasted. However, it is not possible to make valid conclusions for all winter maintenance operators based on a sample of four winter maintenance operators and the lack of exposure data.

4.1.3 Actigraph Data

Similar to the naturalistic data collection, it was not possible to make valid generalizations of the actigraph based on a sample of four drivers. However, the actigraph data did provide additional insight into possible explanations for the results obtained by the vehicle sensors. A total of 516,867 minutes of actigraph data were collected from the four participants during a three-month period. Participants averaged 8.71 hours of sleep per day, 8.98 hours of sleep per day during non-winter emergencies, 7.87 hours of sleep 24 hours prior to a winter emergency, 8.31 hours of sleep per day during consecutive winter emergency shifts, and 7.30 hours of sleep 24 hours prior to an SCE. Overall, participants averaged less sleep during winter emergencies versus non-winter emergencies. However, much of the difference was likely contributed to Participant #1. Participant #1 averaged 6.31 hours of sleep 24 hours prior to a winter emergency, 7.48 hours of sleep during consecutive winter emergency shifts, and only 4.55 hours of sleep 24 hours prior to an SCE.

Previous research has demonstrated that extended time awake, an inadequate amount of sleep, and time of day all increase fatigue among drivers (Ferguson et al., 2012). Participant #1 averaged approximately two hours of sleep less per night during the 24 hours prior to the start of a winter emergency compared to the amount of sleep obtained during non-winter emergencies. Furthermore, Participant #1 averaged approximately four hours less sleep during the 24 hours prior to an SCE compared to the amount of sleep obtained during non-winter emergencies. Most people need approximately eight hours of sleep per night to feel well rested (Van Dongen et al., 2003). Thus, Participant #1 experienced an increased risk of fatigue due to extended time awake and an inadequate amount of sleep (Ferguson et al., 2012). This likely explains why Participant #1 accounted for all of the drowsy driving SCEs.

4.1.4 Questionnaire Data

The questionnaires provided a great deal of information regarding fatigue in winter maintenance operations. Questionnaire results showed that winter maintenance operators and managers were familiar with the adverse effects of fatigue in winter maintenance operations. In general, winter maintenance operators' and managers' patterns of responses were significantly different for most of the questions. This difference may have been the result of winter maintenance operators underreporting fatigue and fatigue-related incidents. Conversely, winter maintenance operators and managers agreed about the sources of fatigue, the impact of fatigue on safety, and the use and effectiveness of fatigue countermeasures. Furthermore, winter maintenance operators reported limited use of the strategies shown to be the most effective in reducing fatigue (e.g., taking breaks, moving one's body, and naps). Below are some of the key results.

- The majority of winter maintenance operators and managers indicated fatigue had a "moderate impact" on winter maintenance operations. Winter maintenance operators were more likely to report greater impacts of fatigue compared to the managers. Furthermore, younger winter maintenance operators were more likely to report lower impacts of fatigue compared to older winter maintenance operators.
- Most winter maintenance operators and managers reported fatigue was "sometimes" experienced while operating a snow plow during winter emergencies. Managers were more likely to report that winter maintenance operators experienced fatigue compared to winter maintenance operators. Additionally, winter maintenance operators who reported

experiencing fatigue while operating a snow plow were more likely to also report greater impacts of fatigue.

- Managers indicated that winter maintenance operators experienced more frequent lapses in concentration while operating a snow plow during a winter emergency compared to winter maintenance operators. Additionally, winter maintenance operators who experienced lapses in concentration while operating a snow plow were more likely to report greater impacts of fatigue.
- Managers believed winter maintenance operators experienced fatigue while driving home after a winter emergency shift more frequently than winter maintenance operators.
- Vibration, seat type, noise, heavy traffic, lights, too much technology, and nighttime operations were all reported to be important sources of fatigue.
- The majority of winter maintenance operators and managers reported breaks were encouraged and that breaks could be taken as needed.
- Managers were more likely to indicate winter maintenance operators preferred driving instead of taking a break compared to the winter maintenance operators.
- Winter maintenance operators reported at least "sometimes" experiencing back pain, tense muscles, leg numbness, and an aching body while operating a snow plow during winter emergencies.
- In general, winter maintenance operators and managers indicated knowledge concerning effective strategies to combat fatigue. However, winter maintenance operators reported limited use of those strategies shown to be most effective in reducing fatigue (e.g., taking breaks, moving one's body, and naps). Additionally, winter maintenance operators relied heavily on caffeine to combat fatigue and continued to drive when feeling fatigued even though they knew it was unsafe and ineffective.
- Managers offered numerous suggestions to improve the safety of winter maintenance operators during winter emergencies, including: more effective encouragement to take breaks, change shift start/end times, offer shift options, reduce shift length, involve operators in the decision-making process, increase personal interactions with winter maintenance operators, increase communication with winter maintenance operators, increase communication with the general motor public, update winter maintenance equipment (e.g., rubber blades), and perform additional preventative maintenance.

The questionnaire results support many of the themes noted in the literature review. Previous research showed that whole-body vibrations and vehicle seat type may have an adverse impact on driver fatigue (Boggs and Ahmadian, 2007; Paschold and Mayton, 2011). The majority of winter maintenance operators and managers indicated that vibration was an important source of fatigue. Paschold and Mayton (2011) found that certain vibrations can cause muscle contractions leading to the development of fatigue. The majority of winter maintenance operators reported experiencing tense muscles and back pain. One way to reduce vibrations is with an air-cushioned seat. Boggs and Ahmadian (2007) found that drivers generally reported less fatigue across driving periods when using air-cushioned seats versus traditional foam seats. Air-cushioned seats provide additional protection against truck vibrations, are more comfortable for drivers, and are likely to limit back pain compared to traditional foam seats. In fact, air-ride seats are already common in most snow plows. More than 80 percent of winter maintenance operators reported their trucks had air-ride seats in place, and 10 percent of winter maintenance operators suggested replacing traditional foam seats with air-ride seats to reduce truck vibrations.

Noise has also been shown to increase driver fatigue over time (Haworth et al., 1988). The majority of winter maintenance operators indicated too much noise was an important source of fatigue. Haworth et al. (1988) described the effect of noise as a stressor, which, along with the cumulative effect of driving in a high-stress environment, can induce higher levels of fatigue than either factor separately. Winter maintenance operators and managers reported increased vehicle maintenance may be an adequate solution to ensuring snow plow cabs are well insulated against excessive noise.

Traffic conditions and the complexity of work have been shown to contribute to the development of driver fatigue (Desmond and Hancock, 2001; Liu and Wu, 2009; Rossi et al., 2011). Consistent with this research, respondents in the current study identified heavy traffic as an extremely important source of fatigue. High-traffic areas can contribute to driver fatigue by requiring sustained attention to the surrounding traffic while also completing driving tasks and communicating with central office personnel. Liu and Wu (2009) reported that fatigue from driving in a complex road environment had a significant negative effect on driver behavior compared to non-fatigued driving in a complex or monotonous road environment. These results indicated that fatigued drivers encountering significant or complex traffic tend to overestimate the distance to signs and have a significantly greater number of lane crossings than non-fatigued drivers. This suggests that fatigued drivers are more likely to swerve to avoid other vehicles or roadside signs. In fact, 85 percent of the fatigue-related SCEs in the current study involved the winter maintenance operators traveling toward or over a lane line or the edge of the road.

However, light traffic or monotonous driving can also have a significant impact of the development of driver fatigue (Desmond and Hancock, 2001; Rossi et al., 2011). Desmond and Hancock (2001) reported that fatigue from driving in a low-demand environment or under low workload conditions may reduce performance more than fatigue from the overload condition. All of the fatigue-related SCEs in the current study occurred in low traffic conditions. Furthermore, the participants in the current study drove the same roads during each winter emergency. It is likely Participant #1 experienced passive fatigue as described by Gimeno et al. (2006). Passive fatigue can be caused by an underload condition or by prolonged periods during which too few mental capacities are exercised. The underload condition typically occurs when the driver is very familiar with the environment, such as driving the same route with a relatively low traffic density. Rossi et al. (2011) used a driving simulator to examine the impact of driving in a monotonous environment and concluded the fatigue produced in the underload condition is a function of the time of day, driving environment, and duration of drive time.

4.2 LIMITATIONS

Although the data collected during this project were comprehensive, there were several factors limiting the research team's recommendations for reducing or eliminating winter maintenance operator fatigue.

- The naturalistic data set only included data from four winter maintenance operators. It was not possible to extrapolate these results to all winter maintenance operators.
- Limited data were collected during non-winter emergencies. Thus, differences between winter emergencies and non-winter emergencies could not be assessed.
- All naturalistic data were collected in Virginia. Winter maintenance operators in other states, especially winter maintenance operators in states that experience significantly more winter emergencies, may experience fatigue differently.
- All naturalistic data were collected in rural areas with relatively low traffic density. Winter maintenance operators in metropolitan areas may experience fatigue differently.
- The research team did not collect a daily log from participants. Thus, the research team could not verify when/if naps were taken, when/if caffeine was consumed, or what (if any) medications were taken. It is possible these factors could affect drivers' levels of fatigue.

4.3 FUTURE RESEARCH

A large gap exists in fatigue-related research in winter maintenance operations. Although this research project was an excellent first step in understanding fatigue in winter maintenance operations, more research is needed. Listed below are areas for future research to better understand the prevalence and impact of fatigue in winter maintenance operations.

- A larger naturalistic driving study with more instrumented trucks and drivers. The current study had four drivers and two trucks, and the majority of data were collected during winter emergencies. Therefore, this project was not able to compare winter emergency driving to non-winter emergency driving. Furthermore, the larger naturalistic study should include drivers/trucks from multiple states to determine if there are differences across states.

- Issue daily log books to drivers to provide a second measure of sleep quantity. The actigraph data from the current study could not be validated. Log books would provide a method to determine if the actigraph devices were functioning. Furthermore, the log books would provide a back-up during cases when the actigraph devices were removed from the wrist for extended periods of time. Log books could collect data about medication and caffeine use, rest/naps, and non-driving activities (for on-duty and off-duty) to examine the effects of these factors in the development of fatigue.

- Design a fatigue management program specifically for winter maintenance operations. Although fatigue management programs have been designed for a number of occupations (e.g., pilots, emergency response teams, CMV drivers), there are many different stressors/task complexities unique to winter maintenance operations. Additional research could then evaluate the effectiveness of that fatigue management program.

4.4 FINAL SUMMARY/RECOMMENDATIONS

The following list of cost-effective, realistic recommendations for reducing or eliminating winter maintenance operator fatigue was derived from the literature review, naturalistic and actigraph data, and the winter maintenance operator and manager questionnaires (listed in no specific order).

- **Encourage use of breaks/naps:** Management should continue to encourage winter maintenance operators to take breaks/naps when fatigued/tired. Results from the questionnaires revealed there was little emphasis on the use of body movement and naps to reduce fatigue.
- **Encourage winter maintenance operator fatigue reporting:** A system, possibly confidential, should be developed to encourage and reinforce winter maintenance operators' self-reports of fatigue. Questionnaire results showed that managers underestimated the impact of fatigue in winter maintenance operators. This may be due to winter maintenance operators underreporting fatigue and fatigue-related incidents.
- **Increased vehicle maintenance:** Winter maintenance operators and managers suggested increased vehicle maintenance as a method to reduce unnecessary truck vibrations and noise. Updated equipment (e.g., rubber blades) was frequently reported as a method to reduce vibrations and noise. Care should be taken to ensure that components used to reduce fatigue, such as those that reduce outside noise and minimize whole-body vibrations, are kept in a good state of repair.
- **Investigate winter emergency shift start/end times (including shift length):** Research shows an increased risk of winter maintenance operator fatigue during circadian lows (between 2:00 a.m. and 6:00 a.m.). Thus, staring or ending a shift during these times may be dangerous. This may also be the best time to encourage drivers to take a break. Furthermore, winter maintenance operators may be at an increased risk of fatigue at the start of a shift and after an extended period of driving. Shift start and end times should be assigned with consideration of circadian lows. As non-driving activities impact the winter maintenance operator's level of fatigue, shift length should take into consideration any possible non-driving responsibilities.
- **Offer shift options:** Winter maintenance operators' rest periods preceding their shifts should be taken into account when scheduling shifts. Research shows sleep schedules that do not correspond to the circadian rhythm tend to provide inadequate amounts of rest. Therefore, if the winter maintenance operator was required to work a night shift just prior to being scheduled, this should be considered by management before requiring another night shift.
- **Involve winter maintenance operators in the decision-making process:** Managers suggested involving winter maintenance operators in the decision-making process. Winter maintenance operators have first-hand knowledge of the impact of fatigue and often have thoughtful suggestions about operational improvements. Additionally, involving winter maintenance operators in the decision-making process will help develop an effective safety culture that minimizes winter maintenance operator fatigue.

- **Increase personal interactions with winter maintenance operators:** Managers suggested increased personal interactions with winter maintenance operators as a method to reducing fatigue. This interaction will help managers identify fatigued winter maintenance operators, identify additional methods to combat fatigue, and develop an effective safety culture that minimizes winter maintenance operators' fatigue.
- **Free Resources:** There are several education and training resources available to assist safety managers in dealing with fatigue and implementing some of the recommendations described above. The first is the North American Fatigue Management Program (NAFMP, www.nafmp.com). The NAFMP is designed to address the issue of driver fatigue using a comprehensive approach on corporate culture, fatigue education, sleep disorders screening and treatment, driver and trip scheduling, and fatigue management technologies. Also, the Commercial Motor Vehicle Driving Safety (http://cmvdrivingsafety.org/) website has a training module on driver drowsiness and fatigue.

APPENDIX A – WINTER MAINTENANCE OPERATOR QUESTIONNAIRE

Environmental Factors Causing Fatigue in Equipment Operators during Winter Operations

Clear Roads Pooled Funded Research Project

SNOWPLOW OPERATOR SURVEY

Under sponsorship of the Clear Roads Pooled Fund Study, the Virginia Tech Transportation Institute (VTTI) is conducting a review and survey of fatigue in equipment operators during winter operations. Clear Roads is an ongoing pooled fund research project aimed at rigorous testing of winter maintenance materials, equipment and methods for use by highway maintenance crews.

The goal of the project is to reduce equipment operator fatigue during winter operations to increase safety, reduce employee absences and improve operator efficiency. The research team is investigating the factors that contribute to operator fatigue, and, based on the results, will recommend practical, low-cost solutions.

As a snowplow operator, your experience and opinions are of great interest and importance to identify these factors (as you're on the front line in winter emergencies). The current survey, which will take about 15 minutes to complete, asks you about your awareness, attitudes and behavior regarding operator fatigue, work and rest schedules, and equipment you use. There is also space for your comments.

Please note the data gathered in this research will be treated with anonymity and no names will be linked to the data collected. You may skip any question that you do not want to answer. Also your participation or lack of participation in the survey has no influence on your job status.

We are requesting the completed survey be mailed to us by **June 14, 2013**

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

Please answer honest and truthfully

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

Please mail the completed survey to the following address:

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

1. **How old are you?**
   - ○ Less than 25 years
   - ○ 25 to 35 years
   - ○ 35 to 45 years
   - ○ 45 to 65 years
   - ○ 65+ years

2. **Do you work for:**
   - ○ State DOT
   - ○ Contractor
   - ○ Owner/Operator
   - ○ Other (Please specify): ____

3. **What state DOT do you work for? If you work for a contractor or as an owner-operator please specify the state where you perform most of your work.**

   ____

4. **How many years have you been working for the DOT (as a state employee, contractor, or owner/operator)?**
   - ○ Less than 1 year
   - ○ 1 to 5 years
   - ○ 5 to 10 years
   - ○ 10 to 15 years
   - ○ More than 15 years

5. **How many years have you been working in winter maintenance operations?**
   - ○ Less than 1 year
   - ○ 1 to 5 years
   - ○ 5 to 10 years
   - ○ 10 to 15 years
   - ○ More than 15 years

6. **On average, what percentage of your time during the winter season is dedicated to snowplow operations (including preparations, maintenance, cleaning, fixing, plowing, etc.)?**
   - ○ Less than 10%
   - ○ 10% to 20%
   - ○ 20% to 50%
   - ○ 50% to 75%
   - ○ More than 75%

7. **When you are not involved in snowplow operations at work, what activities do you perform (e.g., driving other types of equipment, clearing trees, etc.)? Please list below.**

____

____

____

8. **Do you always drive the same snowplow truck <u>during winter emergencies</u>?**
   - ○ Always
   - ○ Most of the time
   - ○ Occasionally

9. **What type of snowplow truck do you drive? Please select the type that you drive more often.**

	Make	Model	Year
Single Axel			
Double axel (tandem)			
Three or more axel			
Other (please specify)_____________			

10. **Please mark (all that apply) the type of equipment on the snowplow truck that was noted above in Question #9.**
   - ☐ Front plow
   - ☐ Belly plow
   - ☐ Wing Plow
   - ☐ Spreader
   - ☐ Air Ride Seat
   - ☐ Chains on wheels
   - ☐ Other: __________________________
   - ☐ Other: __________________________

11. **What type of warning lights does your truck have (please check all that apply)?**
   - ☐ Strobe
   - ☐ Rotating Halogen Light
   - ☐ "Wig-Wag"
   - ☐ Other: __________________________

12. In your opinion, how important are the following elements in regards to increasing your level of fatigue while operating a snowplow truck during winter emergencies (please select one option for each row)?

	Extremely Important	Very Important	Important	Somewhat Important	Not Important
Vibration	☐	☐	☐	☐	☐
Type of seat	☐	☐	☐	☐	☐
Too much noise	☐	☐	☐	☐	☐
Light from headlamps	☐	☐	☐	☐	☐
Heavy traffic	☐	☐	☐	☐	☐
Too much technology inside the truck	☐	☐	☐	☐	☐
Too little technology inside the truck	☐	☐	☐	☐	☐
Nighttime operations	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

13. What are the major sources of vibration while you drive during winter operations, please list from the most to the least important (e.g., chains, blades, etc.)?

1. ____
2. ____
3. ____
4. ____
5. ____

14. Based on your experience, what are the best ways to reduce/eliminate the vibration sources mentioned in question 13 (please list from the most effective to the least effective)?

1. ____
2. ____
3. ____
4. ____
5. ____

15. What are the major sources of noise while you drive during winter operations? Please list from the most to the least important (e.g., engine, blades, etc.).

1. ____
2. ____
3. ____
4. ____
5. ____

16. Based on your experience, what are the best ways to reduce/eliminate the noise sources mentioned in question 15 (please list from the most effective to the least effective)?

1. ____
2. ____
3. ____
4. ____
5. ____

17. To what degree do you think fatigue impacts your operation of a snowplow during winter emergencies?

- ○ No impact
- ○ A minimal impact
- ○ Moderate impact
- ○ A Significant impact

18. How often do you feel tired (or not alert) when operating the snowplow during winter emergencies?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always

19. While operating a snowplow during winter emergencies, how often do you experience a lapse of concentration (e.g., forgot what you were doing, dozed off, etc.)?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always

20. How often do you experience the following conditions while operating a snowplow during a winter emergency? (Please select one option for each row)

	Never	Rarely	Sometimes	Most of the time	Always
Back pain	☐	☐	☐	☐	☐
Leg numbness	☐	☐	☐	☐	☐
Aching body	☐	☐	☐	☐	☐
Tense muscles	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

21. How often do you feel extremely tired when driving back home after you have completed your shift during a winter emergency?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always

22. When you're operating a snowplow during a winter emergency, how do you know you're getting tired or fatigued? Please select all that apply.

- ☐ Yawning
- ☐ Experience difficulty staying in the correct lane
- ☐ Nodding off
- ☐ Problem with concentration
- ☐ Feeling drowsy
- ☐ Experience tense muscles, aching, numbness or other physical discomfort
- ☐ Tired eyes: Heavy eyelids
- ☐ Other, Please specify: ____

23. What are the major distractions inside your cab that increase your level of fatigue while operating a snowplow during winter emergencies? (Please rate from 1 to 9, 1 being the most important)

	Rating
Interacting with communication device	
Looking at communication device	
Looking at control panel	
Using cellphone	
Talking/listening to CB	
Looking at digital maps	
Looking at paper maps	
Taking notes	
Other _________________________________	

24. When you feel tired or fatigued while operating a snowplow during a <u>winter emergency</u>, what do you do (please select one option for each row)?

	Never	Rarely	Sometimes	Most of the time	Always
Take a break from driving	☐	☐	☐	☐	☐
Move body (i.e., walk, stretch, exercise)	☐	☐	☐	☐	☐
Have a conversation on cell phone or CB/radio	☐	☐	☐	☐	☐
Drink caffeine	☐	☐	☐	☐	☐
Take a quick nap	☐	☐	☐	☐	☐
Listen to the radio/music	☐	☐	☐	☐	☐
Use over the counter stimulant (e.g., NoDoze)	☐	☐	☐	☐	☐
Continue driving	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

25. In your opinion, how effective are the following strategies to reduce fatigue while operating a snowplow during <u>winter emergencies</u> (please select one option for each row)?

	Not effective at all	Slightly effective	Somewhat effective	Effective	Very effective
Take a break from driving	☐	☐	☐	☐	☐
Move body (i.e., walk, stretch, exercise)	☐	☐	☐	☐	☐
Have a conversation on cell phone or CB/radio	☐	☐	☐	☐	☐
Drink caffeine	☐	☐	☐	☐	☐
Take a quick nap	☐	☐	☐	☐	☐
Listen to the radio/music	☐	☐	☐	☐	☐
Use over the counter stimulant (e.g., NoDoze)	☐	☐	☐	☐	☐
Continue driving	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

26. On average, please estimate how long your "normal shift" is while operating a snowplow during a winter emergency.

- ○ less than 8 hours
- ○ 8 hours
- ○ 9 hours
- ○ 10 hours
- ○ 11 hours
- ○ 12 hours
- ○ 13 hours
- ○ 14 hours
- ○ 15 hours
- ○ More than 15 hours
- ○ Other (please specify): ______________________________

27. While operating the snowplow during winter emergencies you usually work:

- ○ Dayshifts
- ○ Nightshifts
- ○ Both

28. What is the maximum number of hours you operated a snowplow during a winter emergency.

- ○ less than 8 hours
- ○ 8 hours
- ○ 9 hours
- ○ 10 hours
- ○ 11 hours
- ○ 12 hours
- ○ 13 hours
- ○ 14 hours
- ○ 15 hours
- ○ More than 15 hours
- ○ Other (please specify): ______________________________

29. In general, how long do you feel you can operate a snowplow during winter emergencies before taking a break?

- ○ Less than 4 hours
- ○ 4 to 5 hours
- ○ 5 to 6 hours
- ○ 6 to 8 hours
- ○ More than 8 hours

30. During <u>winter emergencies</u>, how many continuous days can you work before taking a day off?

____

31. How often are you asked to operate a snowplow more than planned during a <u>winter emergency</u>?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always

32. Are you required to take regular breaks while operating the snowplow during <u>winter emergencies</u>?

- ○ Yes
- ○ No
- ○ Additional Comments: ____

33. If you answered "yes" to question 32, how often are you required to take a break during a <u>winter emergency</u>?

____

34. How often do you actually take a break from driving the snowplow during a <u>winter emergency</u> (regardless of required breaks)?

- ○ Whenever I need to
- ○ Every ____ hours
- ○ Other (please explain): ____

35. On average, how long (in minutes) are you breaks when operating a snowplow during a <u>winter emergency</u>?

____

36. In general, please indicate how much you agree with the following statements with respect to their ability to <u>prevent</u> you from becoming fatigued while driving.

	Strongly Disagree	**Disagree**	**Neither**	**Agree**	**Strongly Agree**
Sleep 7-8 consecutive hours for a main sleep period	☐	☐	☐	☐	☐
Maintain a healthy diet	☐	☐	☐	☐	☐
Exercise	☐	☐	☐	☐	☐
Sleep in a room that is completely dark, cool, and quite	☐	☐	☐	☐	☐

37. In general, please indicate how much you agree with the following statements.

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Management encourages you to take breaks whenever you need to	☐	☐	☐	☐	☐
You are able to take breaks whenever you need to	☐	☐	☐	☐	☐
You always feel that you have enough time to do your work	☐	☐	☐	☐	☐
You received educational materials regarding fatigue	☐	☐	☐	☐	☐
You received training regarding ways to combat fatigue	☐	☐	☐	☐	☐
You prefer to continue driving the snowplow rather than taking a break during winter emergencies	☐	☐	☐	☐	☐
It is easy for you to take breaks whenever you feel the need	☐	☐	☐	☐	☐
You can refuse to work in a winter emergency if you feel that you are tired and not have had enough sleep	☐	☐	☐	☐	☐
You feel that you are pressured to work more than you feel comfortable/reasonable during a winter emergency	☐	☐	☐	☐	☐
In general, the manager does a good job assigning shifts and hours	☐	☐	☐	☐	☐

38. Are there any procedures in place at your DOT that check if you are fit and ready to begin work before you begin your shift during a winter emergency?

- ○ Yes
- ○ No
- ○ Additional comments: ____

39. If you answered "yes" in question 38, please describe the procedure that is in place or provide a reference document.

____

____

____

____

____

40. How often are you notified to operate a snowplow during a <u>winter emergency</u> on less than 8 hours' notice?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always

41. Last year how many recordable crashes did you have while operating a snowplow during a <u>winter emergency</u>?

- ○ None
- ○ 1
- ○ 2
- ○ 3
- ○ More than 3
- ○ Additional comments:

  ____

42. What % of your time have you "dozed off" while operating a snowplow during a winter emergency?

- ○ Never
- ○ 1% to 10%
- ○ 10% to 25%
- ○ 25% to 50%
- ○ 50% to 75%
- ○ 75% to 99%
- ○ Always

43. **Please write any additional suggestions you may have to improve winter safety operations.**

____
____
____
____
____

Thank you for completing the survey!

APPENDIX B – WINTER MAINTENANCE MANAGER QUESTIONNAIRE

Environmental Factors Causing Fatigue in Equipment Operators during Winter Operations

Clear Roads Pooled Funded Research Project

Safety Management Personnel Survey

Under sponsorship of the Clear Roads Pooled Fund Study, the Virginia Tech Transportation Institute (VTTI) is conducting a review and survey of fatigue in equipment operators during winter operations. Clear Roads is an ongoing pooled fund research project aimed at rigorous testing of winter maintenance materials, equipment and methods for use by highway maintenance crews.

The goal of the project is to reduce equipment operator fatigue during winter operations to increase safety, reduce employee absences and improve operator efficiency. The research team is investigating the factors that contribute to operator fatigue, and, based on the results, will recommend practical, low-cost solutions.

As a manager, your knowledge and opinions are important to identify these factors. The current survey, which will take about 15 minutes to complete, asks you about characteristics of the workforce, equipment, work hours, existing driver fatigue monitoring practices and fatigue training and regulation. There is also a space for your comments and suggestions.

Please answer honest and truthfully, your responses will be anonymous.

Thank you very much for your assistance in making the roads safer for all road users.

Please note the data gathered in this research will be treated with anonymity and no names will be linked to the data collected. You may skip any questions that you do not want to answer. Also your participation or lack of participation in the survey has no influence on your job status.
We are requesting the completed survey be mailed to us by **June 14, 2013**

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

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

Please mail the completed survey to the following address:
Matt Camden
Virginia Tech Transportation Institute
3500 Transportation Research Plaza
Blacksburg, VA 24061

1. **How many years have you been working for the Department of Transportation?**
    - ○ Less than 1 year
    - ○ 1 to 5 years
    - ○ 5 to 10 years
    - ○ 10 to 15 years
    - ○ More than 15 years

2. **What is your position?**
    - ○ Upper Level Management
    - ○ Middle Level Manager
    - ○ Supervisor

3. **How many years have you been working in your current position?**
    - ○ Less than 1 year
    - ○ 1 to 5 years
    - ○ 5 to 10 years
    - ○ 10 to 15 years
    - ○ More than 15 years

4. **What state DOT do you work for?**

    ____

5. **How old are you?**
    - ○ Less than 25 years
    - ○ 25 to 35 years
    - ○ 35 to 45 years
    - ○ 45 to 65 years
    - ○ 65+ years

6. **How many years have you been working in winter maintenance operations?**
    - ○ Less than 1 year
    - ○ 1 to 5 years
    - ○ 5 to 10 years
    - ○ 10 to 15 years
    - ○ More than 15 years

7. As a winter safety manager you are responsible for (please select all that apply):

- ○ Schedule
- ○ Safety Training
- ○ Driver evaluation
- ○ Selection of safety equipment for the trucks
- ○ Driver evaluation before beginning the shift (if applicable)
- ○ Other (please specify): ____________________________
- ○ Other (please specify): ____________________________

8. As a manager of winter maintenance operations, please estimate what you are responsible for (please specify number):

	Snowplow Trucks (1)	Permanent workforce of snowplow drivers (2)	Miles of Roads (3)	Temporary workforce of snowplow drivers (4)
Number				

9. Of the miles of roads reported in question 8, please estimate the number of miles for:

	Miles
Urban Interstate	
Rural Interstate	
Urban Primary Roads	
Rural Primary Roads	
Urban Secondary Roads	
Rural Secondary Roads	

10. In the past year, how many reported crashes did your fleet have during a winter emergency? (Please limit your response to the trucks you reported on question 8)

____

11. What percentages of these crashes do you estimate that:

- ○ The snowplow operator was judged to be "not at fault" or non-preventable: _______%
- ○ Snowplow operator fatigue was the major cause for the crash: _______%
- ○ Snowplow operator fatigue was a contributing factor: _______%

12. When the drivers are not involved in snowplow operations at work, what activities do they perform (e.g., driving other types of equipment, clearing trees, etc.)? Please list below.

	Most of the time (1)	Sometimes (2)	Rarely (3)
____________________	O	O	O
____________________	O	O	O
____________________	O	O	O

13. To what degree do you think fatigue impacts your safety of snowplow operators during <u>winter emergencies</u>?

- O No impact
- O A minimal impact
- O Moderate impact
- O A Significant impact

14. In your opinion, how important are the following elements in regards to increasing the level of fatigue while operating a snowplow truck during winter emergencies (please select one option for each row)?

	Extremely Important	Very Important	Important	Somewhat Important	Not Important
Vibration	☐	☐	☐	☐	☐
Type of seat	☐	☐	☐	☐	☐
Too much noise	☐	☐	☐	☐	☐
Light from headlamps	☐	☐	☐	☐	☐
Heavy traffic	☐	☐	☐	☐	☐
Too much technology inside the truck	☐	☐	☐	☐	☐
Too little technology inside the truck	☐	☐	☐	☐	☐
Nighttime operations	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

15. What are the major sources of vibration while operating a snowplow during winter operations, please list from the most to the least important (e.g., chains, blades, etc.)?

____
____
____
____
____

16. **Based on your experience, what are the best ways to reduce/eliminate the vibration sources mentioned in question 15 (please list from the most effective to the least effective)?**

____
____
____
____
____

17. **In your opinion, what are the major sources of noise that increase the level of fatigue while operating a snowplow during <u>winter emergencies</u>? Please list from the most to the least important (e.g., engine, blades, etc.).**

____
____
____
____
____

18. **Based on your experience, what are the best ways to reduce/eliminate the noise sources mentioned in question 17 (please list from the most effective to the least effective)?**

____
____
____
____
____

19. **To the best of your knowledge, how often do you think the drivers experience the following conditions while operating a snowplow during a <u>winter emergency</u>? (Please select one option for each row)**

	Never	Rarely	Sometimes	Most of the time	Always
Back pain	☐	☐	☐	☐	☐
Leg numbness	☐	☐	☐	☐	☐
Aching body	☐	☐	☐	☐	☐
Tense muscles	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

20. **To the best of your knowledge, how do you think the drivers know they are getting tired or fatigued? Please select all that apply.**
    - ☐ Yawning
    - ☐ Experience difficulty staying in the correct lane
    - ☐ Nodding off
    - ☐ Problem with concentration
    - ☐ Feeling drowsy
    - ☐ Experience tense muscles, aching, numbness or other physical discomfort
    - ☐ Tired eyes: Heavy eyelids
    - ☐ Other, Please specify: ____

21. **When the drivers feel tired or fatigued while operating a snowplow during a winter emergency, what do you think they do to stay alert (please select one option for each row)?**

	Never	Rarely	Sometimes	Most of the time	Always
Take a break from driving	☐	☐	☐	☐	☐
Move body (i.e., walk, stretch, exercise)	☐	☐	☐	☐	☐
Have a conversation on cell phone or CB/radio	☐	☐	☐	☐	☐
Drink caffeine	☐	☐	☐	☐	☐
Take a quick nap	☐	☐	☐	☐	☐
Listen to the radio/music	☐	☐	☐	☐	☐
Use over the counter stimulant (e.g., NoDoze)	☐	☐	☐	☐	☐
Continue driving	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

22. **In your opinion, how effective are the following strategies to reduce fatigue while operating a snowplow during <u>winter emergencies</u> (please select one option for each row)?**

	Not effective at all	Slightly effective	Somewhat effective	Effective	Very effective
Take a break from driving	☐	☐	☐	☐	☐
Move body (i.e., walk, stretch, exercise)	☐	☐	☐	☐	☐
Have a conversation on cell phone or CB/radio	☐	☐	☐	☐	☐
Drink caffeine	☐	☐	☐	☐	☐
Take a quick nap	☐	☐	☐	☐	☐
Listen to the radio/music	☐	☐	☐	☐	☐
Use over the counter stimulant (e.g., NoDoze)	☐	☐	☐	☐	☐
Continue driving	☐	☐	☐	☐	☐
Other (please specify): ____________________	☐	☐	☐	☐	☐

23. **How often do you estimate (in general) a snowplow operator feels tired (or not alert) when operating the snowplow during <u>winter emergencies</u>?**
    - ○ Never
    - ○ Rarely
    - ○ Sometimes
    - ○ Most of the time
    - ○ Always

24. **While operating a snowplow during <u>winter emergencies</u>, please estimate how often the drivers experience a lapse of concentration (e.g., forgot what you were doing, dozed off, etc.)?**
    - ○ Never
    - ○ Rarely
    - ○ Sometimes
    - ○ Most of the time
    - ○ Always

25. **How often do you believe the snowplow operators are extremely tired when they are driving back home after they have completed their shift during a <u>winter emergency</u>?**
    - ○ Never
    - ○ Rarely
    - ○ Sometimes
    - ○ Most of the time
    - ○ Always

26. On average, how long is the "normal shift" of a snowplow operator during a <u>winter emergency</u>?

- ○ less than 8 hours
- ○ 8 hours
- ○ 9 hours
- ○ 10 hours
- ○ 11 hours
- ○ 12 hours
- ○ 13 hours
- ○ 14 hours
- ○ 15 hours
- ○ More than 15 hours
- ○ Other (please specify): ________________________________

27. What is the maximum number of hours a snowplow operator has worked during a <u>winter emergency</u>?

- ○ less than 8 hours
- ○ 8 hours
- ○ 9 hours
- ○ 10 hours
- ○ 11 hours
- ○ 12 hours
- ○ 13 hours
- ○ 14 hours
- ○ 15 hours
- ○ More than 15 hours
- ○ Other (please specify): ________________________________

28. In general, how long do you feel a driver can operate a snowplow during <u>winter emergencies</u> before taking a break?

- ○ Less than 4 hours
- ○ 4 to 5 hours
- ○ 5 to 6 hours
- ○ 6 to 8 hours
- ○ More than 8 hours

29. During winter emergencies, how many continuous days can a snowplow operator work before taking a day off? ____

30. Are the drivers required to take regular breaks while operating the snowplow during winter emergencies?

- ○ Yes
- ○ No

31. If you answered "yes" to question 30, how often are drivers required to take a break during a winter emergency?

____

32. In general, how often do the snowplow operators actually take a break from driving the snowplow during a winter emergency (regardless of required breaks)?

- ○ Whenever I need to
- ○ Every ____ hours
- ○ Other (please explain): ____

33. On average, how long (in minutes) are the breaks during a winter emergency?

____

34. In general, please indicate how much you agree with the following statements with respect to their ability to prevent operators from becoming fatigued while driving.

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Sleep 7-8 consecutive hours for a main sleep period	☐	☐	☐	☐	☐
Maintain a healthy diet	☐	☐	☐	☐	☐
Exercise	☐	☐	☐	☐	☐
Sleep in a room that is completely dark, cool, and quite	☐	☐	☐	☐	☐

35. **In general, please indicate how much you agree with the following statements.**

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Management encourages snowplow operators to take breaks whenever they need to	☐	☐	☐	☐	☐
Snowplow operators are able to take breaks whenever they need to	☐	☐	☐	☐	☐
Snowplow operators always feel that they have enough time to do their work	☐	☐	☐	☐	☐
Snowplow operators received educational materials regarding fatigue	☐	☐	☐	☐	☐
Snowplow operators received training regarding ways to combat fatigue	☐	☐	☐	☐	☐
Snowplow operators prefer to continue driving the snowplow rather than taking a break during winter emergencies	☐	☐	☐	☐	☐
It is easy for operators to take breaks whenever they feel the need	☐	☐	☐	☐	☐
Snowplow operators can refuse to work in a winter emergency if they feel tired and have not had enough sleep	☐	☐	☐	☐	☐
Operators feel they are pressured to work more than they feel comfortable/reasonable during a winter emergency	☐	☐	☐	☐	☐
Management does a good job assigning shifts and hours	☐	☐	☐	☐	☐

36. **Are there any procedures in place at your DOT that check if the snowplow operator is fit for duty before beginning their shift during a winter emergency?**
   - ○ No
   - ○ Yes (please explain): ____

37. **If you answered "yes" in question 36, please describe the procedure that is in place or provide a reference document.**

   ____
   ____
   ____
   ____
   ____

38. How often are snowplow operators asked to report for work on short notice in preparation for a winter emergency (less than 8 hours)?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always

39. How often are snowplow operators asked to work more than planned during a winter emergency?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Most of the time
- ○ Always
- ○ Additional Comments: ____

40. What percentage of your drivers do you believe have "dozed off" while operating a snowplow during a winter emergency?

- ○ None
- ○ 1% to 10%
- ○ 10% to 25%
- ○ 25% to 50%
- ○ 50% to 75%
- ○ 75% to 99%
- ○ All of them

41. Please describe the type of fatigue training the snowplow operators receive and how often it is offered.

____

____

____

____

42. In your opinion, what are the major obstacles in your organization to combat fatigue (please list from the most to the least important)?

1: ____

2: ____

3: ____

43. Please write any additional suggestions you may have to improve winter safety operations.

____

____

____

____

____

Thank you for completing the survey!

APPENDIX C – INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants

in Research Projects Involving Human Participants

Title of Project: Environmental Factors Causing Fatigue in Equipment Operators during Winter Operations

Investigators: Jeffrey Hickman, Matthew Camden, Gerardo Flintsch, and Alejandra Medina

I. Purpose of this Research/Project

Winter maintenance driver fatigue can be a major problem. Drivers work long, stressful hours during winter storms. This can lead to higher accident rates and increased health issues. The goal of this project is to develop recommendations to reduce this fatigue. Data will be collected from video cameras installed on winter maintenance trucks as they drive during these winter storms. Approximately four or five winter maintenance workers will be recruited for this study.

II. Procedures

If you agree to participate, you would be asked to do the following:

1. Read and sign this Informed Consent Form.
2. Fill out tax forms and provide your Social Security Number for compensation purposes. Also, complete a brief demographic questionnaire and be fitted with an actigraph watch. This meeting will take approximately 30 minutes.
    a. Items 1 and 2 will all take place in a private room at your VDOT terminal.
3. Drive a winter maintenance truck as normally scheduled and on normal routes for three months. Note: the truck used in the study may not be your preferred truck.
    a. The truck will have VTTI's video monitoring system installed. This system will be on whenever the truck is on.
4. Be continuously recorded by video cameras mounted in the cab.
    a. Please note that participant confidentiality will be maintained. Video recordings will not be released to anyone outside of VTTI unless permission is obtained from you. However, data may be released in conjunction with a government inquiry or subpoena.
5. Wear a wrist activity monitor (called actigraph watch) that measures sleep quantity and sleep quality for the length of your participation.
6. During the first month of data collection, allow an experimenter to check operation of the data collection equipment once a week at the Christiansburg VDOT terminal. During the second and third months of data collection, allow an experimenter to check operation of the data collection equipment and to download actigraph data twice a month at the Christiansburg VDOT terminal. These meetings will be scheduled before or after your scheduled shift and should take approximately 30 minutes to complete.

7. During months two and three of data collection, allow an experimenter to check operation of the data collection equipment in the truck twice a month.

You are helping us evaluate driver fatigue during winter operations. Any tasks you perform or opinions you have will only help us do a better job evaluating the problem of driver fatigue. Therefore, we ask that you perform to the best of your abilities.

Please Note: The equipment installed on the truck will allow us to collect vehicle data, which will include:

- Acceleration (Longitudinal and Lateral)
- Turn signal use
- Brake pedal use
- Yaw Rate

III. Risks

There are risks or discomforts to which you may be exposed to in volunteering for this research. They include the following:

1. The risk of a crash associated with driving a truck as you usually do.
2. Stress associated with being recorded while driving.
3. There is an additional risk not encountered in everyday driving. While driving the truck, cameras will record continuous video of your face, actions, and surrounding traffic. In the event of an accident, there is a risk that the video and vehicle parametric data could be obtained in conjunction with a government inquiry, or in litigation or dispute resolution. However, under normal circumstances your identity and the organization you work for will be kept confidential**.**

The following precautions will be taken to ensure minimal risk to you:

1. All data collection equipment is mounted in such a way that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable way.
2. You will be instructed to follow your company's safety protocol.
3. You are not liable for research equipment damaged in a vehicular crash.
4. Your participation (or withdrawal) in this study does not have any influence on your status as an employee with your current company.
5. You can withdraw from the study at any time.
6. The video recordings will not reveal your name.
7. With your permission, VTTI will only share your video recordings for research reporting purposes and at research conferences.

IV. Benefits

No promise or guarantee of benefits is being made to encourage you to participate. However, with your collaboration, the results from this study will help improve driving safety. Past experience with similar studies, involving commercial-vehicle drivers, indicate that you may find the study interesting.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participating, your name will be separated from the data and replaced with a number. That is, your data will not be attached to your name, but rather to a number (e.g., Driver No.1). At no time will the researchers release data that identifies an individual to anyone other than VTTI staff working on the project without your written consent.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

While you are driving the vehicle, a camera will videotape your face and over your shoulder. Additionally, video cameras will capture views of the roadway: forward roadway, rear view of the left side of the truck, and rear view of the right side of the truck. No audio will be captured.

If you are involved in a crash while participating in this study, the data collection equipment in your vehicle will likely capture the events leading up to the event. You are under NO LEGAL OBLIGATION to voluntarily mention the data collection equipment or your participation in this study at the time of a crash or traffic offense.

We will do everything we can to keep others from learning about your participation in the research. We may disclose information about you as required by law, in conjunction with a government inquiry, or in litigation or dispute resolution. You should understand that this informed consent does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research.

This informed consent also does not prevent the researchers from disclosing matters such as child abuse, or subject's threatened violence to self or others. In terms of a vehicle, this could also include items such as driving under the influence of drugs or alcohol or allowing an unlicensed minor to drive the vehicle. If this type of behavior is observed, we reserve the right to remove you from the study and inform the appropriate authorities of what we have observed. In all cases, we will notify you first of the behaviors we have observed prior to removing you from the study or informing others of our observations.

The video and other data from this study will be stored in a secured area at the Virginia Tech Transportation Institute for 10 years. Access to the digital video files will be under the supervision of the Principal Investigator and lead researcher involved in the project. The video files and other data from this study will be accessible by VTTI researchers, data analysts associated with this project, and for follow-up analytical projects at VTTI. The video files will not be released to unauthorized individuals without your written consent. Further, although your employer will know you are participating, under normal circumstances the data gathered from you will not be made available to your employer.

VI. Compensation

You will be compensated for participating in this study. For every month you participate (3 months total) you will receive $100. You would therefore receive a total of $300.00 for completing the 3-month long study as requested. Payment will be provided with a mailed check. If you go on vacation or long-term leave for a week or more, you will not be compensated for that time. Payment will be prorated per day if you elect to withdraw from the study or if your employment is terminated during the study.

If you do not have the actigraph device at the final meeting, you need to return the actigraph device to VTTI within 7 days at which time your full payment will be mailed. If the actigraph device is not returned within 7 days of the final meeting, or if the device is not returned in proper working order (e.g., due to submersion in water), a $150 replacement cost will be deducted from your compensation. However, you will not be responsible for equipment that breaks or malfunctions through normal wear and tear (e.g., watch band breaks or battery dies) or due to a crash.

You are responsible for reporting your earnings to the IRS.

VII. Freedom to Withdraw

Participation in this research is voluntary. You are free to withdraw at any time without penalty. If you choose to withdraw, you will only be compensated for the portion of time you participated (i.e., on a daily basis). Furthermore, you are free to not answer any question or respond to experimental situations without penalty. If you withdraw or are dismissed from the study, we will retain data collected before your withdrawal/dismissal, but delete any data collected in the interval between when we become aware of the withdrawal/dismissal and before we are able to remove the data collection equipment.

Withdrawal from this study will not adversely affect your employment status.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained. This form is valid for the period listed at the bottom of the page.

IX. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1) Follow the experimental procedures as well as you can.
2) Inform the experimenter if you have difficulties of any type.
3) Inform the experimenter if any equipment breaks.
4) To perform the driving task without interfering with any of the on-board equipment.
5) To wear the actigraph watch as much as possible with the exception of the time periods when it could potentially be submerged in water (e.g., bathing, showering, swimming, etc.).
6) To return all equipment and/or watches to VTTI at the end of the study. If any equipment and/or watches are not returned in proper working order, a replacement cost will be deducted from your compensation. However, you will not be responsible for equipment that breaks or malfunctions through normal wear and tear (e.g., watch band breaks or battery dies) or due to a crash.

X. Participant's Permission

Check one of the following:

Use of Video Data at Technical Presentations

☐ VTTI **has my permission** to show the digital video including my image for research or research reporting purposes (such as presentations). No videos will be made available for the general public.

☐ VTTI **does not have my permission** to show the digital video including my image for research or research reporting purposes. I understand that VTTI will maintain possession of the data for research purposes.

I have read and understood the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

Participant's Name (Print)	Signature	Date
Experimenter's Name (Print)	Signature	Date

Should I have any questions about this research or its conduct, I may contact:
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If I should have any questions about the protection of human research participants regarding this study, I may contact:

Dr. David Moore
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Blacksburg, VA 24060

APPENDIX D – DEMOGRAPHIC QUESTIONNAIRE

Demographic Questionnaire

1. Date: _______________
2. Age: __________years
3. Gender (Check one): ☐ Male ☐ Female
4. Eye color: ☐ Brown ☐ Blue ☐ Green ☐ Hazel
5. Height: _____ft _____in
6. Weight: __________lbs
7. Body build (check one): ☐ Small frame ☐ Medium frame ☐ Large frame
8. Highest level of education:
   ☐ Didn't complete High School ☐ High School graduate
   ☐ Some College ☐ 2 years College degree
   ☐ 4 years College degree ☐ Masters Degree
   ☐ Professional degree ☐ Doctorate degree
9. Do you wear contact lenses? (Check one): ☐ No ☐ Yes (Lens color: ___________)
10. Do you wear glasses at *night* when driving? ☐ No ☐ Yes
    If Yes, check all that apply: ☐ Metal frame ☐ Plastic frame ☐ Anti-Glare Coating
11. Which of the following groups is <u>most</u> representative of your background? (Check one)
    ☐ African/American ☐ Asian/American ☐ Caucasian/American
    ☐ Pacific Islander ☐ Hispanic/American ☐ Native American
    ☐ Middle Eastern
12. How long have you been driving winter maintenance vehicles?

    _____years _____months
13. How long have you been working for VDOT? _____years _____months

14. How long did you work for your previous employer (your job before this one)? _____years _____months

15. How many moving violations have you had in the:

    Last 12 months ________ Last 36 months ________

16. How many vehicular crashes (both on and off the job) have you been involved in during the:

    Last 12 months ________ Last 36 months ________

17. How many of these crashes (both on and off the job) were considered "your fault" during the:

    Last 12 months ________ Last 36 months ________

APPENDIX E – USER GUIDE FOR ACTIGRAPH DEVICE

OCTAGON BASIC ACTIGRAPH USER GUIDE

General Information

- Octagon Basic Motionlogger Actigraph (“Octagon Basic”) (Figure 47) is a device that can be used to measure the amount of rest and movement by putting it on the non-dominant wrist.

Figure 47. Octagon Basic Motionlogger Actigraph

- Octagon basic is water resistant; however it cannot be submerged in any body of water.
- Data is accumulated over a user-selectable time period. The Octagon Basic can store up to 2 Mb of non-volatile memory. The battery lasts approximately 60 days. When the watch has 53 days of battery runtime a warning will be displayed. The program default setting should refuse to initialize the Octagon Basic has more than 60 days of battery runtime. The battery may need to be replaced before initializing the Octagon Basic for a new driver.
- If the battery voltage is below 2.90 replace the battery prior to initialization regardless of battery runtime days.
- Software required are “ACT Millennium” and “Action 4”.
- Conduct downloading of data from Octagon Basic inside protected area when possible.
- Store the interface unit in a bubble wrap bag to avoid dust or damage.

I. Connecting the Octagon Basic Interface to Computer

1. **The Octagon Basic Interface unit (Figure 48) is a device for initializing the Octagon Basic and downloading data from Octagon Basic.**

Figure 48. Octagon Basic Interface

2. Connect the Octagon Basic Interface Unit to the computer by a serial cable. Insert the 9-pin-female end of the serial cable into an open serial port on the back of the computer (Figure 49). Then attach the 9-pin-male end to the back of the Interface Unit (Figure 50).

Figure 49. Serial Port on Computer Back

Figure 50. Port and On/Off Toggle Switch on Back of Interface

II. Setting up Configuration

1. **Open the ACT Millennium software on the computer.**

2. **Go to the drop-down menu labeled Configuration, and then select Communications. "Communication parameters window will then appear.**

3. **On the tab labeled Interface, make sure that the setting is on Auto Switching Interface.**

4. **On the tab labeled Com Port, select Com 1.**

5. **On the tab labeled Baud Rate, select 38400, and then click OK.**

6. **Go to the menu Configuration and choose Actigraph Type. Select the Octagonal as the model type, Oct Basic, as the Actigraph Model, and then click OK.**

7. **Go to the menu Configuration, and choose Battery Logs. Under Octagon Basic, change the default to recommended setting (see table below), and then click OK.**

Setting	Warning	Refusal
Default	**21 days**	**30 days**
Recommended	**53 days**	**60 days**

Octagon Basic should not be initialized once the battery life reaches the warning day (i.e., 53 day). Replace the battery with a new one. Go to "Section X. Change Octagon basic Battery" for how to change the battery.

8. **To save the configuration settings, go to the menu Configuration and choose Save.**

9. **Check the configuration status at the left bottom of the Act Millennium window to confirm the settings as below:**

Auto	**38400**	**COM 1**	**Octagon Basic**

- **Auto for *Auto Switching Interface***
- **38400 for *Baud Rate***
- **COM 1 for *Com Port***
- **Octagon Basic for *Batter Logs***

10. **If any of the settings above do not match the configuration status in the window, correct the setting by repeating the configuration procedure.**

III. CHECKING OCTAGON BASIC OPERATION AND BATTERY RUNTIME

The Header Information can provide information about each Octagon basic device (e.g., its status or battery runtime). On the first day of data collection for each driver, check the Battery Runtime Days. If the battery runtime is more than 60 days, give the driver another actigraph watch or replace the battery.

1. Connect the Actigraph Interface Unit to the computer by a serial cable.

2. Turn on the interface power switch on and verify the indicator light is green as shown in Figure 51. The switch is located on the rear of the interface to the side of the serial port connection as shown in Figure 51. <u>NOTE</u>: the interface requires external power to operate. This power is supplied by either a 9-volt battery or the 110-volt AC adapter.

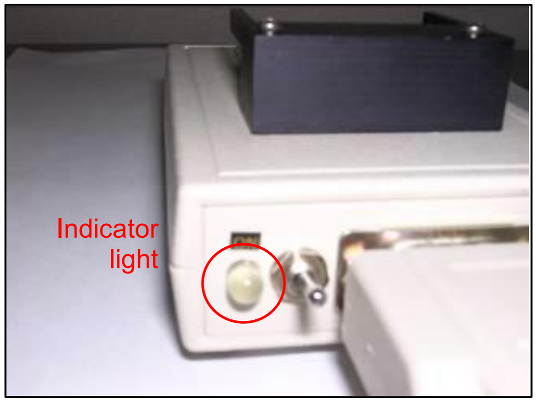


Figure 51. Power Switch On and Indicator Light Green

Figure 52. Proper Actigraph Watch Interface Placement for Downloading Data

3. Place the Octagon Basic on the Interface by lining up the contact plate on the side of the Octagon basic with the spring-loaded contact pins of the Interface. When placing the watch on the interface, put the wrist bands flat as displayed in Figure 52. NOTE: some wrist bands may interfere with properly fitting the Octagon Basic fully into the interface unit.

4. Click the **"Download Actigraph"** icon (watch with arrow to the right) or press "**F6**".

5. Data transfer occurs and the "File Summary" window appears including "Status" and "Battery Runtime Days".

6. A window will appear to save the header information. You do not need this information, so click, "**Cancel**".

IV. Initializing Octagon Basic

1. **Open the Act Millennium software. Prior to initialization, check the configuration status at the bottom left of the Act Millennium window to confirm the settings as below:**

Auto	38400	COM 1	Octagon Basic

   If any of these settings above do not match the configuration status in the window, correct the setting by repeating the configuration procedure under the *Setting up Configuration* section above.
2. Place the Octagon Basic in the **Octagon Basic Interface** by lining up the contact plate on the side of the Octagon Basic with the spring loaded contact pins of the Interface.

3. Turn the interface power switch on and verify the indicator light is green (see Figure 51). If the light is red, the internal 9-volt battery must be replaced or the 110-volt adapter must be used. The red light indicates the internal battery power is too low to use the interface without additional external power.

4. To start initializing the Octagon Basic, go to **Actigraph** menu in the task bar and choose **Initialize** or press "**F4**". "Set Current Time" window will appear.

5. Make sure that the day and time under **CURRENT TIME** are correct. NOTE: the interface works in military time.

6. If the **CURRENT TIME** is correct, click **Continue**.

7. If the **CURRENT TIME** is incorrect, change the time by typing the accurate time/date information (in military time) under the "**SET CURRENT TIME**" boxes, then click **Set Current Time**.

8. The next screen will prompt you to choose a "Model Type" and "Actigraph Model". Make sure to choose the following, and then click **OK**.

   - Model Type: **Octagonal**
   - Actigraph Model: **Oct Basic**
9. The next screen will prompt you to choose a sampling mode. Choose **Zero Crossing Mode**, and the click **Next**.

10. The next screen will prompt you for the "Epoch Length". Choose **1 Minute**, and then click **Next**.

11. The next window will be used to enter the **Octagon Basic ID**. The ID consists of (i) the participant number, and (ii) the date in which the actigraph is initialized. These two types of information are divided by an underscore. For example, when the participant number

is 01 and the actigraph was initialized on March 1, 2013, the ID would be 01_030113 (Month 03, Day 01, and Year 13). Write down the Octagon Basic ID in the data collection file.

12. The next screen is the “Event” window. Make sure both options are checked, and click **Next**.

13. The next window will be the “Wakeup Time/Date Entry” window, which is used to set start-up time for data collection. Select **Immediate** (3 minutes from current time), and then click **Next**.

14. If a future start date is selected the “Wakeup Time/Date Entry” window will displace an “Enter Wakeup Date and Time” box. Set the future date and time for the Octagon Basic to begin collecting data. The Wakeup Time/Date by default cannot be greater than 30 days from the current Time/Date. If the selected future Wakeup Time/Date is greater than 30 days, an error message will display. Click “**OK**” and reenter an acceptable Wakeup Time/Date.

15. The “Run Time” window will appear. Write down the device start time on the data collection file. Click **“OK**”.

16. The “Confirm” window appears to ensure that you wish the operation to overwrite the memory. To continue, click **Yes**. Click **No** is you wish to abort the initialization.

17. Place the Octagon Basic in the Interface unit then click **OK**. Actigraph watch initialization starts (initialization header information messages display).

18. An “Information” message reading “Remove Actigraph” will appear. Remove Octagon Basic from the interface, and the click **OK**. Another window will appear stating the initialization was successful. Click **OK**. If unsuccessful, restart the initialization process.

19. Then the interface power switch to the “OFF” or down position. If 110-volt AC power was used, disconnect the cord from the power supply and interface unit.

20. Conduct “Verify Initialization”

    IMPORTANT: do not remove Octagon Basic during initialization. If Octagon Basic is removed during initialization, the above initialization procedure must be repeated.

V. Verifying Initialization

1. Once the data collection start time written on the *Data Collection Record* has passed, verify that the device is collecting data.

2. Connect the interface unit to the computer, place the Octagon Basic in the interface and turn the interface power switch to the “On” position.

3. In the task bar of the Act Millennium software, choose **Telecom** icon. This icon is the monitor button.

4. The windows shown in Figure 53 and Figure 54 permit you to monitor the actigraph while it is in the interface. "I"s represent the clock signal from the actigraph indicating the device is running.

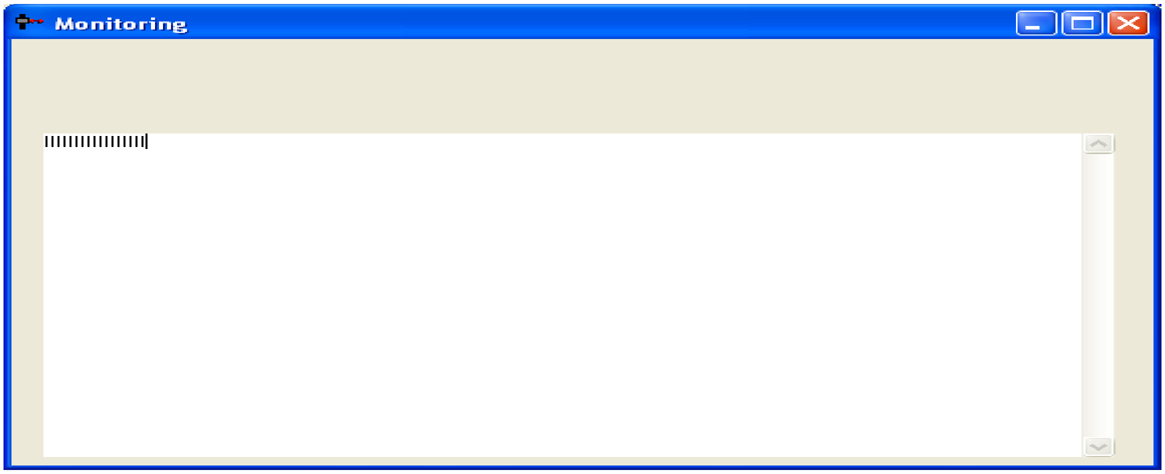


Figure 53. Telecom Monitoring Screen with "I"s Only

Figure 54. Telecom Monitoring Screen with Evidence of Data Collection Activity

5. If the unit is collecting data (wakeup time reached and memory not full) slight movements of the interface (with the actigraph in the interface) will produce dashes on the screen, indicating the device is collecting as in Figure 54. If the unit is not collecting data the display will remain "I"s as in Figure 53.

6. Close the window and remove the Octagon Basic from the interface.

7. If the Octagon Basic is not collecting data, verify that the Wakeup Time/Date has passed. If the time has passed, wait one minute and attempt to verify initialization again. If the

second attempt continues to show the unit is not collecting data it may be necessary to change the battery, re-initialize the unit or return it for repair.

VI. Downloading Data from Octagon Basic

1. **Open ACT Millennium software.**

2. **Place Octagon Basic on the interface unit and turn the power switch on in the same manner as described previously and click OK.**

   IMPORTANT

   - **Do not remove the Octagon Basic during downloading data. If Octagon Basic is moved during downloading, the entire process must be repeated.**
   - **If the watch does not interact, perform a Loop Test to verify connection.**
   - **If the watch has any physical damage or rattles at all, please give the watch to researcher in charge to have it fixed. Give a new watch to the participant.**
   - **Always take a spare watch with fresh batteries to the field.**
   - **Always take a spare watch band to the field.**

3. **Go to Actigraph menu in the task bar and choose Download or press F6.**

4. **The "File Summary" window will appear (Figure 55).**

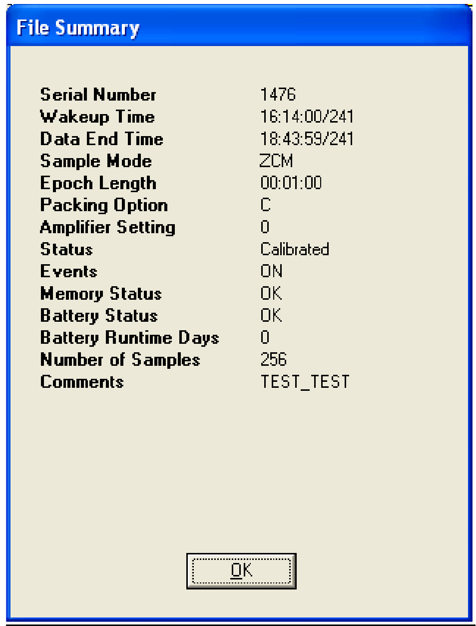


Figure 55. "File Summary" Window

5. **"File Downloaded" window will appear. Click Yes to save to the file.**

6. **Save the file. The file name consists of (i) the participant number, and (ii) the date in which the data is downloaded. These two items are divided by an underscore. For example, when participant number is 01 and the date of downloading data is March 15, 2013, the ID would be *01_031513*.**

7. **Record the file name on the *Data Collection Record*.**

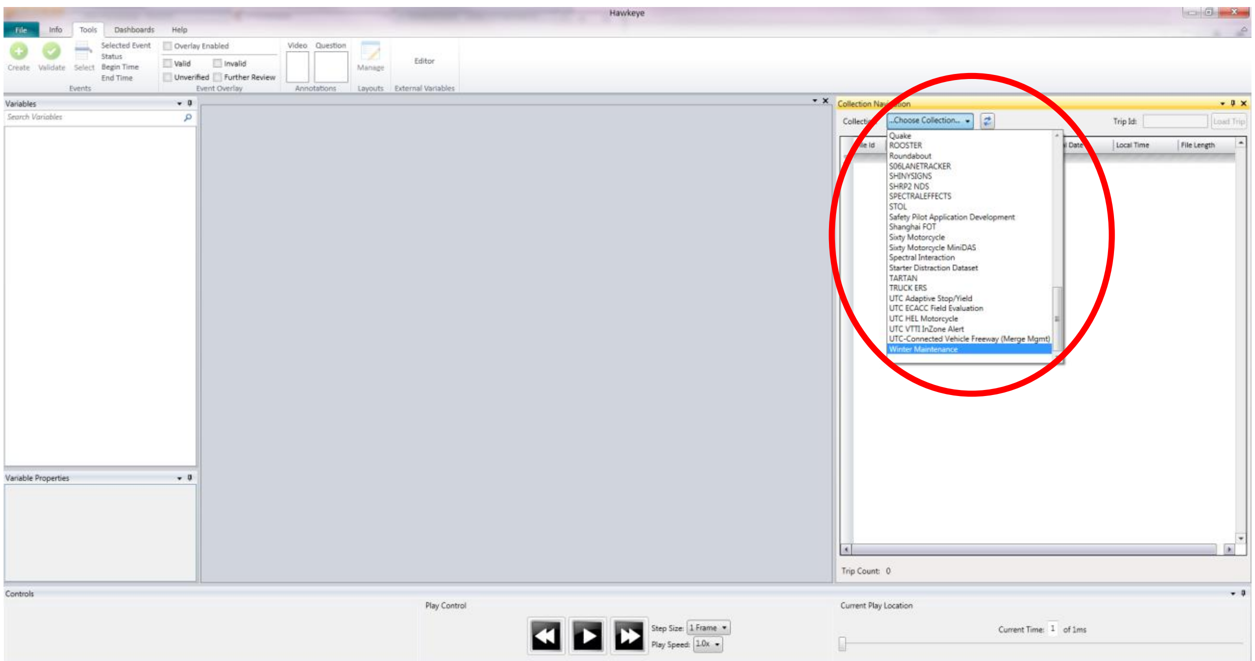
APPENDIX F – TRIGGER VALIDATION PROTOCOL

Install Hawkeye:

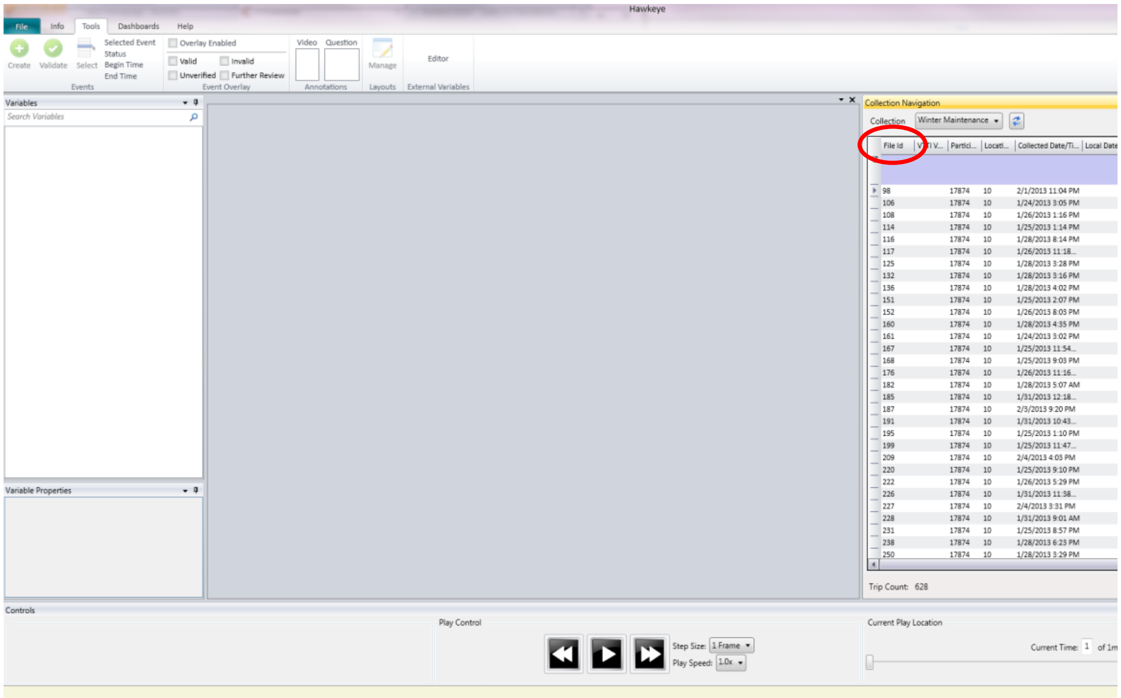
1. Go to \\vanguard\VTTI Programs\Ocelot\Release
2. Click “Ocelot”
3. Accept the user agreement and install.

Loading Hawkeye:

1. Load Hawkeye on your computer (Start Menu → All Programs → VTTI → TransLab → Hawkeye).
2. Open the **Winter Maintenance** collection (Collection → Scroll down to Winter Maintenance).

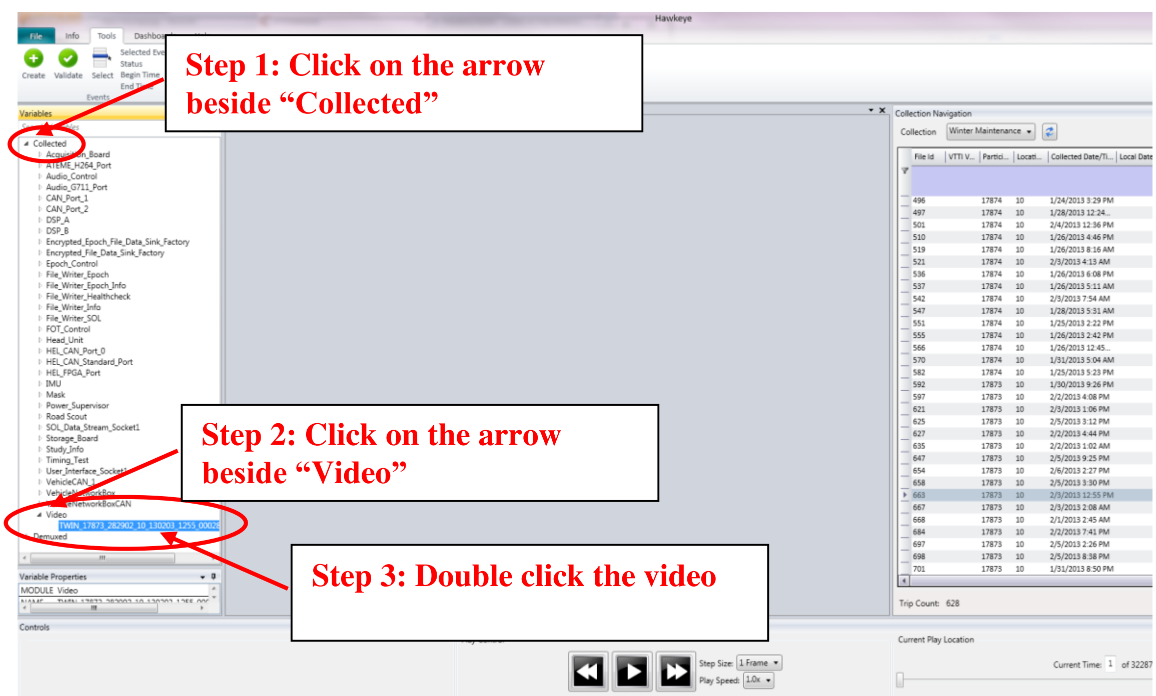


3. Sort the Winter Maintenance files in ascending order (click File ID)



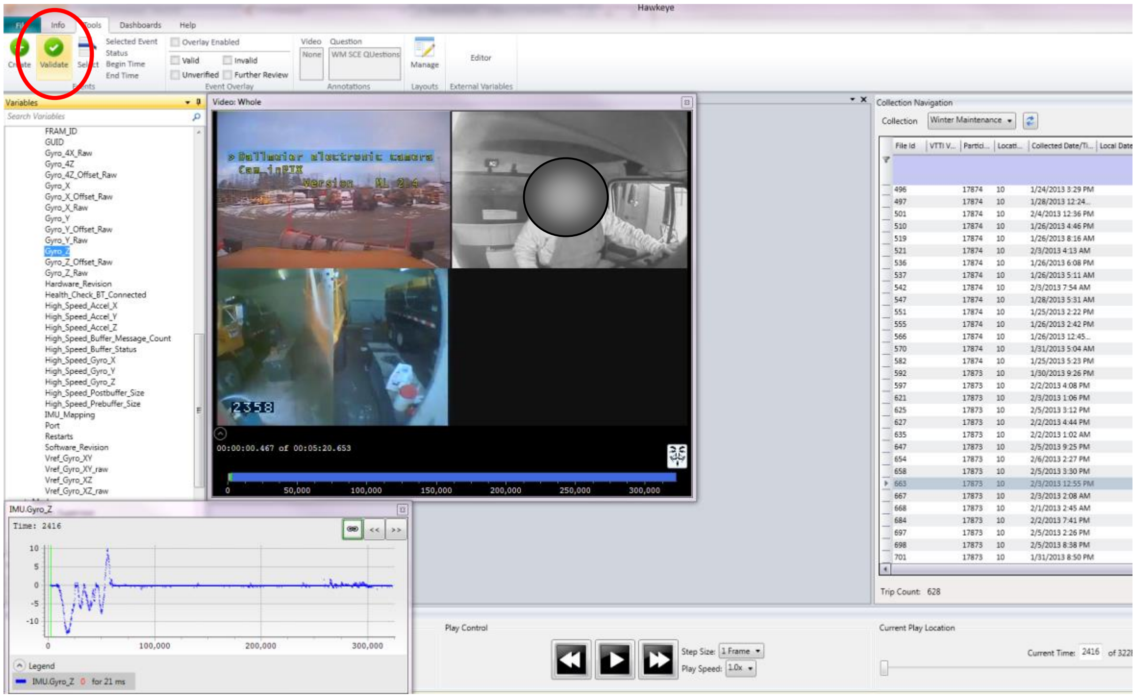
Open SCE Trigger for Analysis:

1. Open the Excel file with the list of File IDs for you to validate.
2. In Hawkeye, double click on the appropriate File ID.
3. Open the following views and arrange on your screen:
    a. Video (Collected → Video → double click on video)



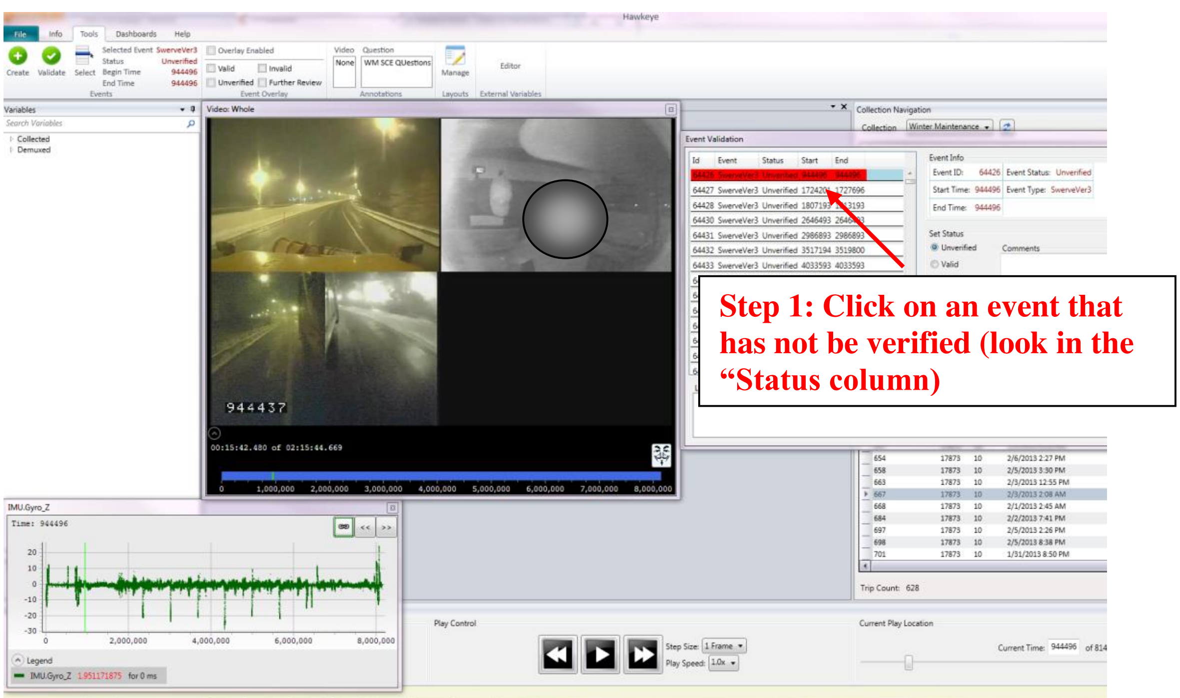
    b. Gyro Z (Collected → IMU → Gyro_Z)

4. Open the list of triggers (click “Validate”).

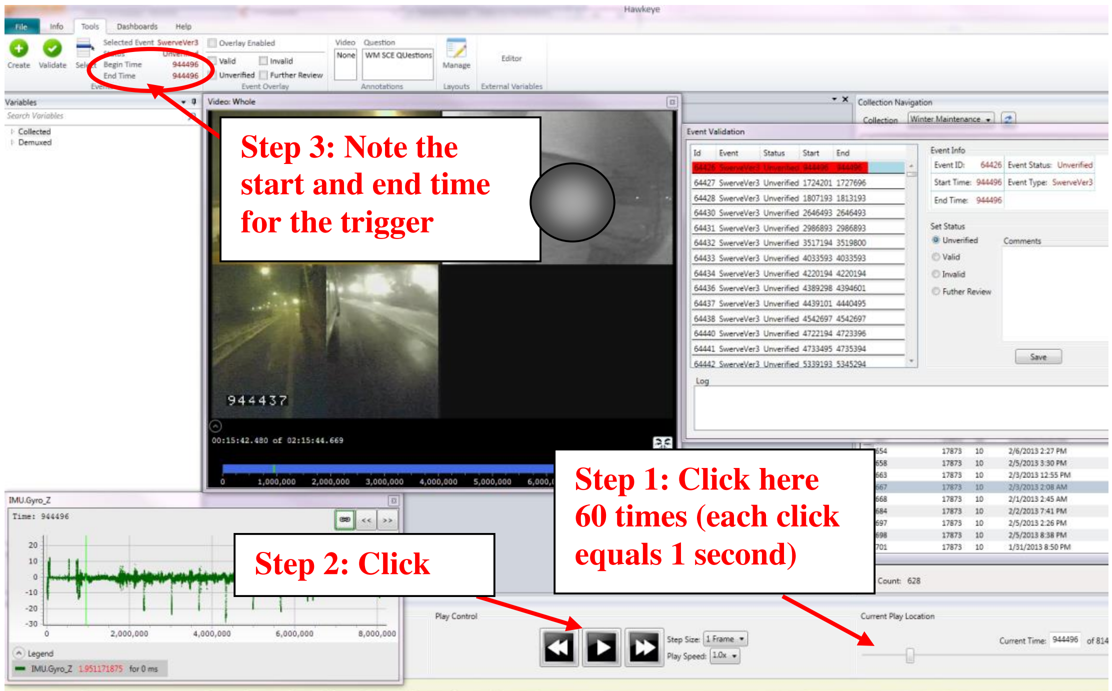


5. Any triggers in the file appear in the list. If there are no triggers, please move on to the next File ID on your list and start over. If triggers do appear on the list, please continue to the next step.

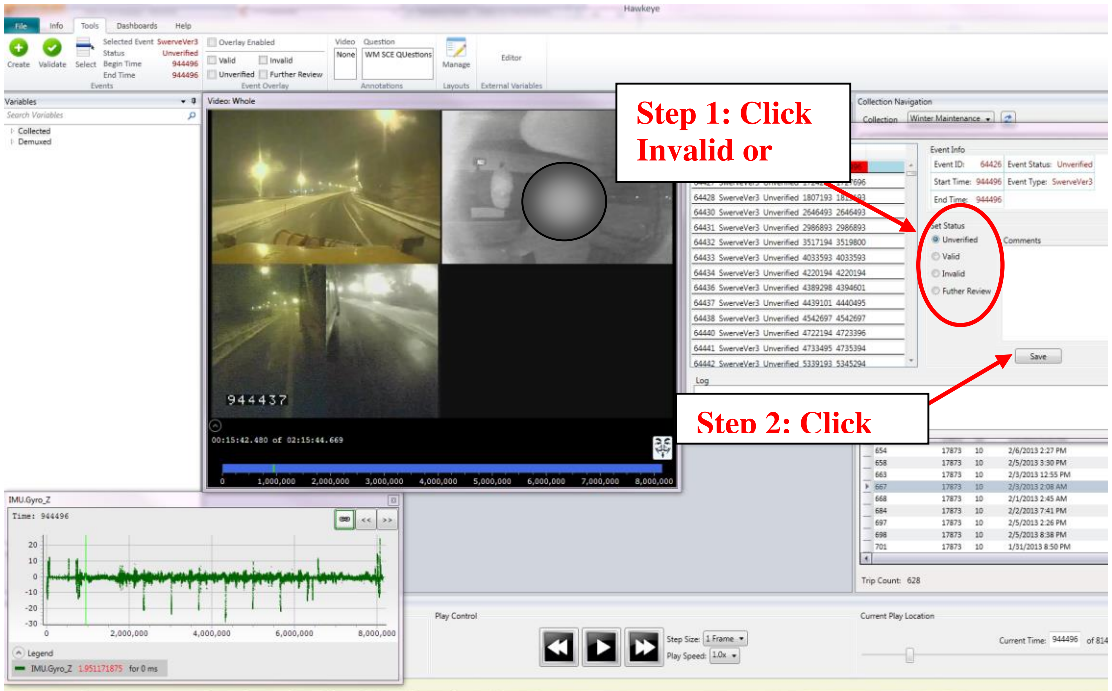
6. Load an “Unverified” trigger by clicking on the event.



7. Go back 60 seconds from the start of the trigger by subtracting 60,000 from the "Current Time" located in the "Current Play Location" window. Then play the video. Ensure you watch 15 seconds (add 15,000 to the end time) after the end of the trigger.



8. Decide if the trigger is valid or invalid (see below for an example valid and invalid swerve trigger). Click the appropriate choice in the Event Validation window. Click Save.



9. If you believe the trigger is a valid SCE, please enter the event in the reduction summary Excel File.
10. Go to the next unverified trigger listed and repeat validation steps.

Triggers Descriptions

SCEs are found by using Hawkeye algorithms to trigger potential crashes in the data. The algorithms might trigger driving maneuvers in which a hard braking was performed, a swerve maneuver was performed, or the vehicle got really close to a lead vehicle.

- **Trigger** – A trigger is used to identify a point of interest (e.g., hard braking) in the data. There are thousands of triggers that will be identified throughout the dataset. Each trigger will be viewed to determine if it is valid or not. It is not necessary that you understand the details of how the trigger is formed, simply that you understand what the different triggers mean. An example of an unvalidated trigger is shown in Table 15.

Table 15. Trigger Type

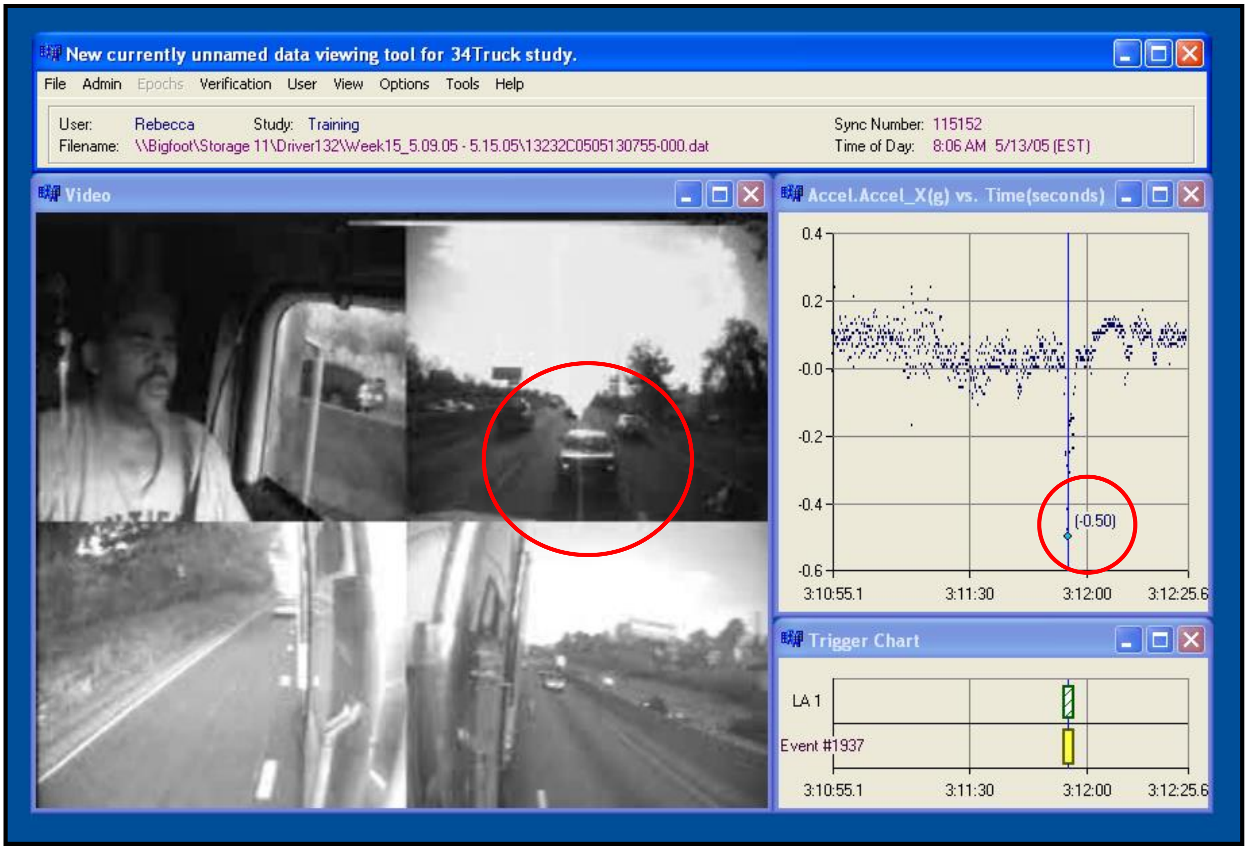
Trigger Type	Definition	Description
Longitudinal Acceleration	Hard braking or sudden acceleration	(1) Acceleration or deceleration greater than or equal to $\|0.20\ g\|$. Speed greater than or equal to 1 mph (1.6 km/h).
Swerve	A sudden "jerk" of the steering wheel to return the truck to its original position in the lane.	(2) Swerve value of greater than or equal to 2 degrees/s^2. Speed greater than or equal to 15 mph (24.14 km/h).
Analyst Identified (AI)	An event that is identified by the analyst but has not been identified by a trigger	Event that was identified by a data analyst viewing video footage; no other trigger is listed above identified the event (i.e. Longitudinal Acceleration, TTC, etc.).

- **Valid trigger** – This is a trigger in which something of interest is happening. For example, if the trigger is a swerve trigger, such as that in **Error! Reference source not found.**, and after reviewing the video you determine that the driver was about to drive off the side of the road and had to swerve to get back on the road, you would mark this as a valid trigger since the truck sensors picked up something that was happening. Previously, less than 10% of the total triggers will be valid triggers.

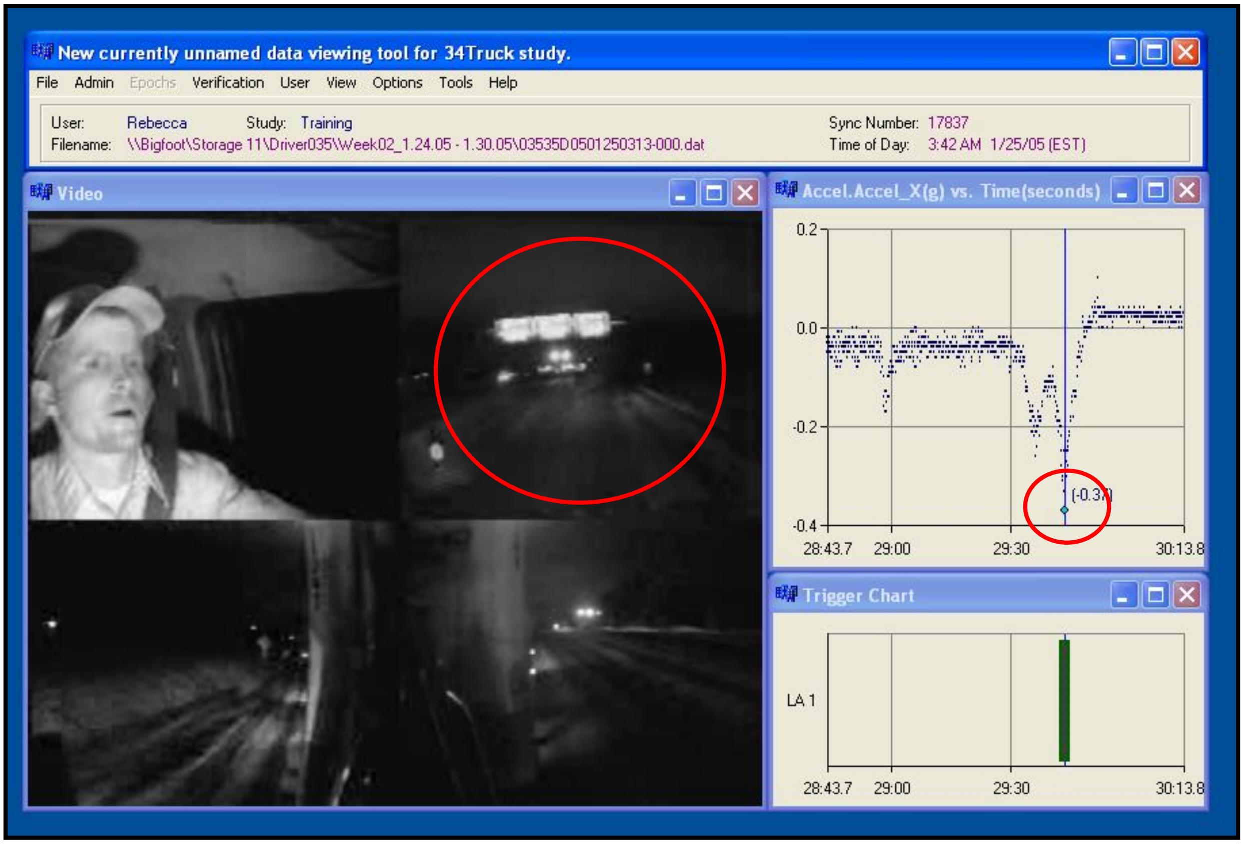
- **Non-conflict trigger** – This is a trigger in which something of interest is not happening, or the severity is not enough to be of interest, according to the criteria for the present study data analysis.

Longitudinal Acceleration Trigger (LA) – hard braking

Valid: In this example, the lead vehicle brakes unexpectedly, causing the truck driver to brake hard (-0.50g).

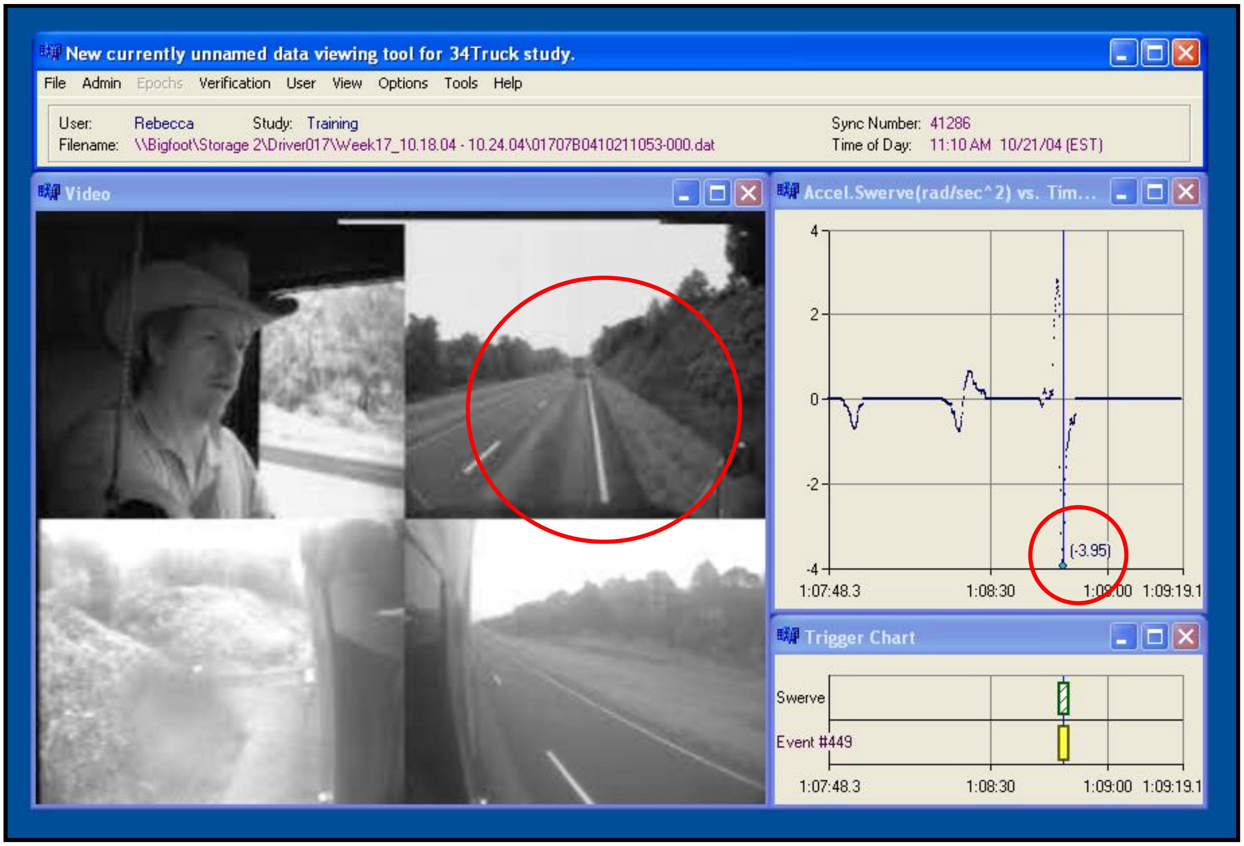


Invalid: In this example, the Accel_X value has dropped below the trigger threshold of -0.35g to -0.37g. Looking at the video, it is clear that there is not a traffic safety threat to the driver and that he is braking to take an exit ramp.

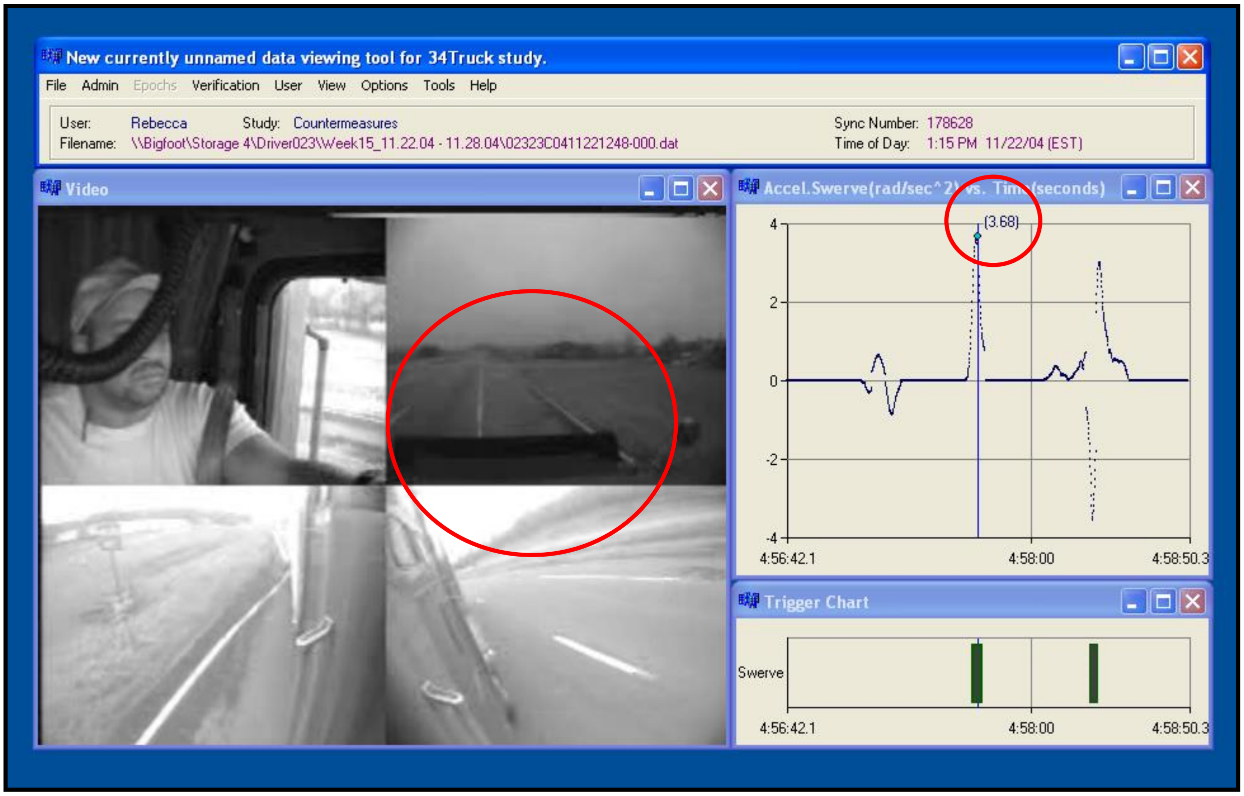


Swerve Trigger (S) – sharp steering

<u>Valid:</u> In this example, the swerve value **(Gyro Rate)** reaches -3.95 degrees/sec^2 (trigger threshold is set at -2 degrees/sec^2) as the driver swerves the truck back onto the road after nearly driving off the right edge of the road while distracted.



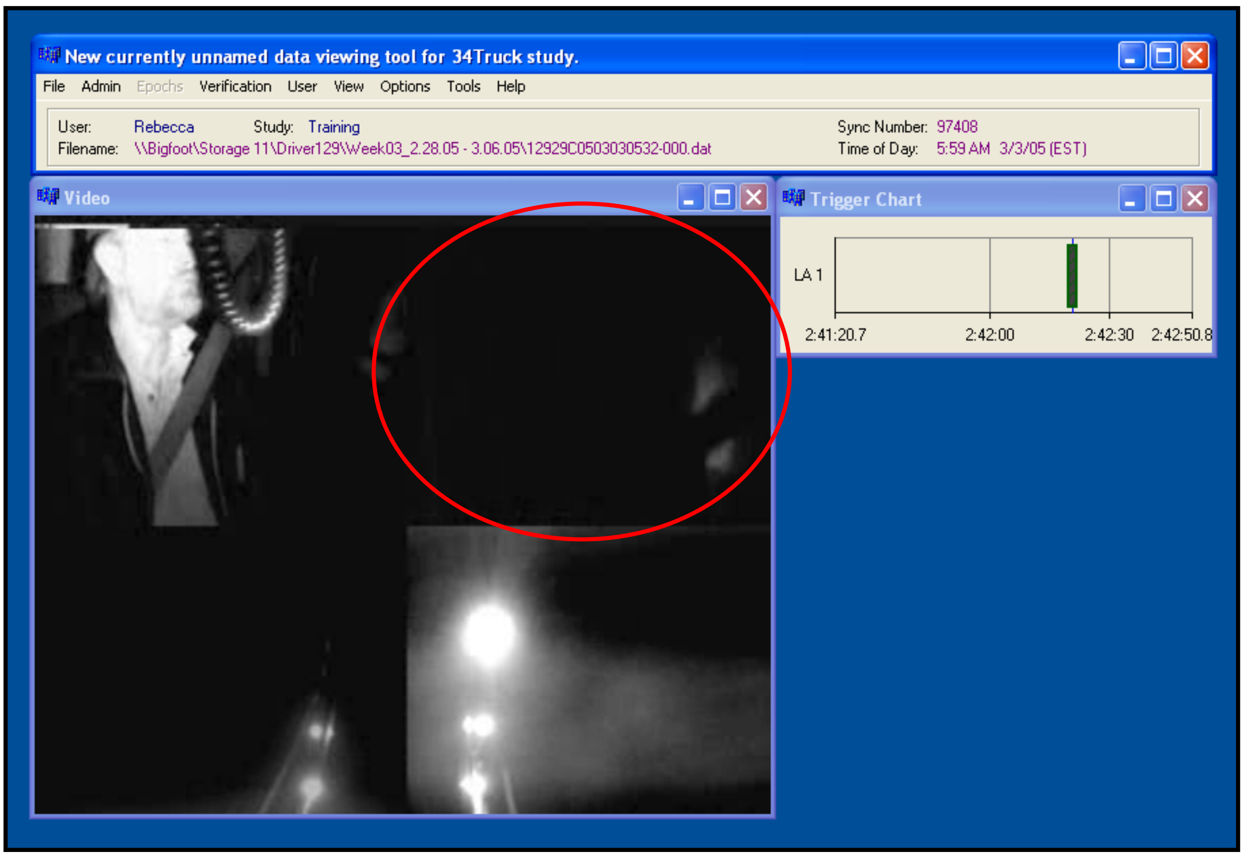
Invalid: In this example, the swerve value **(Gyro Rate)** has gone above the trigger threshold value of 2 degrees/sec^2 to 3.68 degrees/sec^2. Looking at the video, it can be seen that the driver is only changing lanes into a turn lane and it not swerving to avoid a conflict.



Other Invalid Triggers

No video: In this example, the trigger is an LA, meaning the driver likely had to brake due to something in front of his truck, but since the front camera is out, it is not possible to see what is happening.

- There are several conditions for which a trigger would be marked as no video:
    - The face camera is out or not working correctly and the screen is completely black or fuzzy.
    - The camera that you need to use to see what is going on is out or not working correctly. For example, if the conflict is happening with a car in front of the truck, and the front camera is out.
    - There is an error and the video won't load in Hawkeye.
    - The video is frozen.



APPENDIX G – DATA DIRECTORY

The following variables will be recorded for all safety-critical events.

<u>Event Variables</u>

1. **Driver ID**

2. **Did the event occur during a winter emergency?**

    a. No
    b. Yes

3. **Pre-Event Speed**

    Note: For events, coded for the period just prior to the occurrence of the critical event and/or just prior to any avoidance maneuver. For example, when braking is involved, the pre-event speed is the speed just prior to the beginning of braking. If there is no avoidance maneuver, enter the speed at the time of the trigger.

4. **Event Classification**

    a. **Crash.** Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off the roadway, pedestrians, cyclists, or animals.
    b. **Curb Strike: Avoidable**. Any contact with a curb or median where it is apparent that the driver could have performed a maneuver to avoid the contact.
    c. **Curb Strike: Unavoidable**. Any contact with a curb or median where it is apparent that the driver could not have performed a maneuver to avoid the contact. The most likely cause for these events are poor roadway design.
    d. **Near-Crash**. Any circumstance requiring a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash, OR any circumstance that results in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance maneuver or response. A rapid, evasive maneuver is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.
    e. **Crash-Relevant Conflict**. Any circumstance that requires a crash avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive maneuver (as defined above), but greater in severity than a "normal maneuver" to avoid a crash OR any circumstance that results in close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance maneuver or response. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A "normal maneuver" for the subject vehicle is defined as a control input that falls within the 99% confidence limit for control inputs for the initial study data sample.

Examples of potential crash-relevant conflicts include hard braking by a driver because of a specific crash threat, or proximity to other vehicles.

f. **Illegal Maneuver**. Any circumstance where either the subject vehicle or the other vehicle performs an illegal maneuver such as passing another vehicle across the double yellow line or on a shoulder. For many of these cases, neither driver performs an evasive action.

Note: Categories adapted from Dingus et al. (2006), and Hickman et al. (2005). Crash: Tire Strike category only used in Hickman et al. (2005). This variable is extremely subjective and is determined using the best judgment of an analyst. Illegal Maneuver is new to Blanco et al. (in press).

5. Vehicles/Non-Motorists Involved

Note: For some events (e.g., those involving transient encroachment into an oncoming lane), it will be difficult to decide whether the event should be considered a one or two vehicle event. Consider the event a two-vehicle event if the crash resulting from the incident would likely have involved two vehicles, and/or if either driver's maneuvers were influenced by the presence of the other vehicle (e.g., if DV1 maneuvered to avoid V2). Consider the event a one-vehicle event if the presence of other vehicles presented no immediate threat and had no effect on DV1's maneuvers or behaviors.

00 = Not applicable (baseline epoch)
01 = 1 vehicle (Subject vehicle only or subject vehicle + object)
02 = 2 vehicles
03 = 3 vehicles
04 = 4 or more vehicles
05 = Subject vehicle + pedestrian
06 = Subject vehicle + pedal cyclist
07 = Subject vehicle + animal
08 = Other

6. Vehicle/Non-Motorist 2 Type

Note: Highly abridged version of GES V5, Body Type; above codes do not match GES codes. Examples of heavy vehicles are shown in the tables below.

00a = Not applicable (baseline epoch)
00b = Not applicable (single vehicle event – no object)
01 = Automobile
02 = Van (minivan or standard van)
03 = Pickup truck
04 = SUV (includes Jeep)
05 = School bus
06 = Transit bus
07 = Greyhound bus
08 = Conversion bus
09 = Single-unit straight truck: Multi-stop/Step Van

10 = Single-unit straight truck: Box
11 = Single-unit straight truck: Dump
12 = Single-unit straight truck: Garbage/Recycling
13 = Single-unit straight truck: Concrete mixer
14 = Single-unit straight truck: Beverage
15 = Single-unit straight truck: Flatbed
16 = Single-unit straight truck: Tow truck
17 = Single-unit straight truck: Other
18 = Single-unit straight truck: Unknown
19 = Straight Truck + trailer
20 = Tractor-trailer: Cab only
21 = Tractor-trailer: Cab + trailer
22 = Tractor-trailer: Flatbed
23 = Tractor-trailer: Tank
24 = Tractor-trailer: Car carrier
25 = Tractor-trailer: Livestock
26 = Tractor-trailer: Lowboy trailer
27 = Tractor-trailer: Dump trailer
28 = Tractor-trailer: Multiple trailers
29 = Tractor-trailer: Multiple trailers/grain
30 = Tractor-trailer: Other
31 = Other large construction equipment
32 = Ambulance
33 = Fire truck
34 = Motorcycle or moped
35 = Police car
36 = Vehicle pulling trailer (other than tractor-trailer)
37 = Other vehicle type
38 = Pedestrian
39 = Pedalcyclist
40 = Deer
41 = Other animal
42 = Object (single vehicle event with relevant object)
43 = Unknown

Table 16. Buses

 School Bus	 Transit Bus
 Greyhound Bus	 Conversion Bus

Table 17. Straight Trucks

 Multistop/Step Van	 Box
 Dump	 Garbage/Recycling
 Concrete Mixer	 Beverage

 Other Large Construction Equipment	 Other: Flatbed
 Other: Tow Truck	 Straight Truck (dump truck) + Trailer

Table 18. Emergency Vehicles

 Ambulance	 Fire Truck

Table 19. Tractor-trailer Trucks

 Tractor-trailer (Cab only)	 Tractor-trailer (Cab plus trailer)
 Tractor-trailer: Flatbed	 Tractor-trailer: Tank

 Tractor-trailer: Car carrier	 Tractor-trailer: Livestock
 Tractor-trailer: Lowboy trailer	 Tractor-trailer: Dump trailer
 Tractor-trailer: Multiple trailers	 Tractor-trailer: Multiple trailers/grain

7. Relevant Object

00a = Not applicable (baseline epoch)
00b = Not applicable (single vehicle event – no relevant object; e.g., shoulder only)
00c = Not applicable (multi-vehicle event, pedestrian, animal, etc.)
01 = Parked motor vehicle

Fixed objects:

02 = Building
03 = Impact attenuator/crash cushion
04 = Bridge structure (e.g., abutment)
05 = Guardrail
06 = Concrete traffic barrier or other longitudinal barrier (e.g., “Jersey Barrier”)
07 = Post, pole, or support (e.g., sign, light)
07a = Mailbox
08 = Culvert/ditch/edge of road
09 = Curb
10 = Embankment
11 = Fence

12 = Wall
13 = Fire hydrant
14 = Shrubbery or bush
15 = Tree *[not overhang – see below]*
16 = Boulder
17 = Loading dock
18 = Loading equipment (e.g., fork lift, pallets)
19 = Cargo

Overhanging objects (only if struck or potentially struck by top of truck/trailer)
20 = Tree branch
21 = Overhanging part of sign or post
22 = Bridge/overpass
23 = Building
24 = Telephone wires

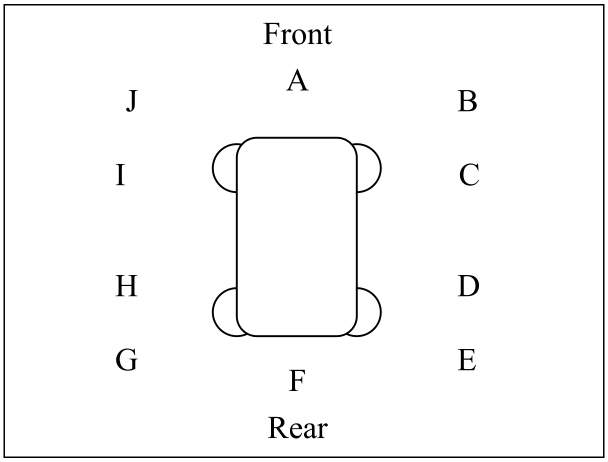
Non-fixed objects:
25 = Vehicle parts, including tire parts
26 = Spilled cargo
27 = Dead animal in roadway
28 = Broken tree limbs or other tree/shrub parts
29 = Trash/debris
30 = Construction barrel
31 = Construction cone

Other:
98 = Other
99 = Unknown object hit
Note: GES A06, First Harmful Event. Options in italics are not A06 codes.

8. Vehicle/Non-Motorist 2 Position (in Relation to V1)

The vehicle in the diagram represents the subject vehicle (V1, the truck). The relative position of Vehicle 2 (in relation to Vehicle 1) is coded for the time in which the Critical Event occurs (i.e., the event creating the crash risk). Vehicles in adjacent left lane are coded J, I, H, or G depending on position. Vehicles in adjacent right lane are coded B, C, D or E depending on position. Please also code the position of animals, pedestrians, pedacyclists and objects.

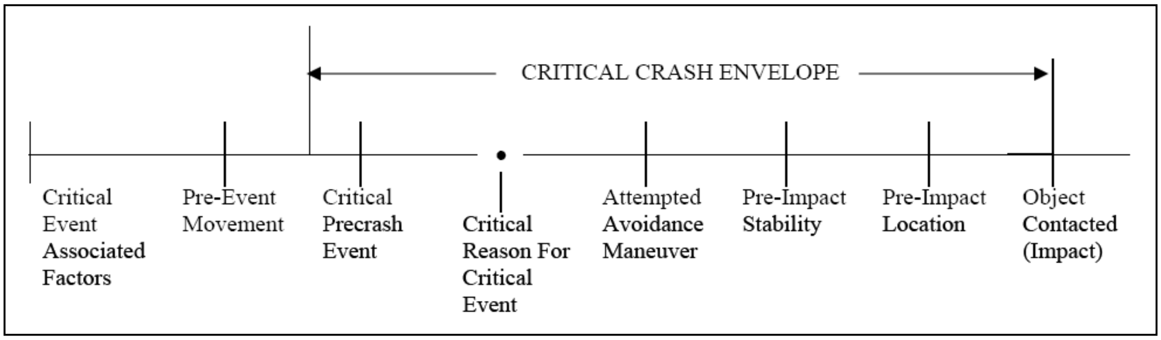
00a = Not applicable (baseline epoch)
00b **=** Not applicable (single vehicle event – no object)
K = Top of vehicle



9. Vehicle 1 Pre-Event Movement

01 = Going straight (and not known to be engaged in movements listed below)
02 = Decelerating in traffic lane
03 = Accelerating in traffic lane
04 = Starting in traffic lane
05 = Stopped in traffic lane
06 = Passing or overtaking another vehicle
07 = Disabled or parked in travel lane
08a = Leaving a parking position, moving forward
08b = Leaving a parking position, backing
09a = Entering a parking position, moving forward
09b = Entering a parking position, backing
10 = Turning right
11 = Turning left
12 = Making a u-turn
13 = Backing up (other than parking)
14 = Negotiating a curve
15 = Changing lanes
16 = Merging
17 = Successful avoidance maneuver to a previous critical event
98 = Other
99 = Unknown

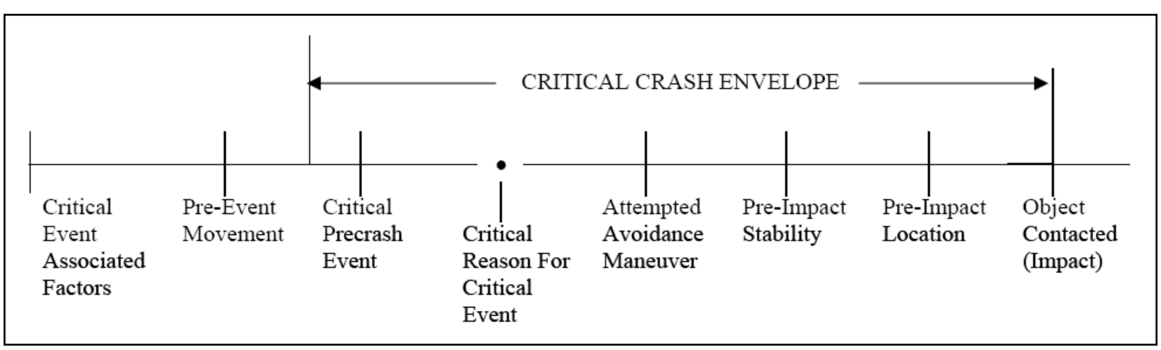
Note: LTCCS Variable 4 with expanded choices for 8 and 9. The Pre-Event Movement is considered to be outside of the Critical Crash Envelope, shown below.



10. Vehicle 2 Pre-Event Movement

00b = Not applicable (single vehicle event)
01 = Going straight (and not known to be engaged in movements listed below)
02 = Decelerating in traffic lane
03 = Accelerating in traffic lane
04 = Starting in traffic lane
05 = Stopped in traffic lane
06 = Passing or overtaking another vehicle
07 = Disabled or parked in travel lane
08a = Leaving a parking position, moving forward
08b = Leaving a parking position, backing
09a = Entering a parking position, moving forward
09b = Entering a parking position, backing
10 = Turning right
11 = Turning left
12 = Making a u-turn
13 = Backing up (other than parking)
14 = Negotiating a curve
15 = Changing lanes
16 = Merging
17 = Successful avoidance maneuver to a previous critical event
98 = Other
99 = Unknown

Note: LTCCS Variable 4 with expanded choices for 8 and 9. The Pre-Event Movement is considered to be outside of the Critical Crash Envelope, shown below.



11. Vehicle 1 Critical Pre-Crash Event

This variable is coded for both vehicles in a two-vehicle incident. However, the Critical Reason (see below), is coded for only one vehicle. For consistency with the Accident Type variable, lane edges between travel lanes and non-travel lanes (e.g., shoulders) are considered road edges. Unlike the Accident Type variable, however, you should code the actual precipitating event and should not project or extrapolate the event.

00 = Not applicable (baseline epoch)

THIS VEHICLE (V1) LOSS OF CONTROL DUE TO:

01 = Blow out or flat tire
02 = Stalled engine
03 = Disabling vehicle failure (e.g., wheel fell off)
04 = Non-disabling vehicle problem (e.g., hood flew up)
05 = Poor road conditions (*wet road,* puddle, pot hole, ice, etc.)
06 = Traveling too fast for conditions
07 = Jackknife event
08 = Cargo shift
09 = Braking
10 = Steering
18 = Other cause of control loss
19 = Unknown cause of control loss

THIS VEHICLE (V1) TRAVELING

20 = *Toward or* over the lane line on left side of travel lane
21 = *Toward or* over the lane line on right side of travel lane
22 = *Toward or* off the edge of the road on the left side
23 = *Toward or* off the edge of the road on the right side
24 = End departure
25 = Turning left at intersection
26 = Turning right at intersection
27 = Crossing over (passing through) intersection
28 = This vehicle decelerating
28a = This vehicle accelerating
29 = Unknown travel direction

OTHER MOTOR VEHICLE (V2) IN LANE

50 = Other vehicle stopped
51 = Traveling in same direction with lower steady speed
52 = Traveling in same direction while decelerating
53 = Traveling in same direction with higher speed
54 = Traveling in opposite direction
55 = In crossover
56 = Backing
59 = Unknown travel direction of other motor vehicle in lane

OTHER MOTOR VEHICLE (V2) ENCROACHING INTO LANE

60 = From adjacent lane (same direction) – *toward or* over left lane line
61 = From adjacent lane (same direction) – *toward or* over right lane line
62 = From opposite direction – *toward or* over left lane line
63 = From opposite direction – *toward or* over right lane line
64 = From parking lane
65 = From crossing street, turning into same direction
66 = From crossing street, across path
67 = From crossing street, turning into opposite direction
68 = From crossing street, intended path not known
70 = From driveway, turning into same direction
71 = From driveway, across path
72 = From driveway, turning into opposite direction
73 = From driveway, intended path not known
74 = From entrance to limited access highway
78 = Encroachment by other vehicle – details unknown

PEDESTRIAN, PEDALCYCLIST, OR OTHER NONMOTORIST

80 = Pedestrian in roadway
81 = Pedestrian approaching roadway
82 = Pedestrian - unknown location
83 = Pedalcyclist or other nonmotorist in roadway
84 = Pedalcyclist or other nonmotorist approaching roadway
85 = Pedalcyclist or other nonmotorist - unknown location

OBJECT OR ANIMAL

87 = Animal in roadway
88 = Animal approaching roadway
89 = Animal – unknown location
90 = Object in roadway
91 = Object approaching roadway
92 = Object – unknown location

OTHER

98 = Other critical pre-crash event
99 = Unknown

Note: LTCCS Variable 5.

12. Vehicle 2 Critical Pre-Crash Event

This variable is coded for both vehicles in a two-vehicle incident. However, the Critical Reason (see below), is coded for only one vehicle.

00a = Not applicable (baseline epoch)

00b = Not applicable (single vehicle event)

THIS VEHICLE (V2) LOSS OF CONTROL DUE TO:
01 = Blow out or flat tire
02 = Stalled engine
03 = Disabling vehicle failure (e.g., wheel fell off)
04 = Non-disabling vehicle problem (e.g., hood flew up)
05 = Poor road conditions (*wet road*, puddle, pot hole, ice, etc.)
06 = Traveling too fast for conditions
07 = Jackknife event
08 = Cargo shift
09 = Braking
10 = Steering
18 = Other cause of control loss
19 = Unknown cause of control loss

THIS VEHICLE (V2) TRAVELING
20 = *Toward or* over the lane line on left side of travel lane
21 = *Toward or* over the lane line on right side of travel lane
22 = *Toward or* off the edge of the road on the left side
23 = *Toward or* off the edge of the road on the right side
24 = End departure
25 = Turning left at intersection
26 = Turning right at intersection
27 = Crossing over (passing through) intersection
28 = This vehicle decelerating
28a = This vehicle accelerating
29 = Unknown travel direction

OTHER MOTOR VEHICLE (V1) IN LANE
50 = Other vehicle stopped
51 = Traveling in same direction with lower steady speed
52 = Traveling in same direction while decelerating
53 = Traveling in same direction with higher speed
54 = Traveling in opposite direction
55 = In crossover
56 = Backing
59 = Unknown travel direction of other motor vehicle in lane

OTHER MOTOR VEHICLE (V1) ENCROACHING INTO LANE
60 = From adjacent lane (same direction) – *toward or* over left lane line
61 = From adjacent lane (same direction) – *toward or* over right lane line
62 = From opposite direction – *toward or* over left lane line
63 = From opposite direction – *toward or* over right lane line
64 = From parking lane
65 = From crossing street, turning into same direction

66 = From crossing street, across path
67 = From crossing street, turning into opposite direction
68 = From crossing street, intended path not known
70 = From driveway, turning into same direction
71 = From driveway, across path
72 = From driveway, turning into opposite direction
73 = From driveway, intended path not known
74 = From entrance to limited access highway
78 = Encroachment by other vehicle – details unknown

PEDESTRIAN, PEDALCYCLIST, OR OTHER NONMOTORIST
80 = Pedestrian in roadway
81 = Pedestrian approaching roadway
82 = Pedestrian - unknown location
83 = Pedalcyclist or other nonmotorist in roadway
84 = Pedalcyclist or other nonmotorist approaching roadway
85 = Pedalcyclist or other nonmotorist - unknown location

OBJECT OR ANIMAL
87 = Animal in roadway
88 = Animal approaching roadway
89 = Animal – unknown location
90 = Object in roadway
91 = Object approaching roadway
92 = Object – unknown location

OTHER
98 = Other critical pre-crash event
99 = Unknown

Note: LTCCS Variable 5.

13. Vehicle 1 Critical Reason for the Critical Event

"This vehicle" will always be used for the vehicle being coded. Note that vehicle-related factors will rarely be apparent to analysts. Analysts will choose one critical reason that appears to be the main critical reason – the critical reason is coded for either V1 or V2, not both.

000a = Not applicable (baseline epoch)
000b = Critical reason not coded to this vehicle

DRIVER RELATED FACTOR: Critical Non-Performance Errors
100 = Sleep, that is, actually asleep
101 = Heart attack or other physical impairment of the ability to act
107 = Drowsiness, fatigue, or other reduced alertness (not asleep)

108 = Other critical non-performance
109 = Unknown critical non-performance

DRIVER RELATED FACTOR: Recognition Errors
110 = Inattention (i.e., daydreaming)
111a = Internal distraction
112 = External distraction
113 = Inadequate surveillance (e.g., failed to look, looked but did not see)
118 = Other recognition error
119 = Unknown recognition error

DRIVER RELATED FACTOR: Decision Errors
120 = Too fast for conditions (*e.g., for safe vehicle control or* to be able to respond to unexpected actions of other road users)
121 = Too slow for traffic stream
122 = Misjudgment of gap or other's speed
123 = Following too closely to respond to unexpected actions (close proximity for 2 or more seconds)
124 = False assumption of other road user's actions
125a = Apparently intentional sign/signal violation
125b = Illegal U-turn
125c = Other illegal maneuver
126 = Failure to turn on head lamps
127 = Inadequate evasive action (e.g., braking only not braking and steering; *release accelerator only instead of braking*)
128a = Aggressive driving behavior: Intimidation: any behavior emitted by a driver while driving that is intended to cause physical or psychological harm to another person.
128b = Aggressive driving behavior: Wanton, neglectful or reckless behavior: excessive risky driving behaviors performed without intent to harm others, such as weaving through traffic, maneuvering without signaling, running red lights, frequent lane changing, and tailgating
138 = Other decision error
139 = Unknown decision error
140 = Apparent recognition or decision error (unknown which)

DRIVER RELATED FACTOR: Performance Errors
141 = Panic/Freezing
142 = Overcompensation
143 = Poor directional control (e.g., failing to control vehicle with skill ordinarily expected)
148 = Other performance error
149 = Unknown performance error
199 = Type of driver error unknown

VEHICLE RELATED FACTOR
200 = Tires/wheels failed
201 = Brakes failed
202 = Steering failed
203 = Cargo shifted
204 = Trailer attachment failed
205 = Suspension failed
206 = Lights failed
207 = Vehicle related vision obstructions
208 = Body, doors, hood failed
209 = Jackknifed
298 = Other vehicle failure
299 = Unknown vehicle failure

ENVIRONMENT RELATED FACTOR: Highway Related
500 = Signs/signals missing
501 = Signs/signals erroneous/defective
503 = View obstructions by roadway design
504 = View obstructed by other vehicles crash circumstance
505 = Road design – roadway geometry (e.g., ramp curvature)
506 = Road design – sight distance
507 = Road design – other
508 = Maintenance problems (potholes, deteriorated road edges, etc.)
509 = Slick roads (low friction road surface due to ice, loose debris, any other cause)
518 = Other highway-related condition

ENVIRONMENT RELATED FACTOR: Weather Related
521 = Rain, snow [Note: code loss-of-control as 509]
522 = Fog
523 = Wind gust
528 = Other weather-related condition

ENVIRONMENT RELATED FACTOR: Other
530 = Glare
531 = Blowing debris
532 = Animal in roadway (no driver error)
533 = Pedestrian or pedalcyclist in roadway (no driver error)
534 = Object in roadway (no driver error)
538 = Other sudden change in ambience
999 = Unknown reason for critical event

Note: LTCCS Variable 6 with revisions in.

14. Vehicle 2 Critical Reason for the Critical Event

The elements for DV2 are either maneuvers or conditions visible from outside the vehicle (e.g., most of the decision error choices) or reasonable general inferences. Analysts will

choose one critical reason that appears to be the main critical reason – the critical reason is coded for either V1 or V2, not both.
00a = Not applicable (baseline epoch)
000b = Not applicable (single vehicle event)
000c = Critical reason not coded to this vehicle

DRIVER RELATED FACTOR
109 = Apparent critical non-performance [includes any apparent driver impairment]

DRIVER RELATED FACTOR: Recognition Errors
119 = Apparent recognition error

DRIVER RELATED FACTOR: Decision Errors
120 = Too fast for conditions (*e.g., for safe vehicle control or* to be able to respond to unexpected actions of other road users)
121 = Too slow for traffic stream
123 = Following too closely to respond to unexpected actions (close proximity for 2 or more seconds)
124 = False assumption of other road user's actions
125a = Apparently intentional sign/signal violation
125b = Illegal U-turn
125c = Other illegal maneuver
126 = Failure to turn on head lamps
127 = Inadequate evasive action (e.g., braking only not braking and steering; *release accelerator only instead of braking*)
128a = Aggressive driving behavior: Intimidation: any behavior emitted by a driver while driving that is intended to cause physical or psychological harm to another person.
128b = Aggressive driving behavior: Wanton, neglectful or reckless behavior: <u>excessive</u> risky driving behaviors performed without intent to harm others, such as weaving through traffic, maneuvering without signaling, running red lights, frequent lane changing, and tailgating
138 = Other decision error
139 = Apparent, unknown decision error

DRIVER RELATED FACTOR: Performance Errors
149 = Apparent performance error
199 = Type of driver error unknown

VEHICLE RELATED FACTOR
200 = Tires/wheels failed
201 = Brakes failed
298 = Apparent other vehicle failure
299 = Unknown vehicle failure

ENVIRONMENT RELATED FACTOR: Highway Related

500 = Signs/signals missing
501 = Signs/signals erroneous/defective
503 = View obstructions by roadway design
504 = View obstructed by other vehicles crash circumstance
505 = Road design – roadway geometry (e.g., ramp curvature)
506 = Road design – sight distance
507 = Road design – other
508 = Maintenance problems (potholes, deteriorated road edges, etc.)
509 = Slick roads (low friction road surface due to ice, loose debris, any other cause)
518 = Other highway-related condition

ENVIRONMENT RELATED FACTOR: Weather Related

521 = Rain, snow [Note: code loss-of-control as 509]
522 = Fog
523 = Wind gust
528 = Other weather-related condition

ENVIRONMENT RELATED FACTOR: Other

530 = Glare
531 = Blowing debris
538 = Other sudden change in ambience
999 = Unknown reason for critical event

15. Which vehicle is considered to be at fault?

The "at fault" vehicle is defined as the vehicle with the assigned Critical Reason with a few exceptions:

1. Animal/pedestrian/pedal cyclist in roadway is considered to be "Vehicle 2" at fault
2. Object in roadway is considered to be "No fault"
3. All environmental factors are considered to be "No fault"

00 = Not applicable (baseline epoch)
01 = Vehicle 1 (subject vehicle)
02 = Vehicle 2 (other vehicle, animal, pedestrian, pedacyclist)
03 = No fault (object, environmental)
04 = Unknown

16. Vehicle 1 Attempted Avoidance Maneuver

00a = Not applicable (baseline epoch)
01 = No avoidance maneuver
02 = Braking (no lockup *or lockup unknown*)
03 = Braking (lockup)
05 = Releasing brakes
06 = Steered to left

07 = Steered to right

08a = Braked and steered to left (no lockup or lockup unknown)

08b = Braked and steered to left (lockup)

09a = Braked and steered to right (no lockup or lockup unknown)

09b = Braked and steered to right (lockup)

10 = Accelerated

11 = Accelerated and steered to left

12 = Accelerated and steered to right

13 = Released gas pedal without braking

14 = Released gas pedal (without braking) and steered to left

15 = Released gas pedal (without braking) and steered to right

98 = Other actions

99 = Unknown if driver attempted any corrective action

Note: LTCCS Variable 7 and also GES V27, Corrective Action Attempted. "Released gas pedal" elements added because this evasive maneuver by subject drivers is sometimes observed.

17. Vehicle 2 Attempted Avoidance Maneuver

00a = Not applicable (baseline epoch)

00b = Not applicable (single vehicle event)

01 = No avoidance maneuver

02 = Braking (no lockup *or lockup unknown*)

03 = Braking (lockup)

05 = Releasing brakes

06 = Steered to left

07 = Steered to right

08a = Braked and steered to left (no lockup or lockup unknown)

08b = Braked and steered to left (lockup)

09a = Braked and steered to right (no lockup or lockup unknown)

09b = Braked and steered to right (lockup)

10 = Accelerated

11 = Accelerated and steered to left

12 = Accelerated and steered to right

13 = Released gas pedal without braking

14 = Released gas pedal (without braking) and steered to left

15 = Released gas pedal (without braking) and steered to right

98 = Other actions

99 = Unknown if driver attempted any corrective action

Note: LTCCS Variable 7 and also GES V27, Corrective Action Attempted. "Released gas pedal" elements added because this evasive maneuver by subject drivers is sometimes observed.

18. Vehicle 1 Crash Type

Comment: Since this variable "includes intent," analysts should *project* likely scenario roles for incidents where outcomes are not definite. In other words, if the trigger-related event had resulted in a crash, what would the crash scenario be? When specific scenarios cannot be projected, use the "Specifics Unknown" choices (e.g., 5, 10, 16, 33, etc.).

Table 20 illustrates the Crash Types.

- 888 = Not applicable (baseline epoch)

Additional clarifications:

- Drive off road codes (e.g., 01 and 06) are used when a vehicle has crossed, or is projected to cross, a roadside delineation such as a lane edge line (going onto the shoulder or median), curb, or the edge of the pavement. This includes scenarios involving parked vehicles and stationary objects if those objects are outside of the roadway delineation (e.g., on an unpaved shoulder).
- Forward impact codes (e.g., 11, 12) are used when the objects are in the travel lane or when there is no lane edge delineation as described above. Thus, a scenario involving a parked vehicle on the pavement where there is no lane edge delineation is coded 12.
- If Single Driver codes (01-16) are used for V1, the V2 Accident Type code is 00b.
- For left-side lane departures into the oncoming traffic lane, code 64/65 if the lateral encroachment is less than a few feet. Code 50/51 only if the lateral encroachment was sufficient to create a significant risk of a head-on crash.
- Hard-braking events at intersections in the absence of a specific crash or crash threat are coded 91 (Intersecting straight paths, specifics unknown).

19. Vehicle 2 Crash Type

888 = Not applicable (baseline epoch)
999 = Not applicable (single vehicle event)

Comment: Since this variable "includes intent," analysts should *project* likely scenario roles for incidents where outcomes are not definite. In other words, if the trigger-related event had resulted in a crash, what would the crash scenario be? When specific scenarios cannot be projected, use the "Specifics Unknown" choices (e.g., 5, 10, 16, 33, etc.).

Table 20 illustrates the Crash Types.

Additional clarifications:

- Single Driver codes (01-16) are not applicable to V2. If a Single Driver code (01-16) was used for V1, the V2 Accident Type code is 00b.

- For left-side lane departures into the oncoming traffic lane, code 64/65 if the lateral encroachment is less than a few feet. Code 50/51 only if the lateral encroachment was sufficient to create a significant risk of a head-on crash.

Table 20. Description of the Crash Types (Thieriez et al., 2002)

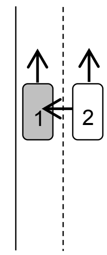
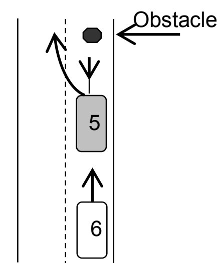
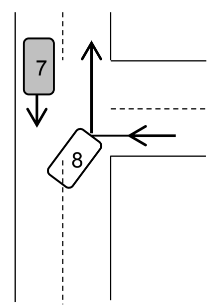
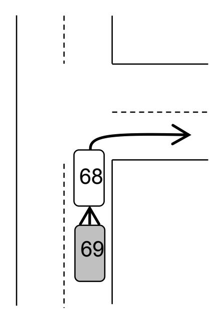
Category	Configuration	ACCIDENT TYPES (Includes Intent)		
I. Single Driver	A. Right Roadside Departure	01 DRIVE OFF ROAD; 02 CONTROL/ TRACTION LOSS; 03 AVOID COLLISION WITH VEH., PED., ANIM.	04 SPECIFICS OTHER	05 SPECIFICS UNKNOWN
	B. Left Roadside Departure	06 DRIVE OFF ROAD; 07 CONTROL/ TRACTION LOSS; 08 AVOID COLLISION WITH VEH., PED., ANIM.	09 SPECIFICS OTHER	10 SPECIFICS UNKNOWN
	C. Forward Impact	11 PARKED VEHICLE; 12 STATIONARY OBJECT; 13 PEDESTRIAN/ ANIMAL; 14 END DEPARTURE	15 SPECIFICS OTHER	16 SPECIFICS UNKNOWN
II. Same Trafficway Same Direction	D. Rear-End	20 STOPPED 21, 22, 23; 24 SLOWER 25, 26, 27; 28 DECELERATING 29, 30, 31	(EACH - 32) SPECIFICS OTHER	(EACH - 33) SPECIFICS UNKNOWN
	E. Forward Impact	34, 35 CONTROL/ TRACTION LOSS; 36, 37 CONTROL/ TRACTION LOSS; 38, 39 AVOID COLLISION WITH VEHICLE; 40, 41 AVOID COLLISION WITH OBJECT	(EACH - 42) SPECIFICS OTHER	(EACH - 43) SPECIFICS UNKNOWN
	F. Sideswipe Angle	44, 45; 46, 45, 47	(EACH - 48) SPECIFICS OTHER	(EACH - 49) SPECIFICS UNKNOWN
III. Same Trafficway Opposite Direction	G. Head-On	50, 51 LATERAL MOVE	(EACH - 52) SPECIFICS OTHER	(EACH - 53) SPECIFICS UNKNOWN
	H. Forward Impact	54, 55 CONTROL/ TRACTION LOSS; 56, 57 CONTROL/ TRACTION LOSS; 58, 59 AVOID COLLISION WITH VEHICLE; 60, 61 AVOID COLLISION WITH OBJECT	(EACH - 62) SPECIFICS OTHER	(EACH - 63) SPECIFICS UNKNOWN
	I. Sideswipe/ Angle	64, 65 LATERAL MOVE	(EACH - 66) SPECIFICS OTHER	(EACH - 67) SPECIFICS UNKNOWN
IV. Change Trafficway Vehicle Turning	J. Turn Across Path	68, 69 INITIAL OPPOSITE DIRECTIONS; 70, 71, 72, 73 INITIAL SAME DIRECTION	(EACH - 74) SPECIFICS OTHER	(EACH - 75) SPECIFICS UNKNOWN
	K. Turn Into Path	76, 77, 78, 79 TURN INTO SAME DIRECTION; 80, 81, 82, 83 TURN INTO OPPOSITE DIRECTIONS	(EACH - 84) SPECIFICS OTHER	(EACH - 85) SPECIFICS UNKNOWN
V. Intersecting Paths (Vehicle Damage)	L. Straight Paths	86, 87; 88, 89	(EACH - 90) SPECIFICS OTHER	(EACH - 91) SPECIFICS UNKNOWN
VI. Miscellaneous	M. Backing Etc.	92 BACKING VEHICLE; 93 OTHER VEHICLE OR OBJECT	98 OTHER ACCIDENT TYPE; 99 UNKNOWN ACCIDENT TYPE; 00 NO IMPACT	

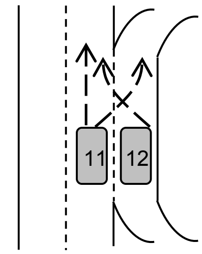
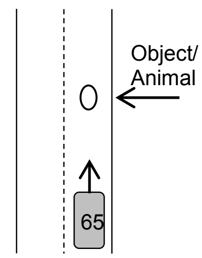
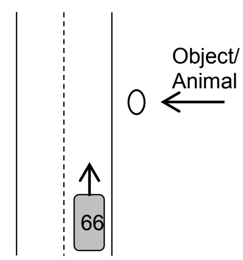
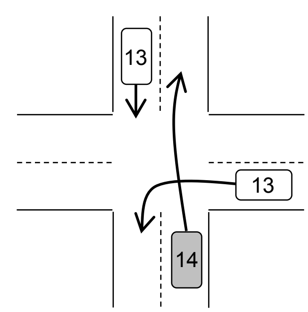
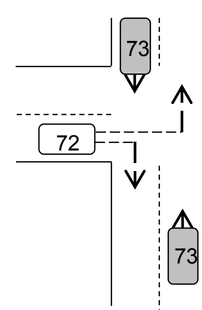
20. Vehicle 1 and Vehicle 2 Incident Type

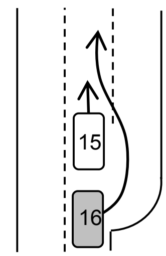
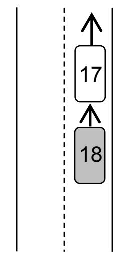
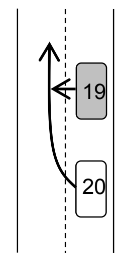
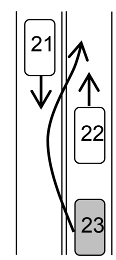
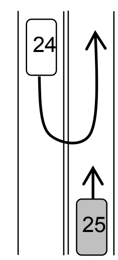
Numbers listed below are shown in Table 21.

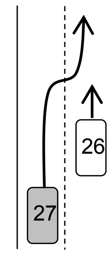
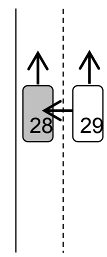
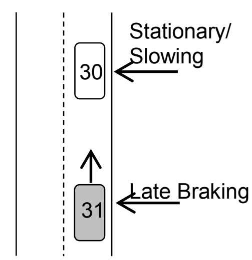
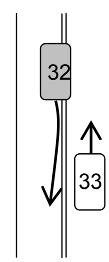
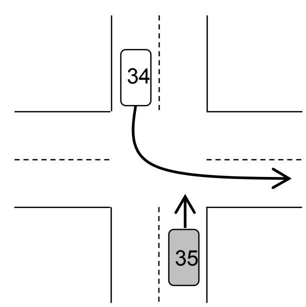
888 =	Not applicable (baseline epoch)
01/02 =	Aborted lane change
05/06/07/08 =	Backing in roadway
68/69 =	Close proximity to turning vehicle
11/12 =	Conflict between merging and existing traffic
65 =	Conflict with animal/pedestrian/pedacyclist/object in roadway (V1 only)
66 =	Conflict with animal/pedestrian/pedacyclist/object on side of road (V1 only)
13/14 =	Conflict with oncoming traffic
72/73 =	Conflict with through traffic
15/16 =	Exit then re-entrance onto roadway
17/18 =	Following too closely
19/20 =	Improper lane change
21/22/23 =	Improper passing
24/25 =	Improper u-turn
26/27 =	Lane change without sufficient gap
28/29 =	Lane drift
30/31=	Late braking for stopped/stopping traffic
32/33=	Lateral deviation of through vehicle
34/35=	Left turn without clearance
36/37 =	Merge out of turn (before lead vehicle)
38/39/40 =	Merge without sufficient gap
41/42 =	Obstruction in roadway
43/44 =	Proceeding through red traffic signal
45/46 =	Roadway entrance without clearance
47/48 =	Slow speed
49/50 =	Slow upon passing
51/52/53=	Sudden braking in roadway
54/55 =	Through traffic does not allow lane change
56/57/58 =	Through traffic does not allow merge
59/60 =	Turn without sufficient warning
61/62 =	Turn/exit from incorrect lane
63/64 =	Wide turn into adjacent lane
67 =	Other single vehicle event (V1 only)
70/71=	Vehicle passes through intersection without clearance
98 =	Other

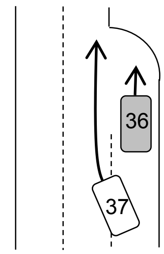
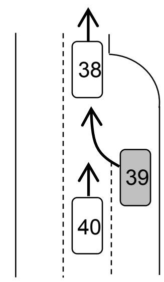
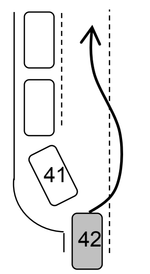
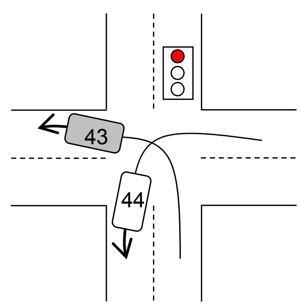
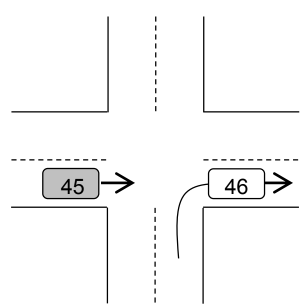
Table 21. Incident Type (Hanowski et al., 2004; Hanowski, et al., 2005; Hanowski et al., 2000; Hickman et al., in press)

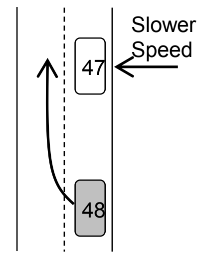
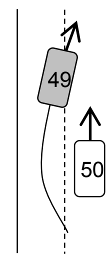
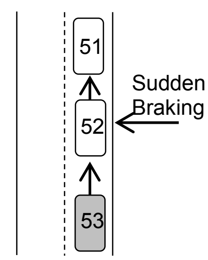
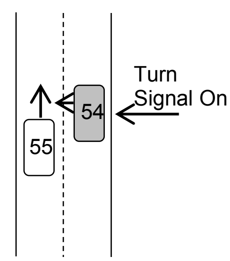
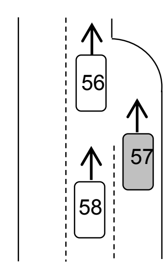
Incident Type	Description	Illustration
Aborted Lane Change	A driver tries to make a lane change into a lane where there is already a vehicle (driver doesn't see vehicle). The driver has to brake and move back into the original lane.	
Backing in Roadway	A driver backs the vehicle while on a roadway in order to maneuver around an obstacle ahead on the roadway.	 
Close Proximity to Turning Vehicle	The lead vehicle is making a right/left turn or changing lanes to the right/left, and the following vehicle comes close to the rear of the lead vehicle as they pass.	

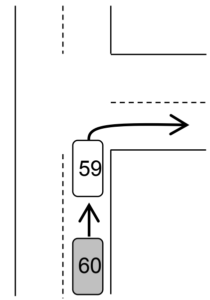
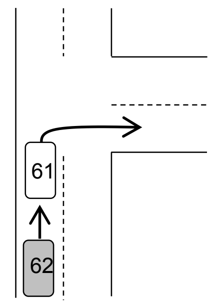
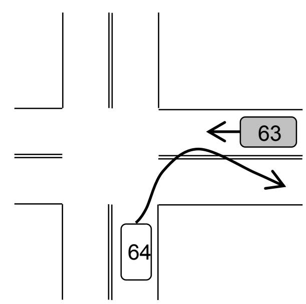
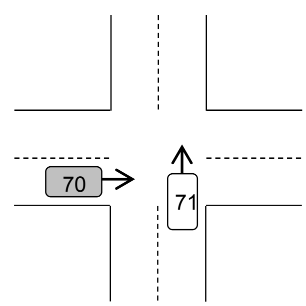
Incident Type	Description	Illustration
Conflict Between Merging and/or Exiting Traffic	Drivers entering and/or exiting a roadway, causing a conflict.	
Conflict With Animal/Pedestrian/Pedal cyclist/Object in Roadway	A vehicle approaches an animal/ pedestrian/pedal cyclist/object in the roadway (on the pavement) and either makes contact with it, or performs an evasive maneuver in order to avoid it.	
Conflict With Animal/Pedestrian/Pedal cyclist /Object on Side of Roadway	A vehicle approaches an animal/ pedestrian/pedal cyclist/object (including a guardrail) on the side of the road and either makes contact with it, or performs an evasive maneuver in order to avoid it.	
Conflict With Oncoming Traffic	A driver is approaching oncoming traffic (e.g., through an intersection, at an intersection) and has to maneuver back into the correct lane to avoid an oncoming vehicle.	
Conflict with Through Traffic	A vehicle starts to turn (right or left) at an intersection, but has to brake to avoid a conflict with traffic passing through the intersection.	

Incident Type	Description	Illustration
Exit Then Re-Entrance Onto Roadway	A driver exits a roadway then crosses a solid white line to re-enter.	
Following Too Closely	A driver does not allow adequate spacing between their vehicle and the lead vehicle (e.g., tailgating).	
Improper Lane Change	A driver makes an improper lane change with regard to another vehicle (e.g., does not use blinker, changes lanes behind another vehicle then does not let vehicle change lanes, changes lanes across multiple lanes, etc.)	
Improper Passing	A driver passes another vehicle when it is illegal or unsafe (e.g., passing across a double yellow line or without clearance from oncoming traffic).	
Improper U-turn	A driver makes a u-turn in the middle of the road (over the double yellow line) and blocks traffic in the opposite direction.	

Incident Type	Description	Illustration
Lane Change Without Sufficient Gap	A driver enters an adjacent lane without allowing adequate space between the driver's vehicle and the vehicle ahead/behind it.	
Lane Drift	A driver drifts into an adjacent lane without intention to make a lane change.	
Late Braking (and/or steering) for Stopped/ Stopping Traffic	A driver fails to slow in advance for stopped or stopping traffic and must brake and/or steer abruptly.	
Lateral Deviation of Through Vehicle	A driver has substantial lateral deviation of a through vehicle. Vehicle may or may not deviate from the lane.	
Left Turn Without Clearance	A driver turns left without adequate clearance from either oncoming through traffic or cross traffic from the left. The driver crosses another driver's path while entering an intersecting roadway.	

Incident Type	Description	Illustration
Merge Out of Turn (Before Lead Vehicle)	A driver merges onto a roadway before the lead vehicle. The lead vehicle must wait for the merged vehicle to pass before it is safe to enter the main highway.	
Merge Without Sufficient Gap	A driver merges into traffic without a sufficient gap to either the front or back of one or more vehicles.	
Obstruction in Roadway	A stationary object blocks through traffic, such as traffic that is backed up.	
Proceeding Through Red Traffic Signal	A driver fails to respond to a red traffic signal, conflicting with a vehicle proceeding through the intersection legally.	
Roadway Entrance Without Clearance	A driver turns onto a roadway without adequate clearance from through traffic.	

Incident Type	Description	Illustration
Slow Speed	A driver is traveling at a much slower speed than the rest of the traffic, causing following traffic to pass the slow vehicle to avoid a conflict.	
Slow Upon Passing	A driver moves in front of another vehicle then slows, causing the second (passed) vehicle to slow as well, or to go around the first vehicle.	
Sudden Braking in Roadway	A driver is traveling ahead of another vehicle and brakes suddenly and improperly in the roadway for traffic, a traffic light, etc., causing the following vehicle to come close to their vehicle or to also brake suddenly.	
Through Traffic Does Not Allow Lane Change	A driver is trying to make a lane change (with their turn signal on) but traffic in the adjacent lane will not allow the lane change to be completed.	
Through Traffic Does Not Allow Merge	Through traffic obstructs (either intentionally or unintentionally) a driver from entering the roadway or from performing any type of merging behavior.	

Incident Type	Description	Illustration
Turn Without Sufficient Warning	A driver slows and turns without using a turn signal or without using a turn signal in advance.	
Turn/Exit From Incorrect Lane	A driver turns onto a side road from the incorrect lane (e.g., a driver makes a right turn from the left lane instead of the right lane).	
Wide Turn Into Adjacent Lane	A vehicle partially enters an adjacent lane when turning. Traffic in the adjacent lane may be moving in the same or opposite direction.	
Vehicle Passes Through Intersection Without Clearance	A vehicle passes through an intersection (signal or non-signal) without adequate clearance from through traffic.	
Other Single Vehicle Event	A vehicle is involved in a single vehicle event. For example runs off the side of the road without a threat of hitting a fixed object.	67
Other	An unidentified incident type occurs.	98

21. Driver 1 Actions/Factors/Behaviors Relating to Event

You may code up to four factors believed to have relevance to the occurrence of the incident; (e.g., as contributing factors). If there are more than four, select the four most important.

00b = None coded
01 = Apparent excessive speed for conditions or location (regardless of speed limit; does not include tailgating, unless above speed limit)
03 = Angry
04 = Other emotional state
05 = Inattentive or distracted (mark only if related to event, not just because a potential distraction is marked)
07 = Driving slowly; below speed limit or in relation to other traffic
08 = Illegal passing (i.e., across double line)
09 = Passing on right
10 = Other improper or unsafe passing
11a = Cutting in, too close in front of other vehicle
11b = Cutting in at safe distance but then decelerated, causing conflict
12 = Cutting in, too close behind other vehicle
13 = Making turn from wrong lane (e.g., across lanes)
14 = Did not see other vehicle during lane change or merge
15 = Driving in other vehicle's blind spot
16 = Aggressive driving, specific, directed menacing actions
17 = Aggressive driving, other; i.e., reckless driving without directed menacing actions
18 = Wrong side of road, not overtaking [includes partial or full drift into oncoming lane]
19 = Following too close
19a = Inadequate evasive action
20 = Failed to signal, or improper signal
21 = Improper turn: wide right turn
22 = Improper turn: cut corner on left turn
23 = Other improper turning
24 = Improper backing, did not see
25 = Improper backing, other
26 = Improper start from parked position
27 = Disregarded officer or watchman
28 = Signal violation, apparently did not see signal
29 = Signal violation, intentionally ran red light
30 = Signal violation, tried to beat signal change
31 = Stop sign violation, apparently did not see stop sign
32 = Stop sign violation, intentionally ran stop sign at speed
33 = Stop sign violation, "rolling stop"
34 = Other sign (e.g., Yield) violation, apparently did not see sign
35 = Other sign (e.g., Yield) violation, intentionally disregarded
36 = Other sign violation
37 = Non-signed crossing violation (e.g., driveway entering roadway)

38 = Right-of-way error in relation to other vehicle or person, apparent recognition failure (e.g., did not see other vehicle)
39 = Right-of-way error in relation to other vehicle or person, apparent decision failure (i.e., did see other vehicle prior to action but misjudged gap)
40 = Right-of-way error in relation to other vehicle or person, other or unknown cause
41 = Sudden or improper stopping on roadway
42 = Parking in improper or dangerous location; e.g., shoulder of Interstate
43 = Speeding or other unsafe actions in work zone
44 = Failure to dim headlights
45 = Driving without lights or insufficient lights
46 = Avoiding pedestrian
47 = Avoiding other vehicle
48 = Avoiding animal
48a = Avoiding object
49 = Apparent unfamiliarity with roadway
50 = Apparent unfamiliarity with vehicle; e.g., displays and controls
51 = Use of cruise control contributed to late braking (does not imply malfunction of cruise control system)
52 = Excessive braking/deceleration creating potential hazard
53 = Loss of control on slippery road surface
54 = Loss of control on dry (or unknown) surface
55 = Apparent vehicle failure (e.g., brakes)
56 = Other

Note: This variable was used in Dingus et al. (2006) although some new elements have been added. Analysts code all that apply and in no order of importance.

22. Comments

Note: This text variable will permit analysts to provide any comments on the event, including information not captured by data variables, assumptions made about the event affecting coding, and coding issues that arose. Ordinarily this will not contain information that is captured by the coded variables.

Environmental Variables:

Driver/Vehicle 1 Variables

Driver/Vehicle 1 (DV1) is always the study subject driver/vehicle (i.e., the truck of truck driver).

23. Driver Safety Belt Worn?

00 = No
01 = Yes
02 = Unknown

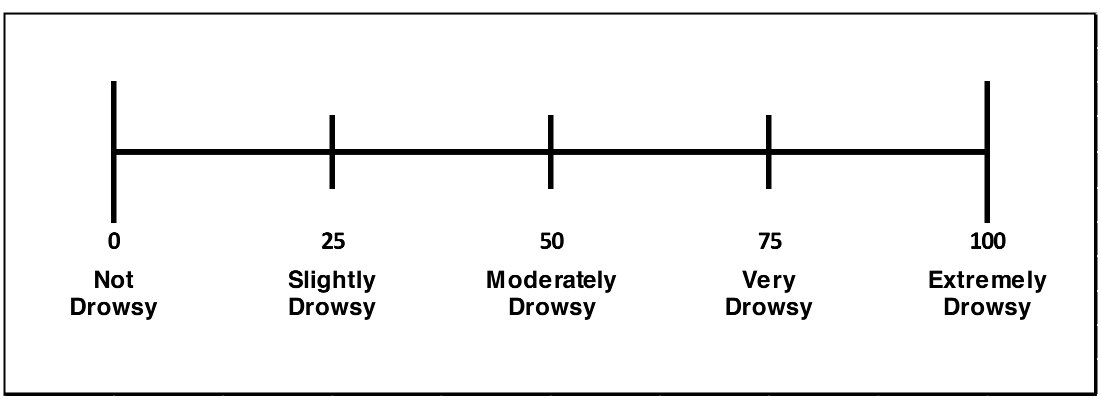
24. Possible to do Observer Rating of Drowsiness (ORD)

00 = Yes
01 = No, wearing sunglasses
02 = No, not enough video
03 = No, cannot see driver's eyes

25. ORD Classification

Rate each video segment by taking into account this description of the drowsiness continuum. However, if you feel that the below descriptions overlook something important or do not properly describe what is being viewed, then supplement the description with your own best judgment in making the rating. Review one minute of video prior to the onset of the trigger.

Please rate each video on a 0-100 continuum.



- **Not Drowsy:** A driver who is not drowsy while driving will exhibit behaviors such that the appearance of alertness will be present. For example, normal facial tone, normal fast eye blinks, and short ordinary glances may be observed. Occasional body movements and gestures may occur.
- **Slightly Drowsy:** A driver who is slightly drowsy while driving may not look as sharp or alert as a driver who is not drowsy. Glances may be a little longer and eye blinks may not be as fast. Nevertheless, the driver is still sufficiently alert to be able to drive.

- **Moderately Drowsy:** As a driver becomes moderately drowsy, various behaviors may be exhibited. These behaviors, called mannerisms, may include rubbing the face or eyes, scratching, facial contortions, and moving restlessly in the seat, among others. These actions can be thought of as countermeasures to drowsiness. They occur during the intermediate stages of drowsiness. Not all individuals exhibit mannerism during intermediate stages. Some individuals appear more subdued, they may have slower closures, their facial tone may decrease, they may have glassy-eyed appearance, and they may stare at a fixed position.
- **Very Drowsy:** As a driver becomes very drowsy eyelid closures of 2 to 3 seconds or longer usually occur. This is often accompanied by a rolling upward or sideways movement of the eyes themselves. The individual may also appear not to be focusing the eyes properly, or may exhibit a cross-eyed (lack of proper vergence) look. Facial tone will probably have decreased. Very drowsy drivers may also exhibit a lack of apparent activity and there may be large isolated (or punctuating) movements, such as providing a large correction to steering or reorienting the head from a leaning or tilted position.
- **Extremely Drowsy:** Drivers who are extremely drowsy are falling asleep and usually exhibit prolonged eye closures (4 seconds or more) and similar prolonged periods of lack of activity. There may be large punctuated movements as they transit in and out of intervals of dozing.

26. Lane Obstruction

Comment: You will mark whether there is enough of an obstruction (e.g., snow, construction cones, etc.) in the driver's lane of travel that he/she is forced to move into an adjacent or oncoming lane.

00 = Yes – forced out of lane

01 = Yes – not forced out of lane

02 = No obstruction

27. Driver 1 Vision Obscured by

00 = No obstruction
01 = Rain, snow, smoke, sand, dust
02 = Reflected glare, sunlight, headlights
03 = Curve or hill
04 = Building, billboard, or other design features (includes signs, embankment)
05 = Trees, crops, vegetation
06 = Moving vehicle (including load)
07 = Parked vehicle
08 = Splash or spray of passing vehicle [any other vehicle]
09 = Inadequate defrost or defog system
10 = Inadequate lighting system *[includes vehicle/object in dark area]*
11 = Obstruction interior to vehicle
12 = Mirrors
13 = Head restraints
14 = Broken or improperly cleaned windshield

15 = Fog
16 = Other vehicle or object in blind spot
97 = Vision obscured – no details
98 = Other obstruction
99 = Unknown whether vision was obstructed

Note: GES Variable D4. Element 16 added because of relevance to large trucks.

Environmental Variables

Environmental variables are coded at the time of the trigger.

28. Light Condition

01 = Daylight
02 = Dark
03 = Dark but lighted
04 = Dawn
05 = Dusk
09 = Unknown

Note: GES A19

29. Weather

01 = No adverse conditions
02 = Rain
03 = Sleet
04 = Snow
05 = Fog
06 = Rain & fog
07 = Sleet & fog
08 = Other (smog, smoke, sand/dust, crosswind, hail)
09 = Unknown

Comment: GES A20

30. Roadway Surface Condition

01 = Dry
02 = Wet
03 = Snow or slush
04 = Ice
05 = Sand, oil, dirt
08 = Other
09 = Unknown

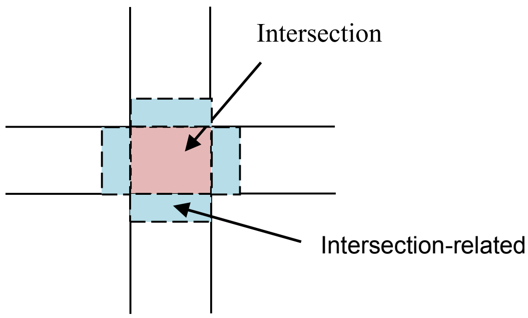
Comment: GES A15.

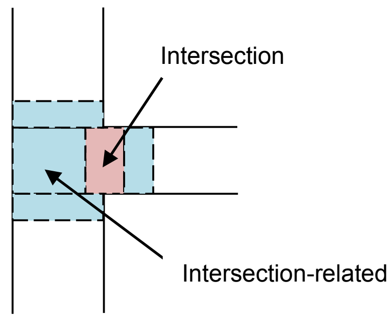
31. Relation to Junction

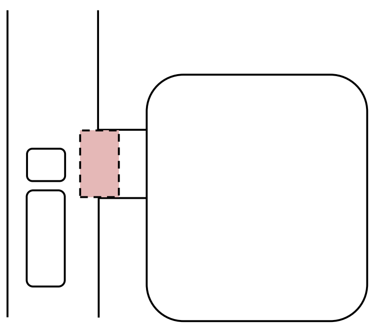
00 = Non-Junction

01 = Intersection

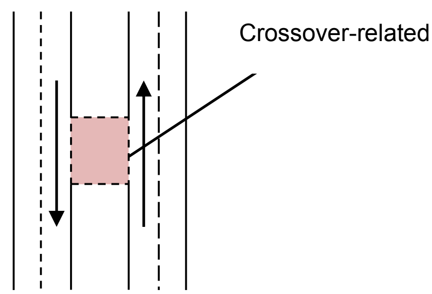
02 = Intersection-related







Note: If the truck is passing a parking lot (instead of a side street,) code as non-junction (instead of intersection-related). But if the truck is turning into the parking lot, code it as intersection.



03 = Driveway, alley access, etc. – the driver has to be completely on the driveway, alley access, etc. in order to code this variable

03a = Parking Lot – the driver has to be completely in the parking lot in order to code this variable; if the driver is turning into a parking lot, code as intersection

04 = Entrance/exit ramp

05 = Rail grade crossing

06 = On a bridge

07 = Crossover related – a crossover is a designated opening within a median used primarily for "U-turns"

08 = Other

09 = Unknown

Comment: GES variable A09

32. Traffic-way Flow

00 = Not physically divided (center 2-way left turn lane)
01 = Not physically divided (2-way trafficway)
02 = Divided (median strip or barrier)
03 = One-way trafficway
09 = Unknown

Note: GES variable V A11. Coded in relation to subject vehicle.

33. Number of Travel Lanes

01 = 1
02 = 2
03 = 3
04 = 4
05 = 5
06 = 6
07 = 7+
09 = Unknown

Note: GES V A12. Per GES, if road is divided, only lanes in travel direction are counted. If undivided, all lanes are counted. Coded in relation to subject vehicle; baseline epoch coded at time of trigger. Count all contiguous lanes at the time & location of the incident; e.g., include entrance or exit lanes if contiguous and separated from through lanes by only painted lines. Do not include lanes if blocked by cones or barrels.

34. Roadway Alignment

01 = Straight
02a = Curve right
02b = Curve left
09 = Unknown

Note: GES V A13, with expansion of curve choices. Coded in relation to subject vehicle; baseline epoch coded at time of trigger.

35. Roadway Profile

01 = Level (or unknown)
02a = Grade up
02b = Grade down
03 = Hillcrest
04 = Sag

Note: GES V A14, with expansion of grade choices. Coded in relation to subject vehicle.

36. Traffic Density

Code the traffic density for the time prior to the pre-crash event. LOS: Level-of-Service.

01 = **LOS A: Free flow** – Individual users are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high. The general level of comfort and convenience provided to the motorist, passenger, or pedestrian is excellent.

02 = **LOS B: Flow with some restrictions** – In the range of stable traffic flow, but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A, because the presence of others in the traffic stream begins to affect individual behavior.

03 = **LOS C: Stable flow, maneuverability and speed are more restricted** – In the range of stable traffic flow, but marks the beginning of the range of flow in which the operation of individual uses becomes significantly affected by the interactions with others in the traffic stream. The selection of speed is now affected by the presence of others, and maneuvering within the traffic stream requires substantial vigilance on the part of the user. The general level of comfort and convenience declines noticeably at this level.

04 = **LOS D: Unstable flow**: **temporary restrictions substantially slow driver** – Represents high-density, but stable traffic flow. Speed and freedom to maneuver are severely restricted, and the driver or pedestrian experiences a generally poor level of comfort and convenience. Small increases in traffic flow will generally cause operational problems at this level.

05 = **LOS E: Flow is unstable; vehicles are unable to pass, temporary stoppages, etc.** – Represents operating conditions at or near the capacity level. All speeds are reduced to a low, but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult, and it is generally accomplished by forcing a vehicle or pedestrian to "give way" to accommodate such maneuvers. Comfort and convenience levels are extremely poor, and driver or pedestrian frustration is generally high. Operations at this level are usually unstable, because small increases in flow or minor perturbations within the traffic stream will cause breakdowns.

06 = **LOS F: Forced traffic flow condition with low speeds and traffic volumes that are below capacity. Queues' forming in particular locations** – This condition exists whenever the amount of traffic approaching a point exceeds the amount which can traverse the point. Queues form behind such locations. Operations within the queue are characterized by stop-and-go waves, and they are extremely unstable. Vehicles may progress at reasonable speeds for several hundred feet or more, and then be required to stop in a cyclic fashion. LOS F is used to describe the operating conditions within the queue, as well as the point of the breakdown. It should be noted, however, that in many cases operating conditions of vehicles or pedestrians discharged from the queue may be quite good. Nevertheless, it is the point at which

arrival flow exceeds discharge slow which causes the queue to form, and LOS F is an appropriate designation for such points.

07 = **Unknown/unable to determine**

37. Construction Zone Related

00 = Not construction zone-related (or unknown)

01 = Construction zone (occurred in zone)

02 = Construction zone-related (occurred in approach or otherwise related to zone)

Note: Any area with one or more traffic cones, barrels, etc. is considered to be a construction zone.

38. Driver Distraction

Note: You may code up to four distractions, in any order, from the following list; you will mark whatever behaviors occur within the 6 s prior to the **event onset** and 1 s after.

INTERNAL DISTRACTION: Person or Object

01 = Talk/sing/dance with no indication of passenger – Driver appears to be vocalizing either to an unknown passenger, to self, or singing to the radio. Also, in this category are instances where the driver exhibits dancing behavior or is whistling.

02 = Interact with or look at other occupant(s) – Driver is talking to a passenger sitting in the passenger's seat or in the sleeper berth that can be identified by the person encroaching into the camera view or the driver is clearly looking at and talking to the passenger.

03 = Look at internal object – Driver removes attention from the forward roadway to look at an object inside the vehicle. This option should only be marked if the driver is not engaging in any other behavior at the same time (e.g., reaching for object, eating/drinking, etc.).

04 = Reach for object in vehicle (including cell phone, CB/other communications device) – Driver may or may not remove attention from the forward roadway to reach for an object inside the vehicle. This option should only be marked if it is unknown what the object is or if driver only reaches for object and does not perform any other behavior (e.g., if driver reaches for cell phone and then dials, then only "dial cell phone" would be marked).

05 = Look back in Sleeper Berth – Driver turns body to look behind him/her into the Sleeper Berth.

06 = Use calculator – Driver uses hand-held calculator. Assumes driver is looking at and may reach for object.

07 = Read book, newspaper, paperwork, etc. – Driver reads a book, newspaper, paperwork, etc., which is visible in the driver's hands, on the driver's lap, on the driver's steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.

08 = Look at map – Driver reads a book, newspaper, paperwork, etc., which is visible in the driver's hands, on the driver's lap, on the driver's steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.

09 = Write on pad, notebook, etc. – Driver reads a map which is visible in the driver's hands, on the driver's lap, on the driver's steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.

10 = Put on/remove/adjust seat belt – Driver puts on, removes, or adjusts his/her seat belt. Assumes driver is looking at and may reach for object.

11 = Put on/remove/adjust sunglasses or reading glasses – Driver puts on, removes, or adjusts his/her sunglasses. Assumes driver is looking at and may reach for object.

12 = Put on/remove/adjust hat – Driver puts on, removes, or adjusts his/her hat. Assumes driver is looking at and may reach for object.

13 = Put on/remove/adjust clothing – Driver puts on or takes off an article of clothing (including gloves). This may also include unbuttoning/buttoning or unzipping/zipping a shirt, adjusting a collar, etc. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Electronic Devices

14 = Dial cell phone – Driver dials a cell phone. This may also include answering the phone or hanging up the phone, if the driver presses a key during this time. Assumes driver is looking at and may reach for object.

15 = Talk or listen to hand-held phone – Driver holds a hand-held phone to ear, appears to be talking and/or listening (if driver dials cell phone and then talks on cell phone, both options are marked).

16 = Talk or listen to hands-free phone – Driver talks or listens to a hands-free phone. This is apparent by an earpiece in the driver's ear.

17 = Adjust earpiece/headset – Driver adjusts, or puts on/takes off, an earpiece/headset that is being used to talk on a hands-free phone. Assumes driver is looking at and may reach for object.

18 = Text message on cell phone – Driver appears to be text messaging on a cell phone. Driver is focusing on the cell phone for an extended amount of time while continuously pressing keys. Assumes driver is looking at and may reach for object.

19 = Talk or listen to CB microphone – Driver talks or listens to a CB microphone. Assumes driver is looking at and may reach for object.

20 = Interact with dispatching device – Driver interacts with or looks at a dispatching device. The driver usually keeps the device on the passenger seat or on the floor between the two seats and holds the device on his/her lap or steering wheel while in use. Assumes driver is looking at and may reach for object.

21 = Interact with GPS – Driver interacts with an after-market GPS device that is mounted on the instrument panel or dash (does NOT include an in-dash satellite radio). This may involve the driver hooking up the system or pressing buttons. Assumes driver is looking at and may reach for object.

22 = Interact with Satellite radio – Driver interacts with an after-market Satellite radio device that is mounted on the instrument panel or dash (does NOT include an in-

dash satellite radio). This may involve the driver hooking up the system or pressing buttons. Assumes driver is looking at and may reach for object.

23 = Use camera – Driver uses a camera (may be a cell phone camera) to take a picture from inside the cab. Assumes driver is looking at and may reach for object.

24 = Use/reach for other device – Driver reaches for or uses an alternate electronic device; does not include any of the devices listed above such as cell phone, camera, etc. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Dining

25 = Eating – Driver eats with, or without, a utensil (i.e., fork or spoon). This also includes the driver opening a food bag or anything closely related to eating just prior to or after the trigger. Assumes driver is looking at and may reach for object.

26 = Drink from a container – Driver drinks from a container, either covered or uncovered. This also includes the driver opening/closing a drink container or anything closely related to drinking just prior to or after the trigger. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Smoking-Related

27 = Smoking-related behavior – reaching, lighting, extinguishing – Driver is reaching (ashing), lighting, or extinguishing a cigarette. May include behaviors such as driver reaching for a lighter or reaching for a pack of cigarettes. Assumes driver is looking at and may reach for object.

28 = Smoking-related behavior – cigarette in hand or mouth – Driver has a cigarette in hand or mouth.

29 = Use chewing tobacco – Driver is using chewing tobacco. This may include putting tobacco into mouth or spitting into container. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Grooming

30 = Personal grooming – Driver is grooming him/herself. This may include combing/fixing hair, applying make-up, shaving, and brushing teeth. Assumes driver is looking at and may reach for object.

31 = Bite nails/cuticles – Driver is biting nails and/or cuticles. Assumes driver is looking at hands.

32 = Remove/adjust jewelry – Driver is removing or adjusting jewelry. This may include, watch, bracelet, necklace or earrings. Assumes driver is looking at and may reach for object.

33 = Other personal hygiene – Driver is conducting some kind of other personal hygiene. This may include rubbing eyes/face, scratching face/neck, or picking nose.

34 = Adjust in seat – Driver adjusts his/her position in the driver's seat.

INTERNAL DISTRACTION: Vehicle-Related

35 = Adjust instrument panel – Driver is adjusting something on the instrument panel. This may include, radio, climate controls, head lights, and other switches to the

front and right of the driver. Assumes driver is reaching for and/or looking at the instrument panel while adjusting.

36 = Pull air horn – Driver reaches up and pulls the air horn on the truck. The air horn is usually located in the upper left corner of the cab. Assumes driver is looking at and may reach for object.

37 = Turn on/off cab light – Driver turns on/off overhead cab light. Assumes driver is looking at and may reach for object.

38 = Clean cab interior – Driver uses some kind of cleaning material(s) to clean/dust the instrument panel, dash, interior windows, etc. Assumes driver is looking at and may reach for object.

39 = Put up/down window – Driver either manually rolls up/down the window or uses a button on the door.

EXTERNAL DISTRACTIONS

40 = Look at outside vehicle, person, animal, object – Driver looks outside the vehicle to another vehicle, person, animal, object or undetermined. May be out the front windshield or side window. Must be apparent that driver is focused on outside vehicle, person, animal, object.

41 = Look out rear window (day cab only with visible rear window) – Driver turns around and looks out the rear window on the cab. Must be apparent that driver is looking out window.

42 = Wave to passing vehicle/driver – Driver looks at and waves to a passing vehicle, either overtaking (same direction) or passing in the opposite direction.

DRIVING-RELATED INATTENTION TO FORWARD ROADWAY

43 = Look at left-side mirror – Driver looks at the left-side mirror (west coast/convex mirror or fender mirror).

44 = Look at right-side mirror – Driver looks at the right-side mirror (west coast/convex mirror or fender mirror).

45 = Check speedometer – Driver glances directly down to the speedometer. Must be apparent that the driver is looking at the speedometer and not in lap.

OTHER

49 = Other – Other potentially distracting behavior.

Note: Adapted from Olson, Hanowski, Hickman, and Bocanegra (2009) and Blanco et al (in press).

39. Comments

Note: This text variable will permit analysts to provide any comments on the event, including information not captured by data variables, assumptions made about the event affecting coding, and coding issues that arose. Ordinarily this will not contain information that is captured by the coded variables.

APPENDIX H – ACTIGRAPH DATA PREP PROTOCOL

1. Copy last downloaded actigraph file from each participant individual folder and paste it in the analysis folder.
2. Modify each actigraph file name to add "**20min Bad**", where **20** is the established minimum number of consecutive minutes to classify as Bad data.
3. Open the actigraph file with Action-W software (Open the software first and open the file from there).
4. Select ZCM from the Available Channels and press Activity. Click OK.
5. Open graph to full screen.
6. Save file as an Epoch-by-Epoch file on the same location and adding **EBE** to the file name:

   File > Save As > Save as type: Epoch By Epoch File > Save
7. Open the Epoch-by-Epoch file. Click OK when a warning pop-up appears.
8. Copy the condition formula to identify the 20 minute Bad data episodes from an already worked EBE file.
9. Use the identified Bad episodes in the EBE file to identify them in the Action-W file.
10. Score sleep on actigraph file:

    Analyze > Score Sleep
11. Get calculated statistics by clicking on the Statistics icon of the tool menu.
12. Copy the 24-Hr statistics table into the corresponding participant worksheet in the Sleep Data.
13. Color the corresponding tab light green.
14. Sum total actigraph time per participant and convert to hours.
15. Convert mean sleep time per day per participant to hours.

APPENDIX I – ADDITIONAL NATURALISTIC DRIVING RESULTS

Table 22. SCE Pre-Crash Event by Severity

Pre-Crash Event	Crash (%)	Crash: Low-hanging Branch (%)	Curb Strike: Avoidable (%)	Near-crash (%)	Crash-relevant Conflict (%)	Total (%)
Animal approaching roadway	0	0	0	0	1.1	**1.1**
Object in/over roadway	1.1	16.3	0	1.1	2.2	**20.7**
Object – unknown location	1.1	0	0	0	0	**1.1**
Loss of control due to poor road conditions	0	0	0	2.2	4.3	**6.5**
Subject vehicle traveling toward or off edge or road on left side	0	0	2.2	1.1	7.6	**10.9**
Subject vehicle traveling toward or off edge of road on right side	1.1	1.1	1.1	16.3	27.2	**46.7**
Subject vehicle traveling toward to over lane line on left side of travel lane	0	0	0	0	7.6	**7.6**
Subject vehicle traveling toward to over lane line on right side of travel lane	0	0	0	0	2.2	**2.2**
Subject vehicle crossing over (passing through) intersection	0	0	0	0	1.1	**0**
Subject vehicle turning right at intersection	0	0	0	1.1	0	**1.1**
Other vehicle in subject vehicle's lane – traveling in same direction with lower steady speed	0	0	0	1.1	0	**1.1**
Total	**3.3**	**17.4**	**3.3**	**22.8**	**53.3**	**100**

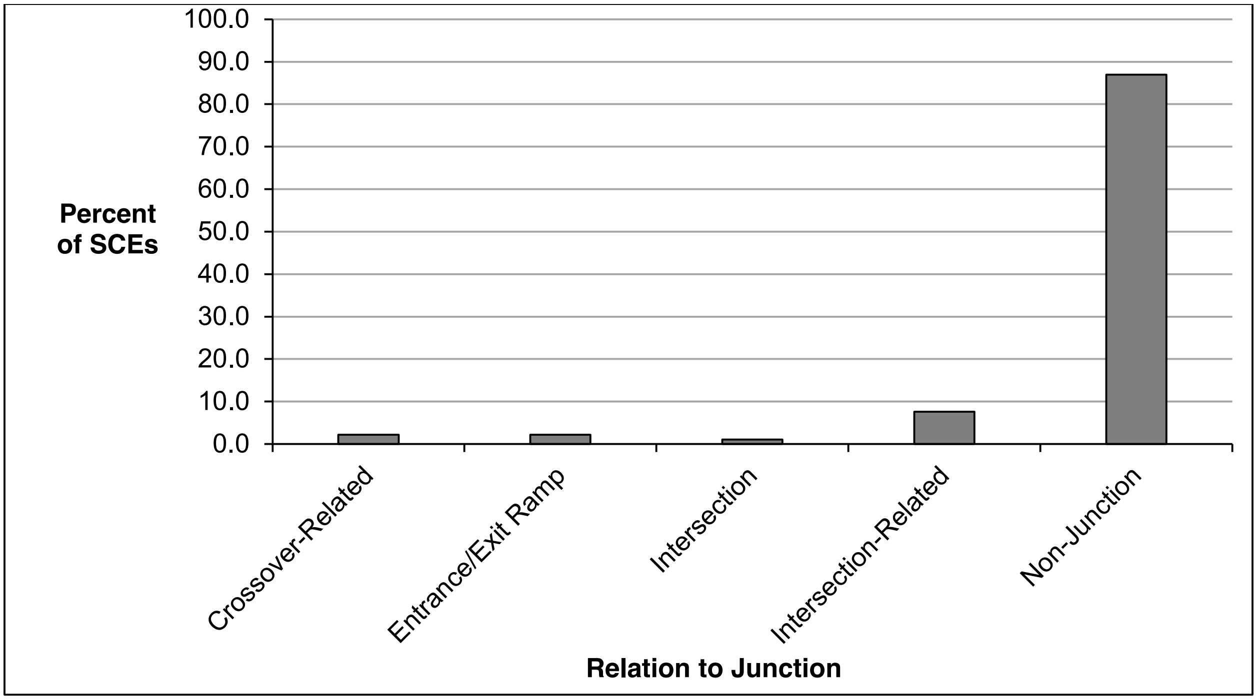


Figure 56. SCEs by Relation to Junction

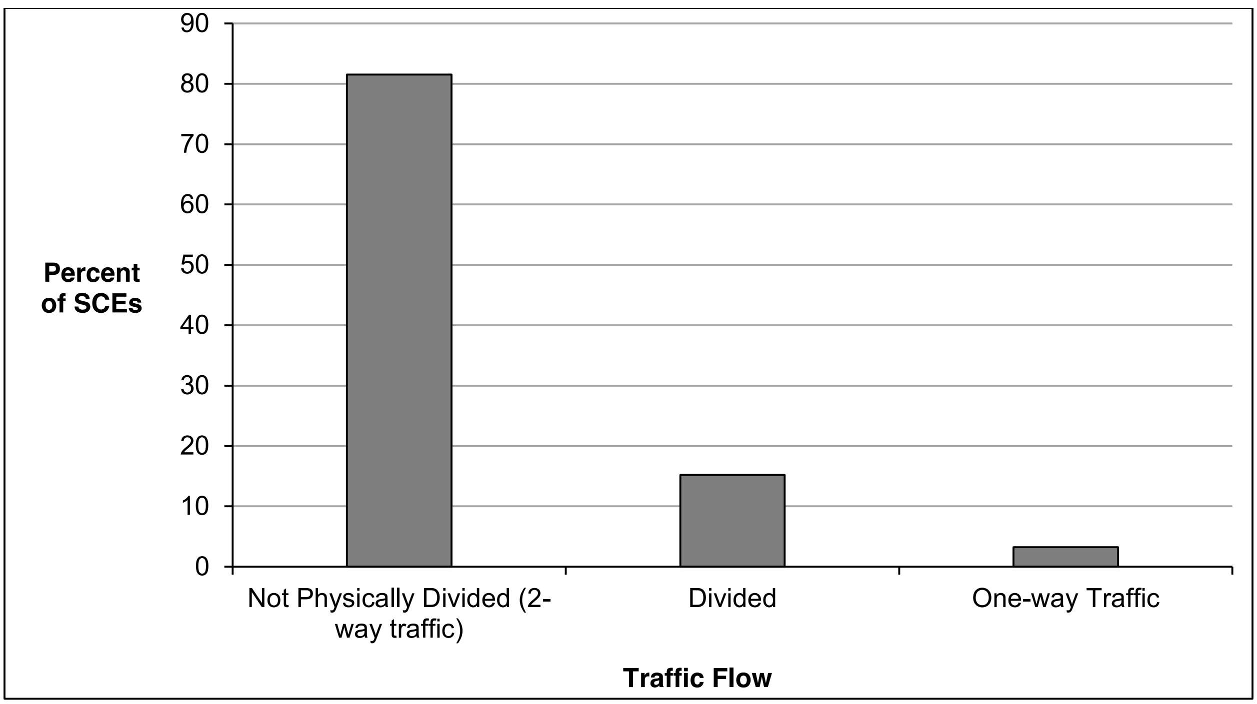


Figure 57. SCEs by Traffic Flow

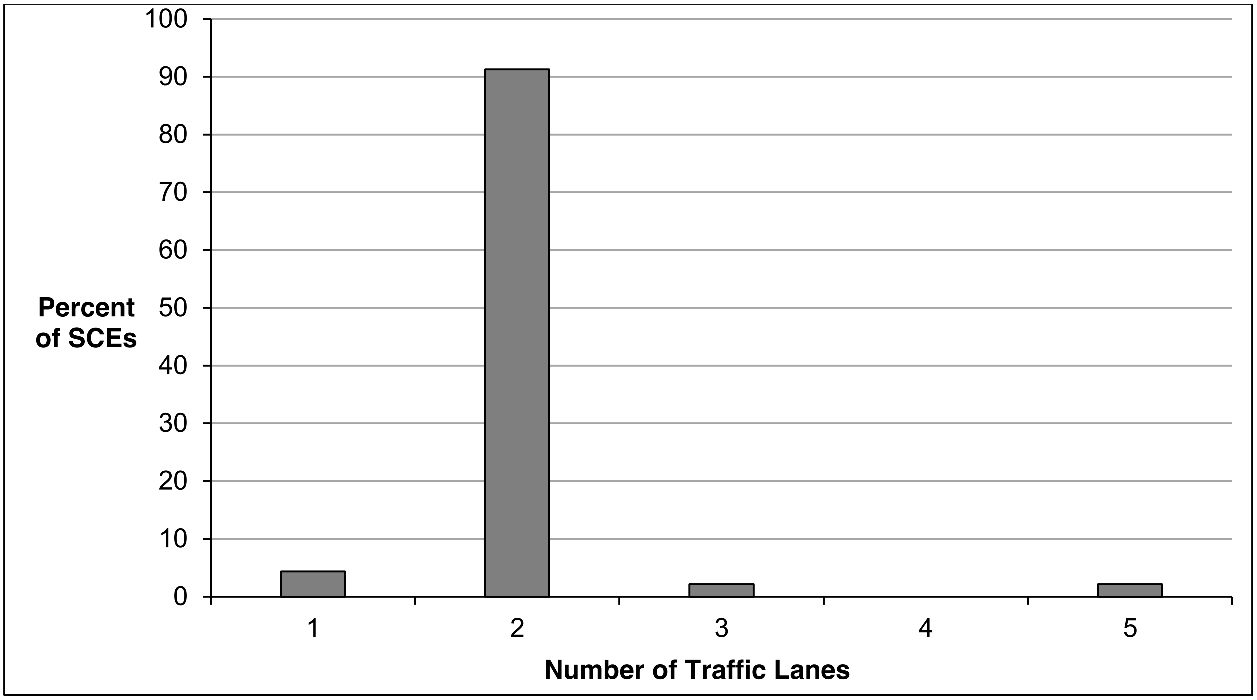


Figure 58. SCEs by Number of Traffic Lanes

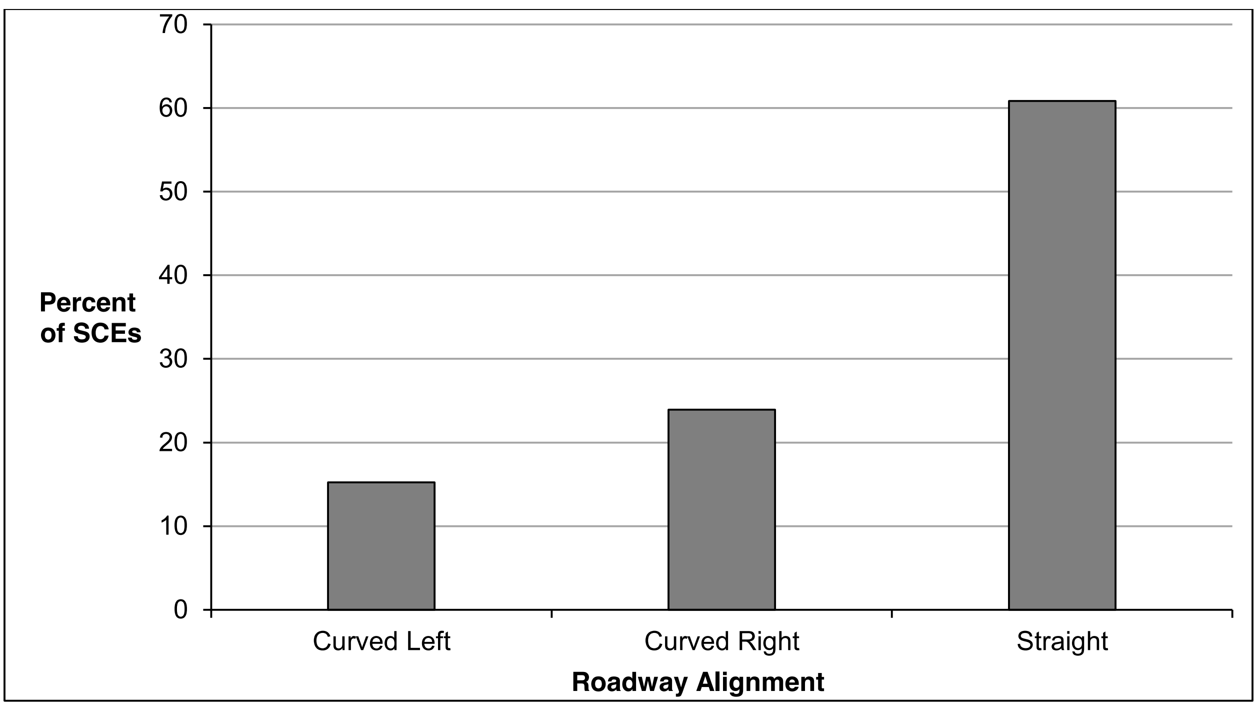


Figure 59. SCEs by Roadway Alignment

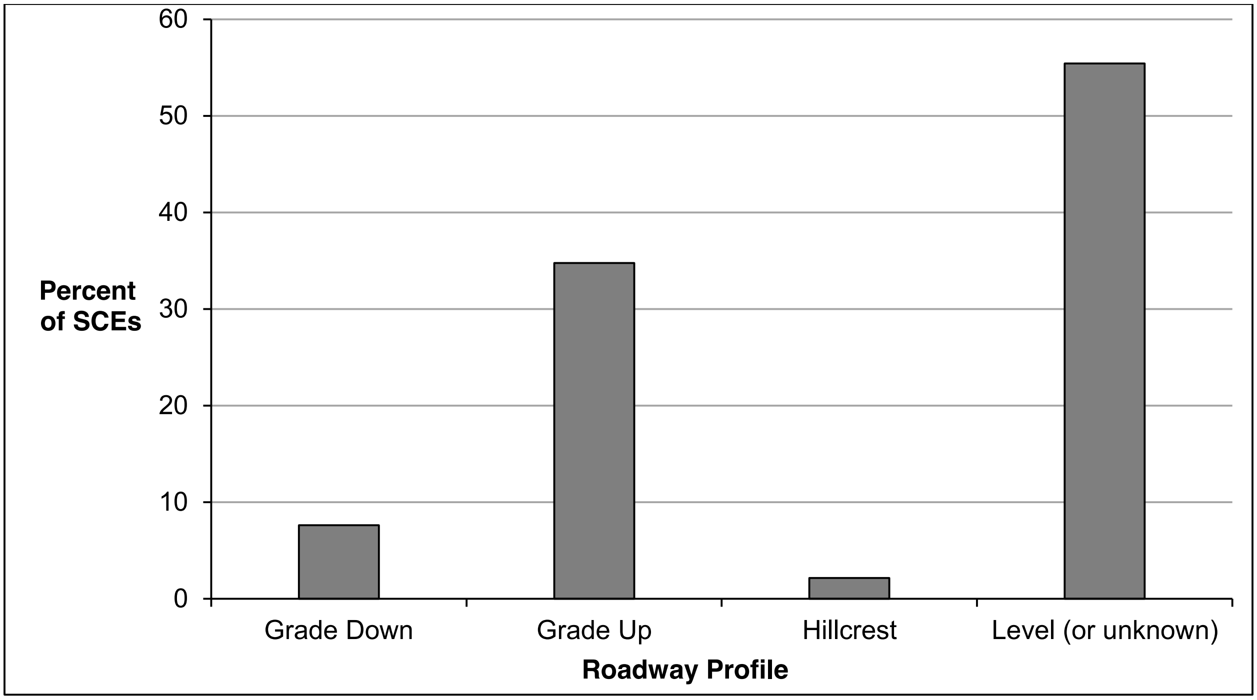


Figure 60. SCEs by Roadway Profile

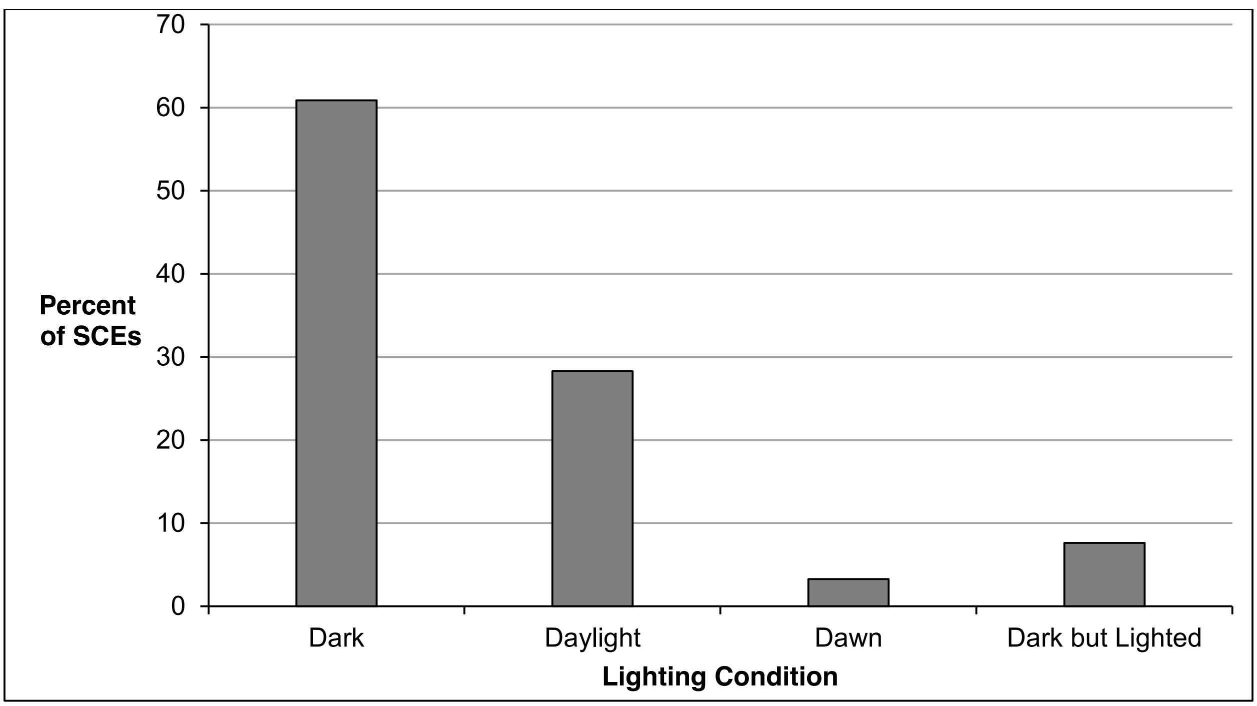


Figure 61. SCEs by Lighting Condition

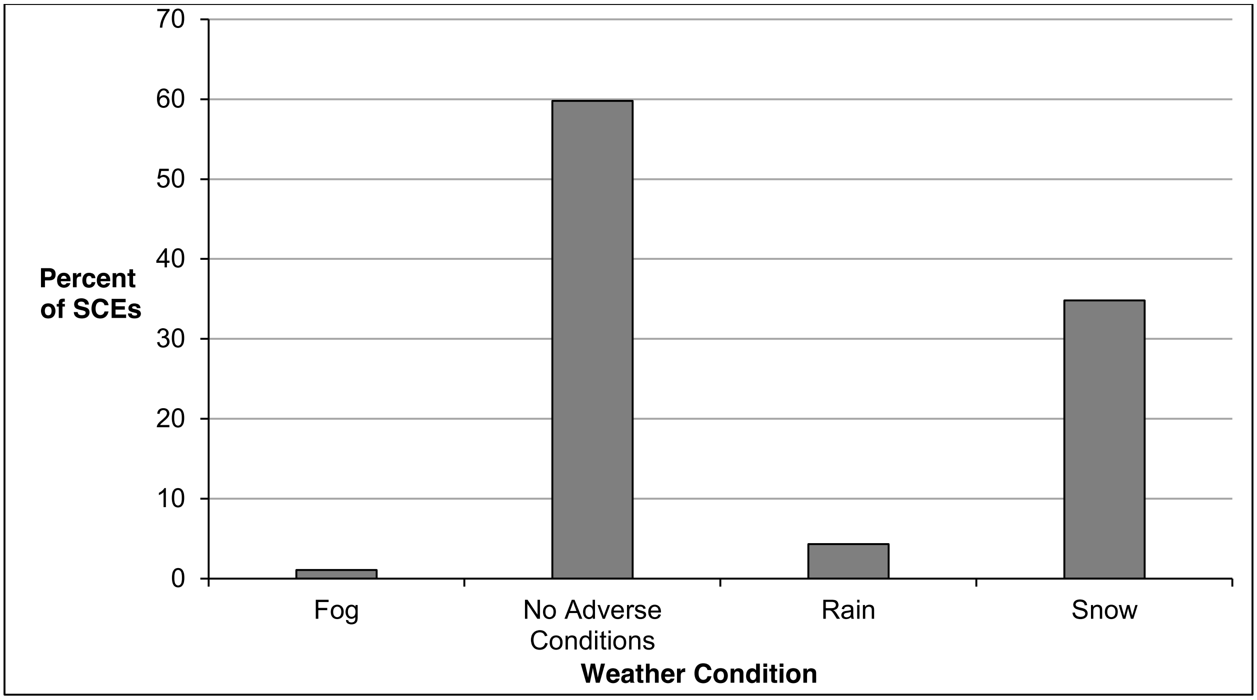


Figure 62. SCEs by Weather Condition

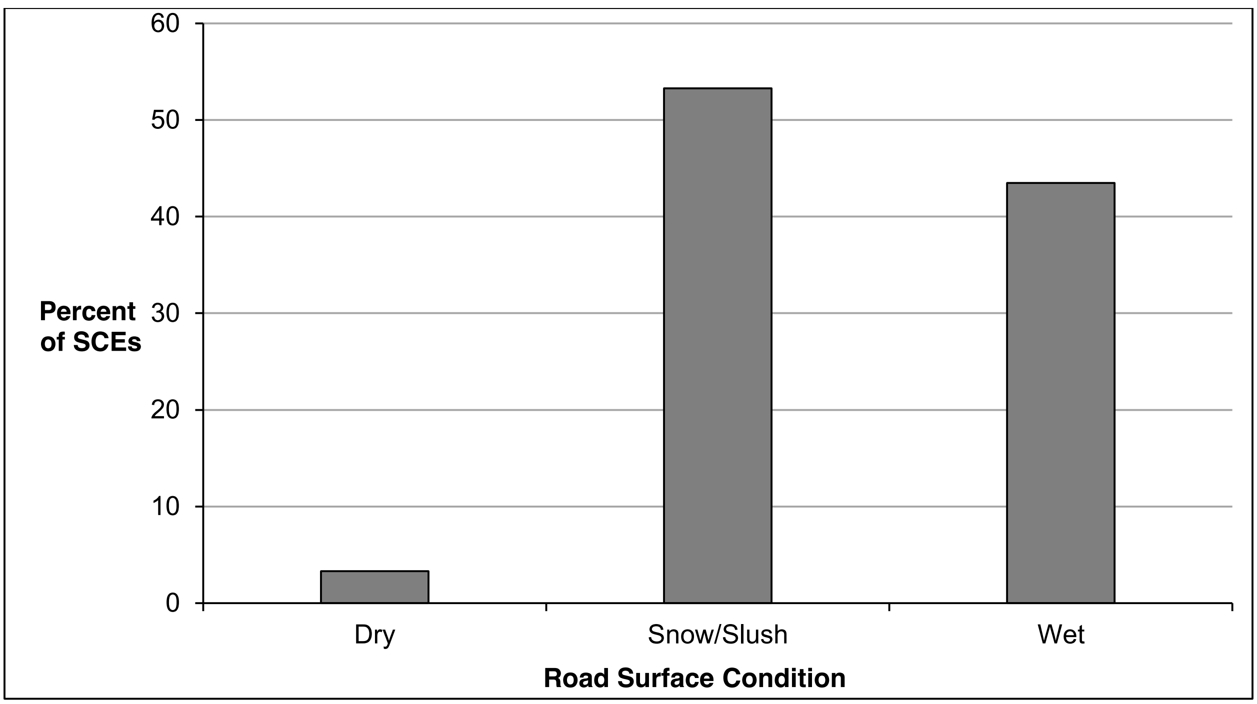


Figure 63. SCEs by Road Surface Condition

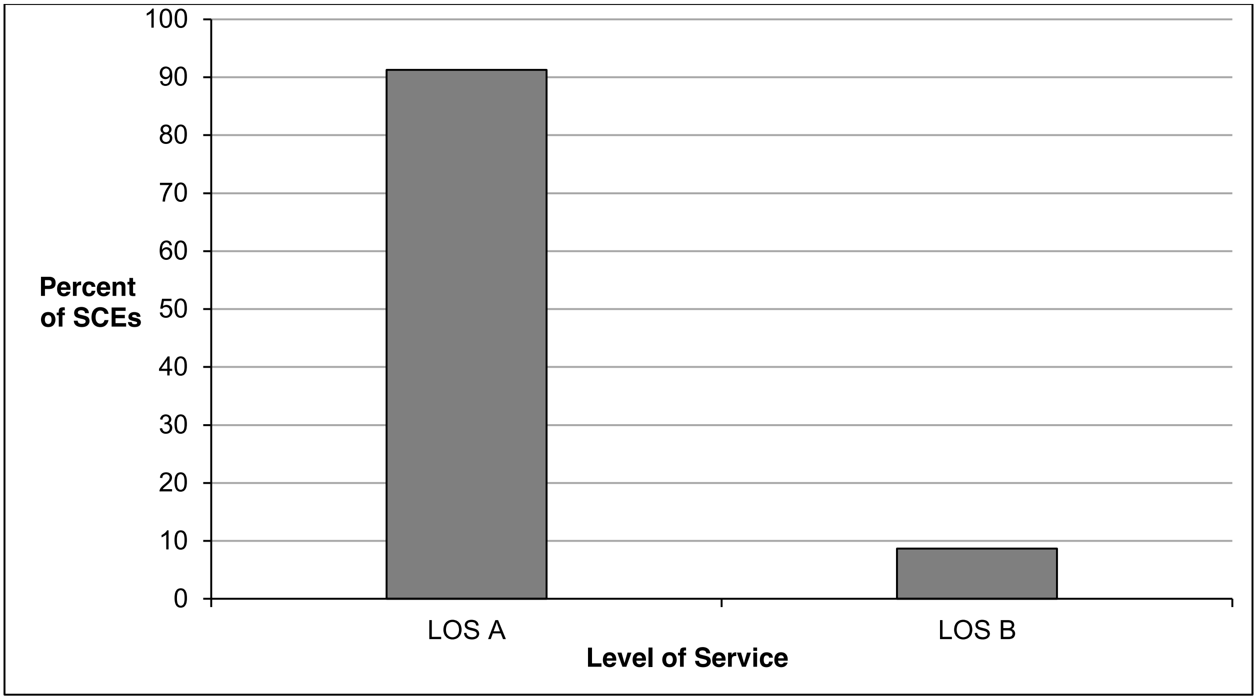


Figure 64. SCEs by Level of Service

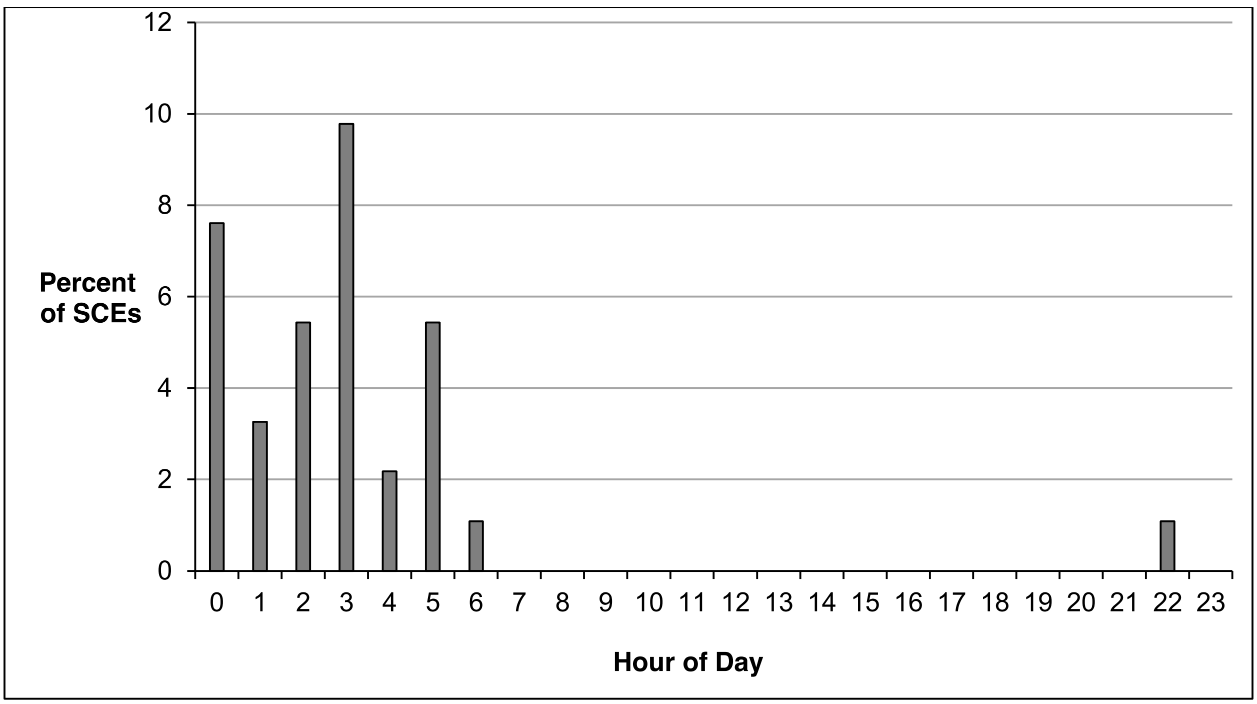


Figure 65. Drowsy Driving SCEs by Hour of Day

APPENDIX J – WINTER MAINTENANCE OPERATOR QUESTIONNAIRE RESULTS

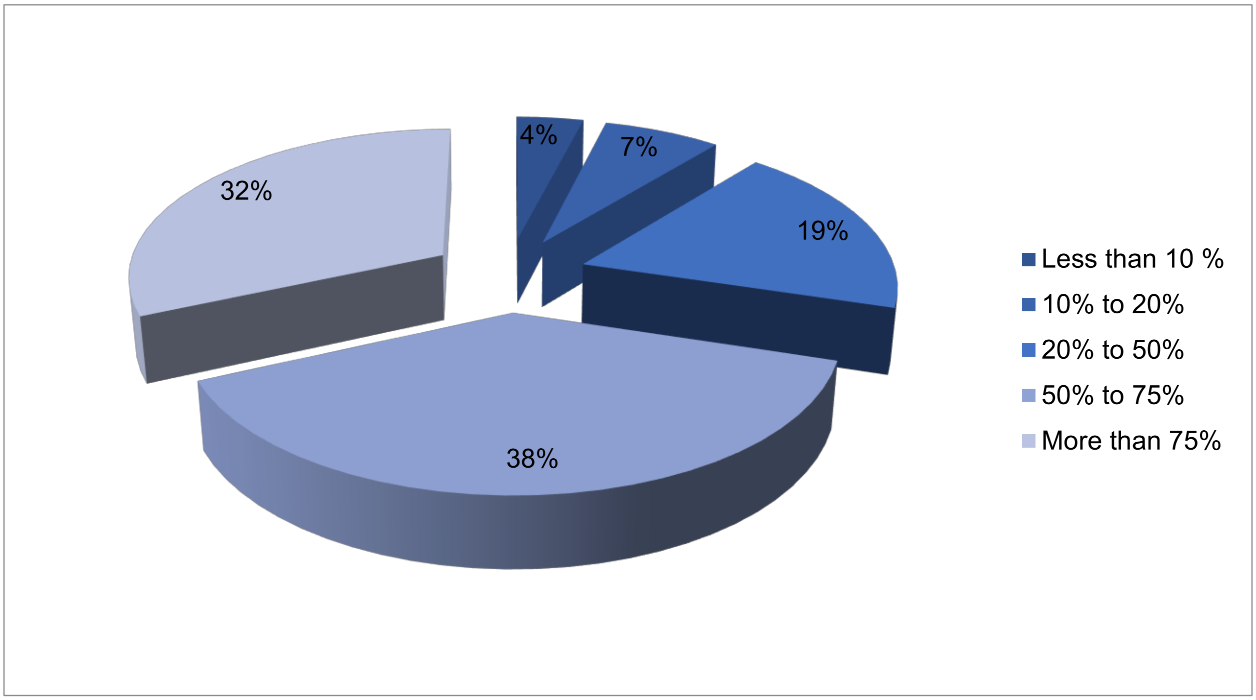


Figure 66. Time Dedicated to Snow Plow Operations during the Winter Season

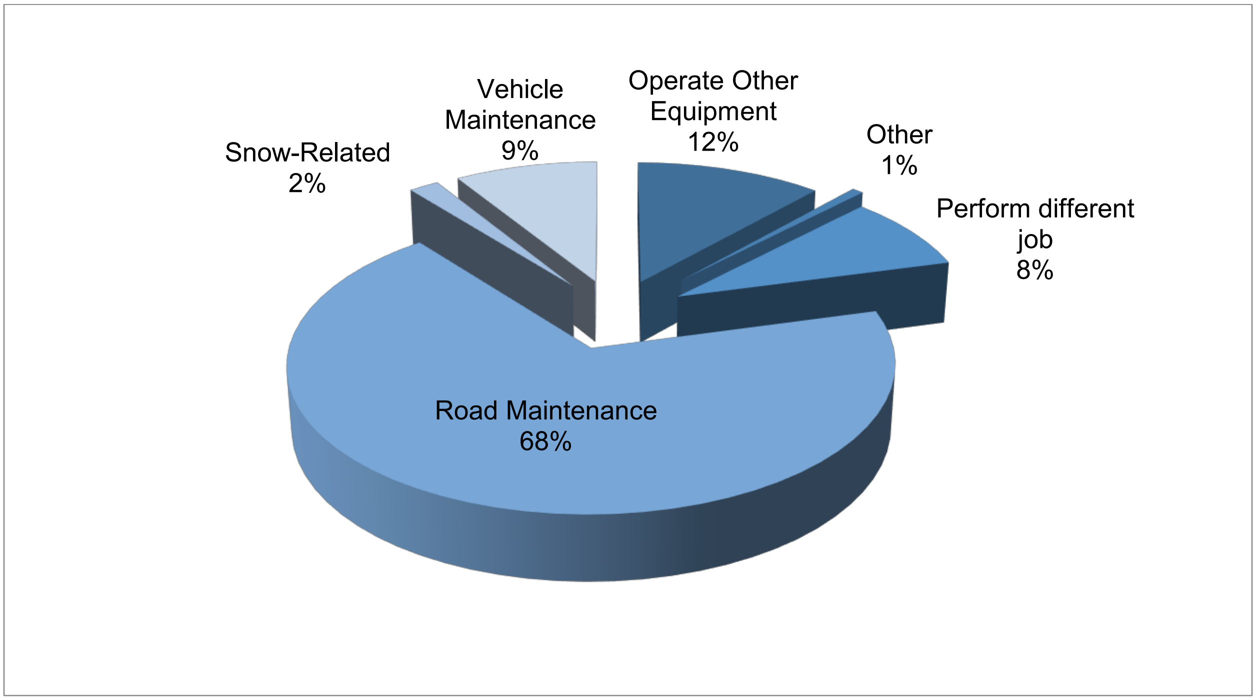


Figure 67. Activities Performed by Winter Maintenance Operators when not involved in Snow Plow Operations

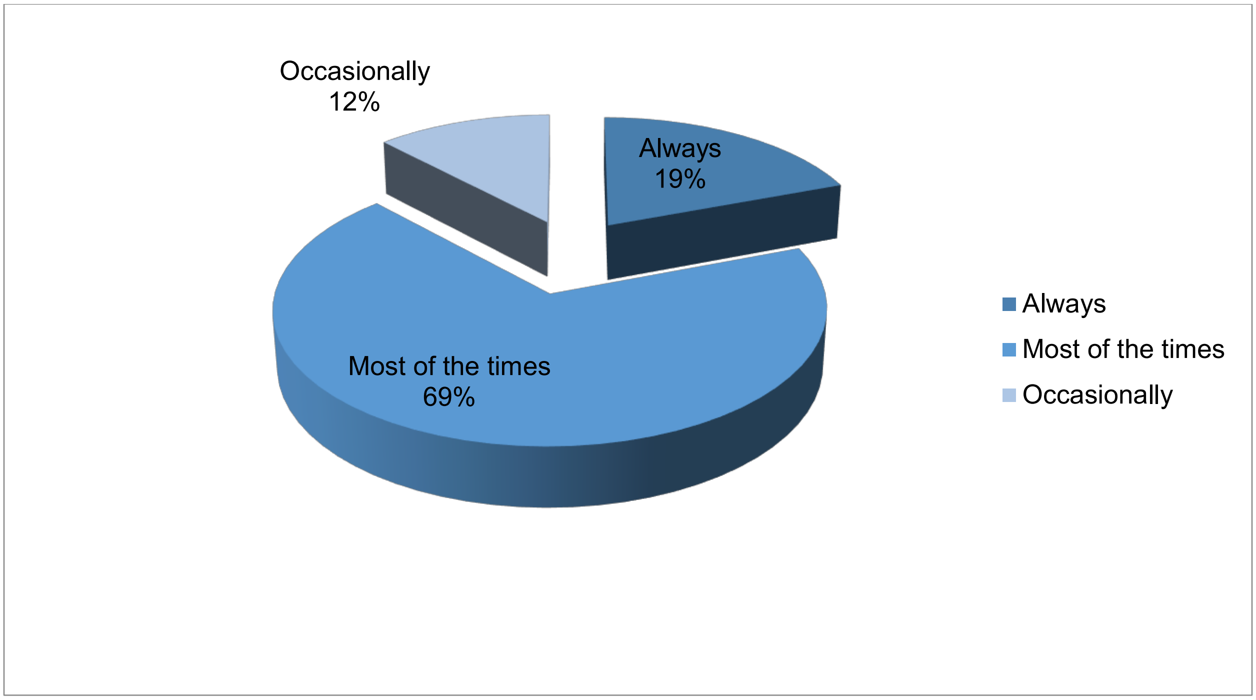


Figure 68. Frequency with which Winter Maintenance Operators Drive the Same Truck

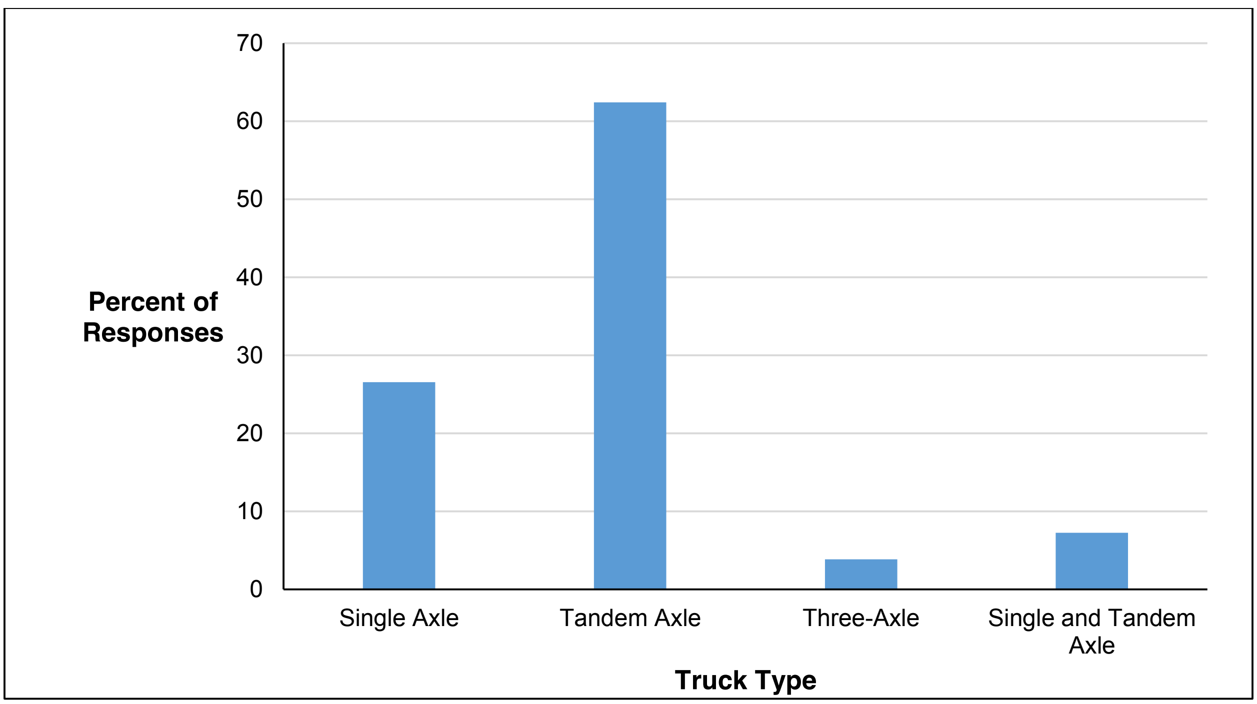


Figure 69. Type of Snow Plow Operated

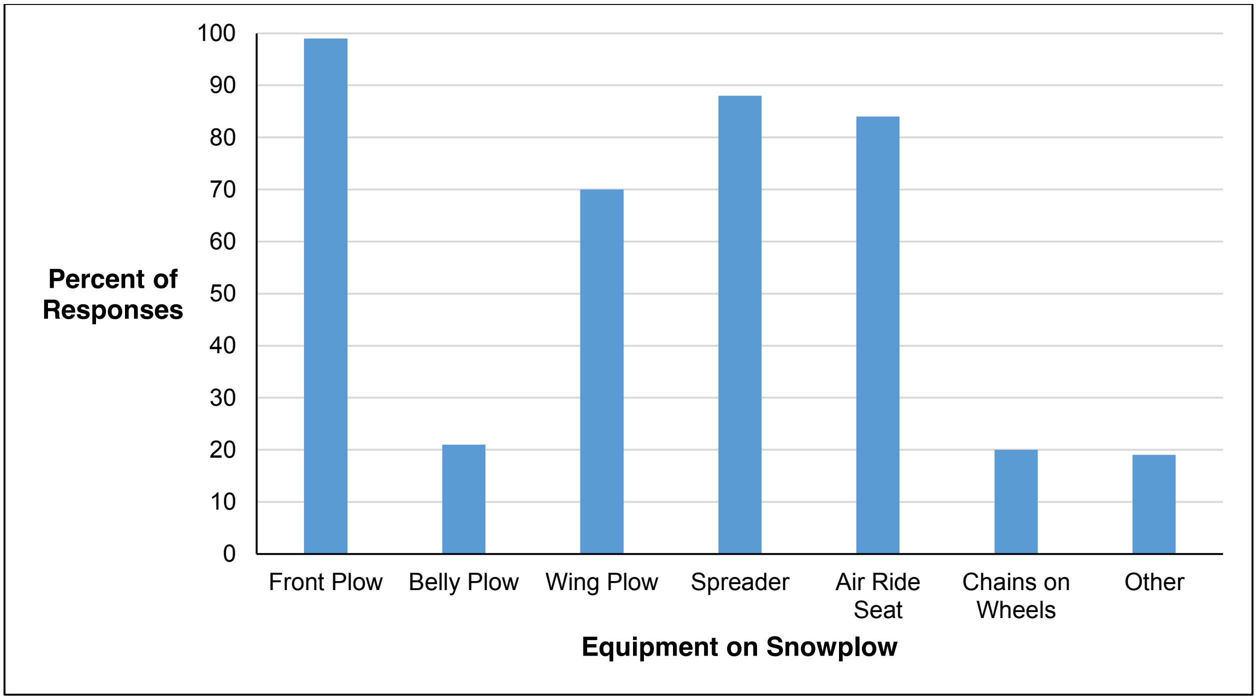


Figure 70. Type of Equipment on Snow Plow

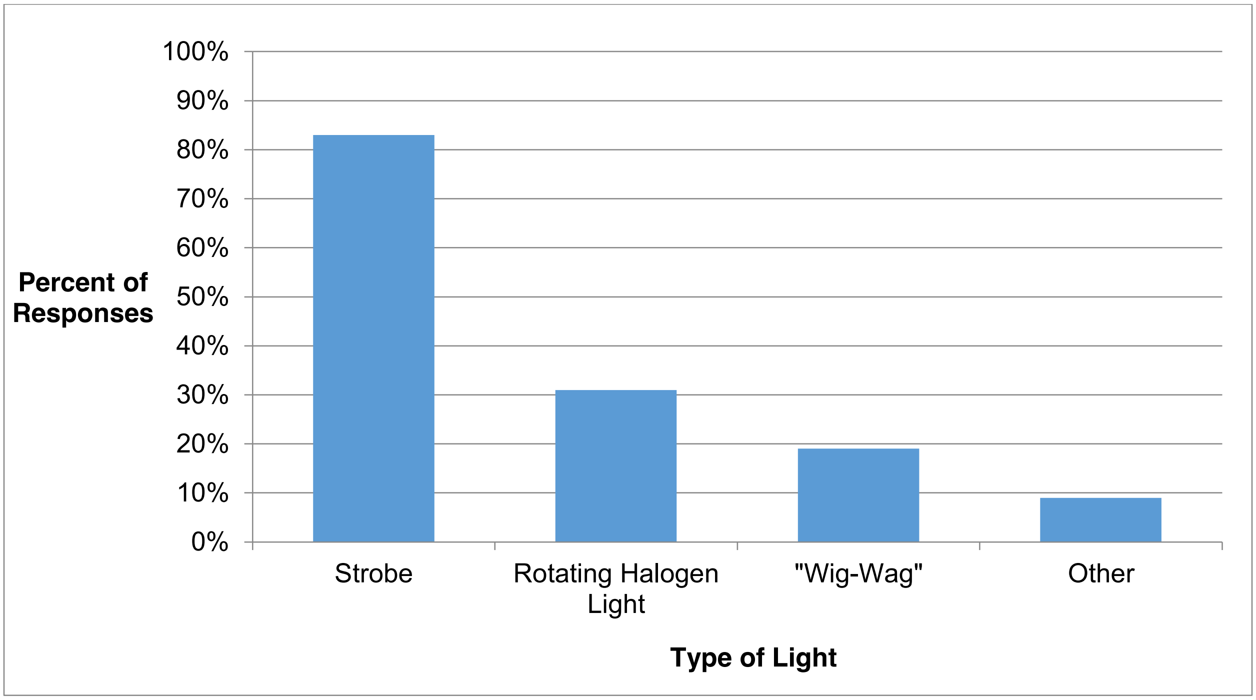


Figure 71. Type of Warning Light

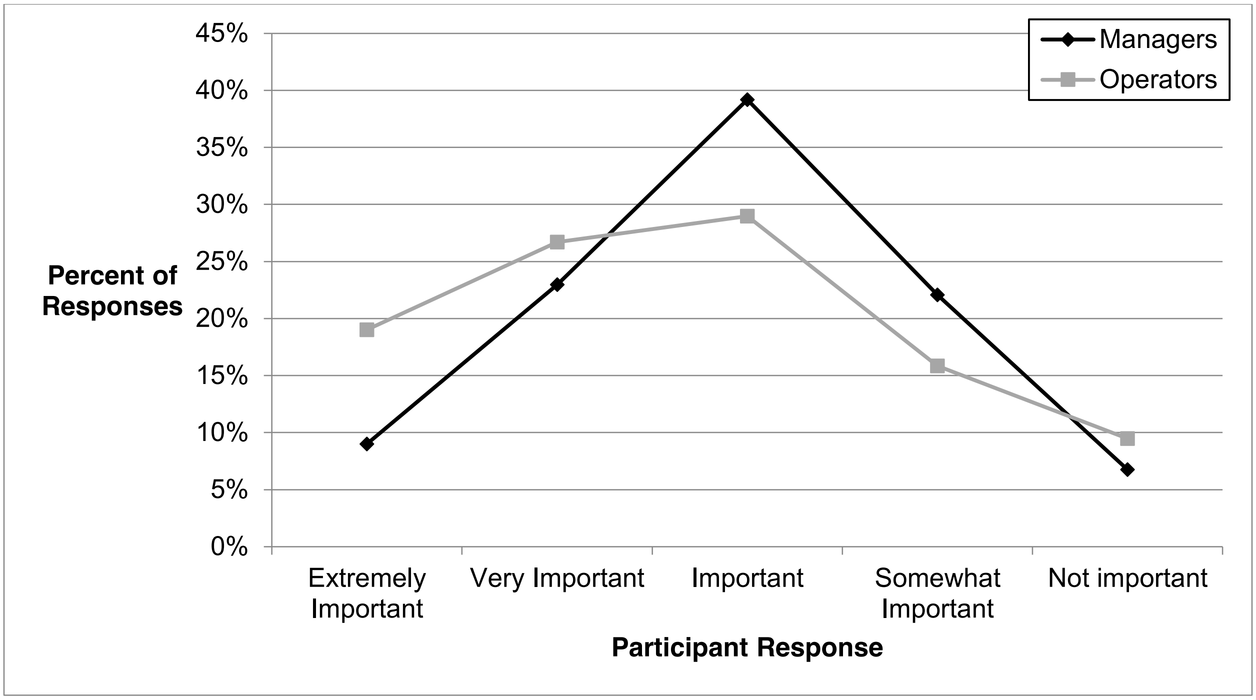


Figure 72. Importance of Vibration as a Source of Fatigue during Winter Emergencies

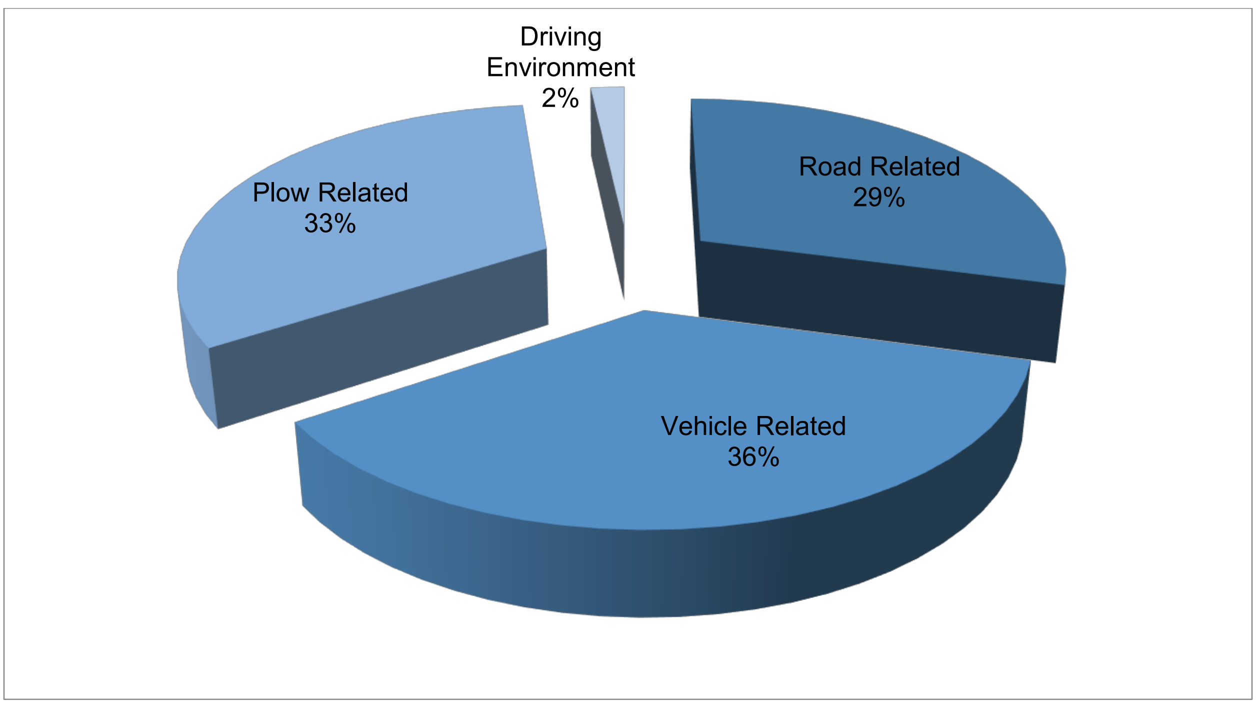


Figure 73. Major Sources of Vibration while Operating a Snow Plow during Winter Emergencies

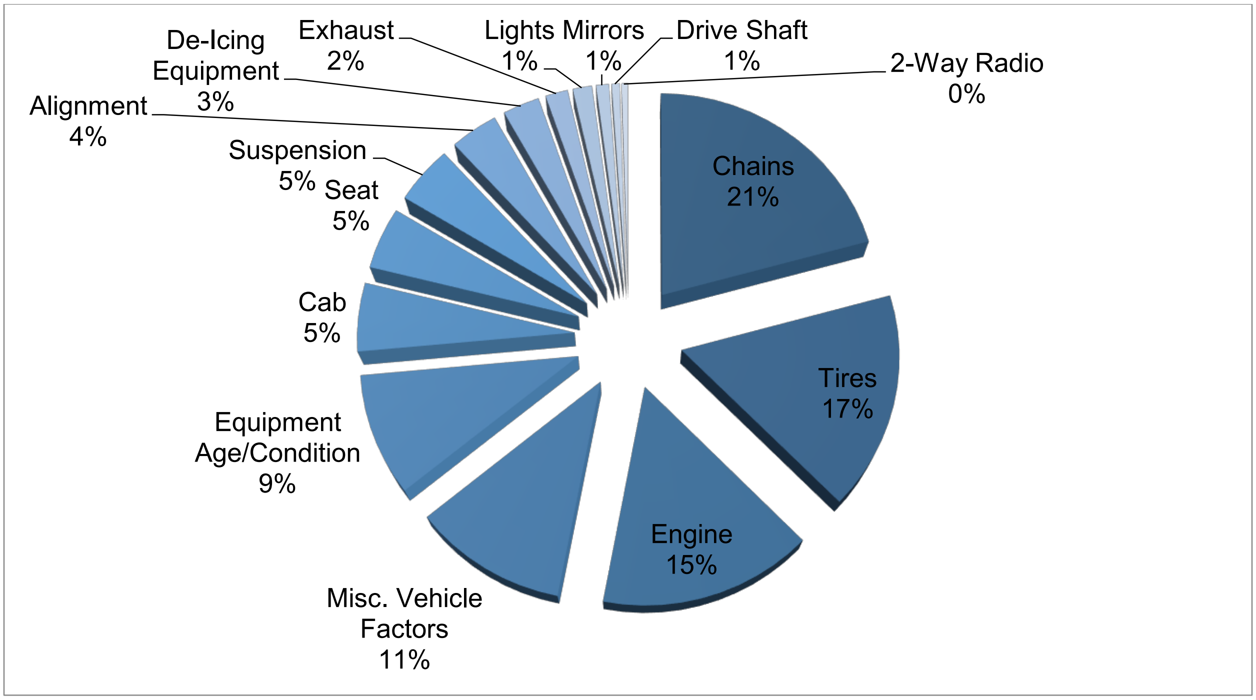


Figure 74. Major Sources of Vibration Related to the Vehicle

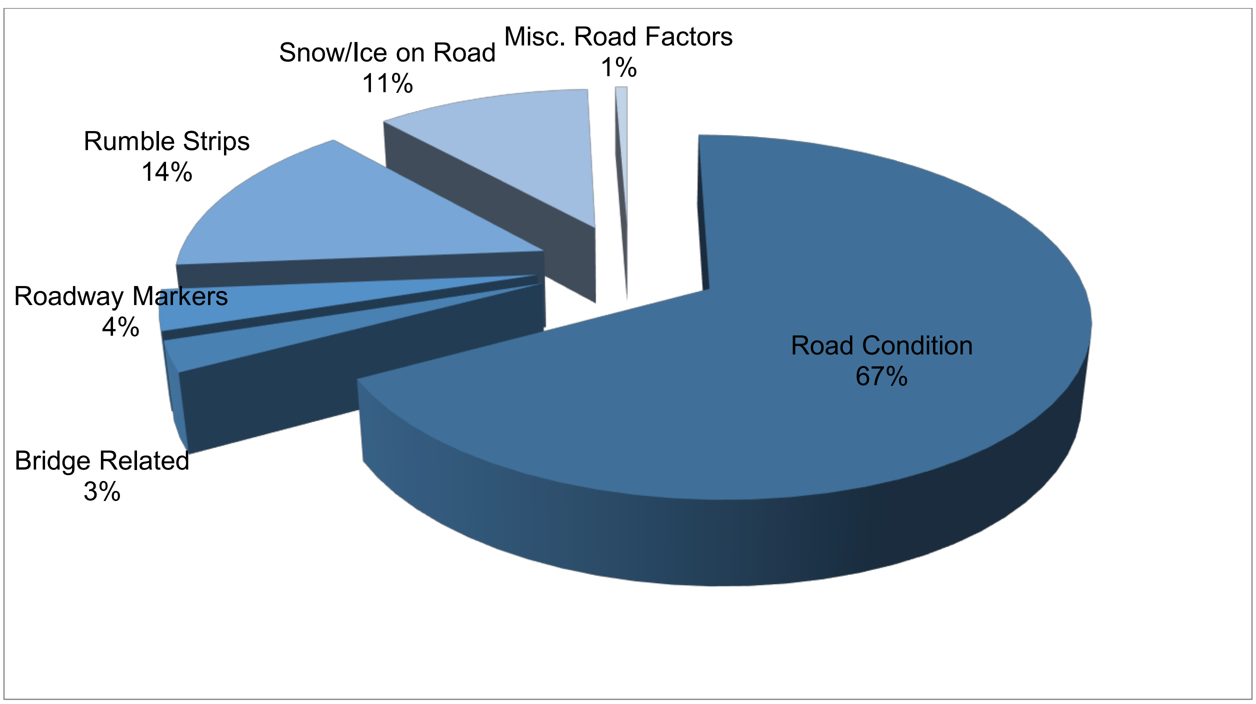


Figure 75. Major Sources of Vibration Related to the Roadway

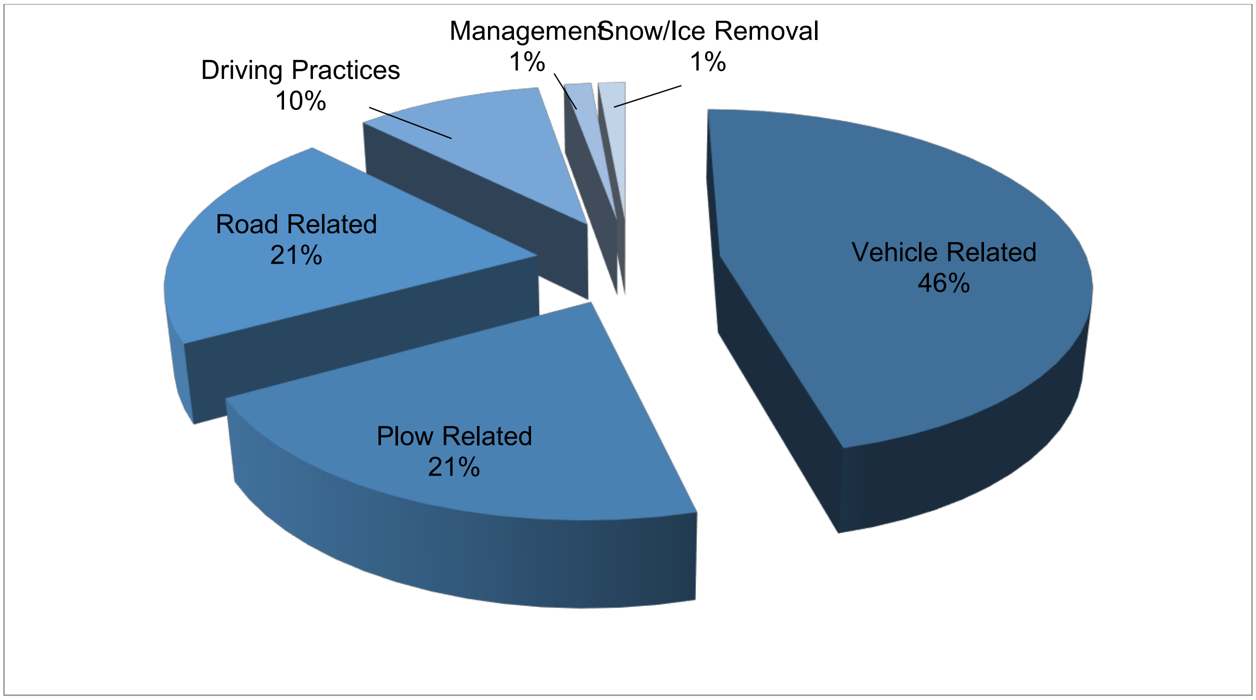


Figure 76. Best Way to Reduce/Eliminate Vibration, by Themes

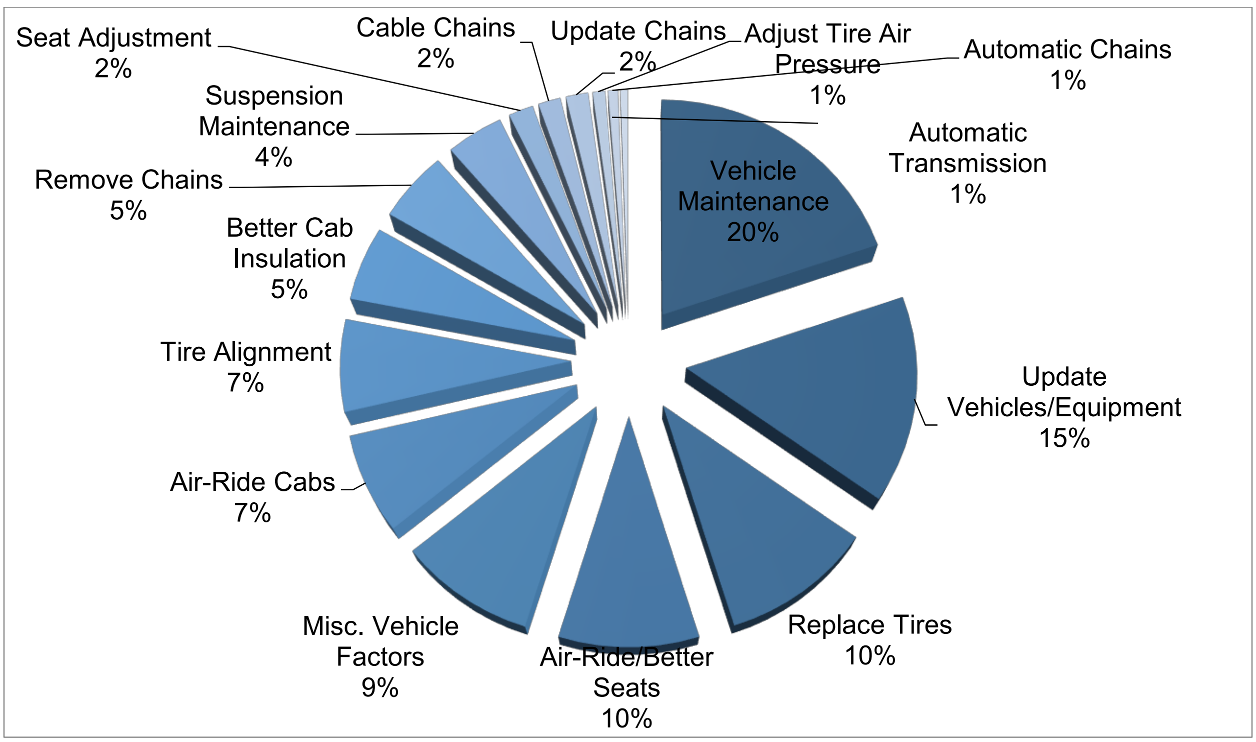


Figure 77. Best Vehicle-related Ways to Reduce/Eliminate Vibration Sources

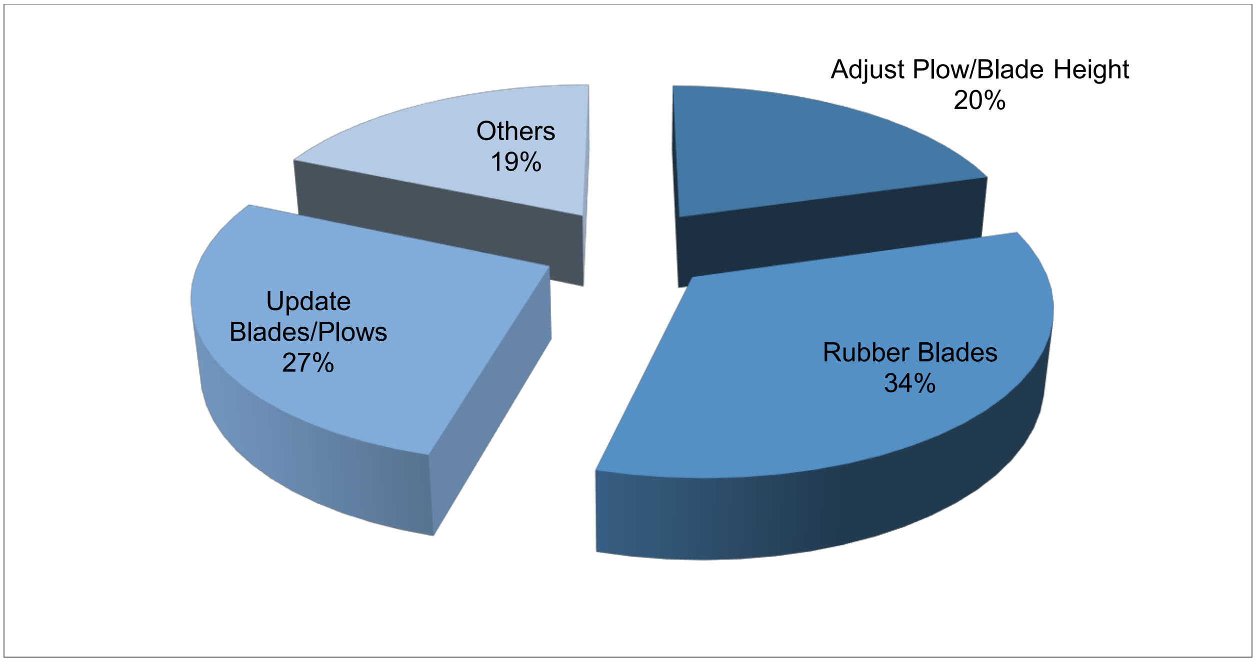


Figure 78. Best Plow-related Ways to Reduce/Eliminate Vibration Sources

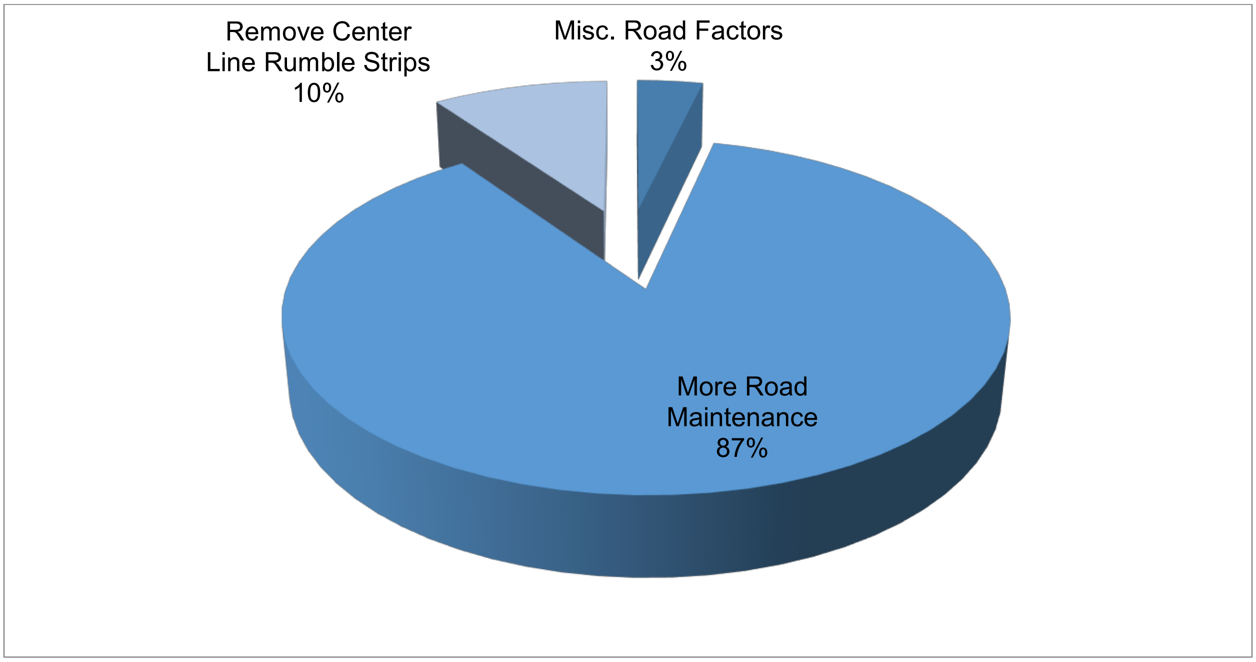


Figure 79. Best Road-related Ways to Reduce/Eliminate Vibration Sources

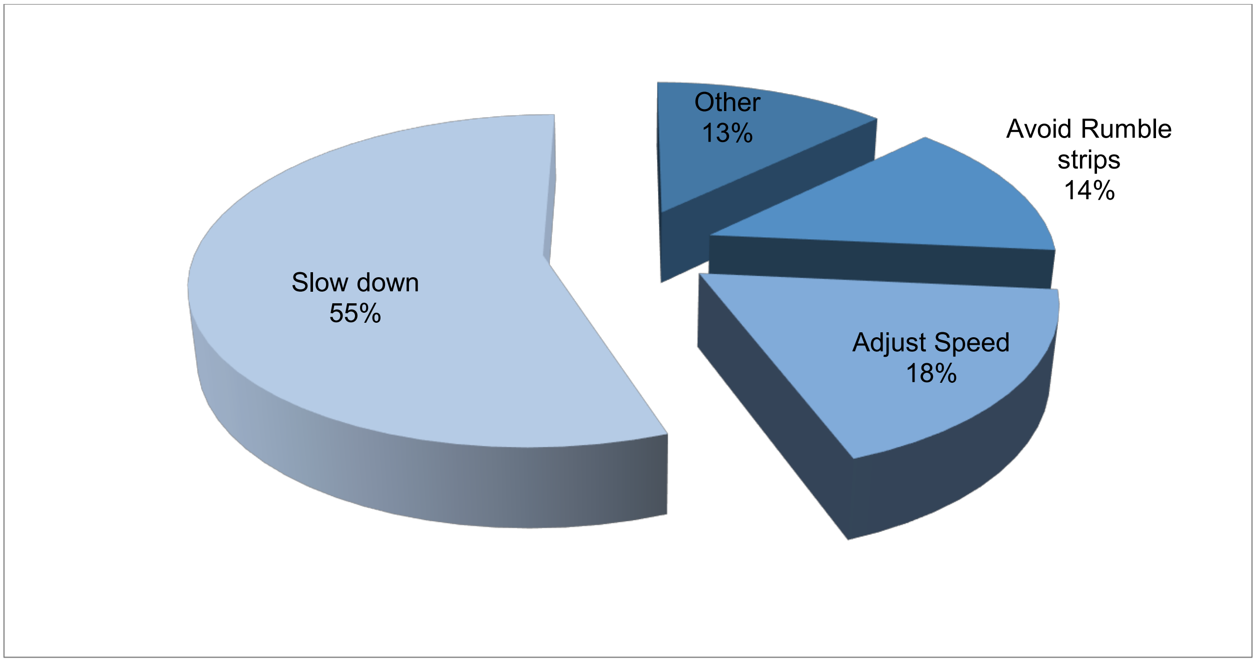


Figure 80. Best Driving Practices to Reduce/Eliminate Vibration Sources

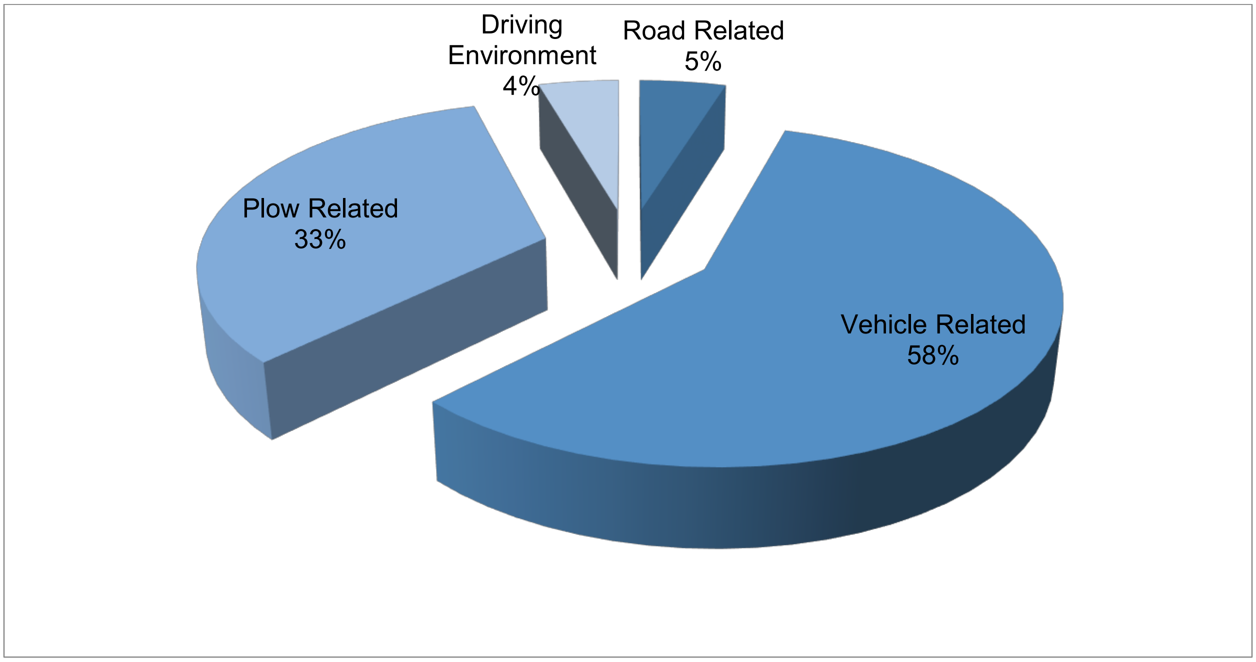


Figure 81. Major Sources of Noise, by Themes

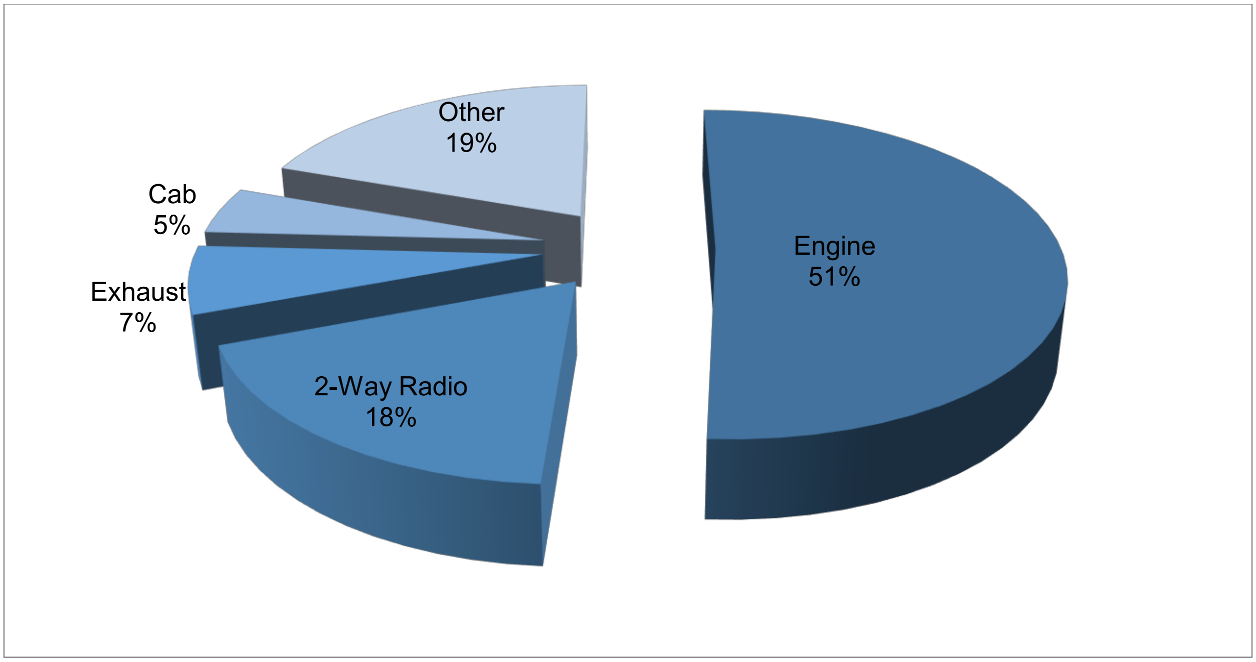


Figure 82. Vehicle-related Sources of Noise

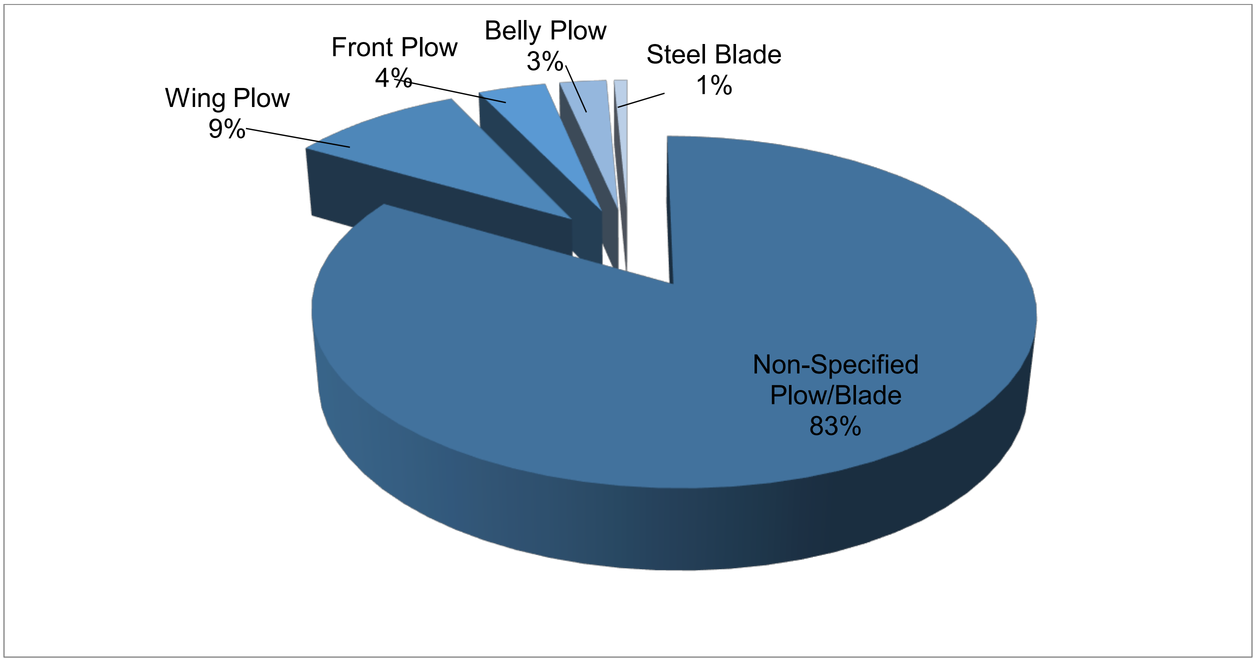


Figure 83. Plow-related Sources of Noise

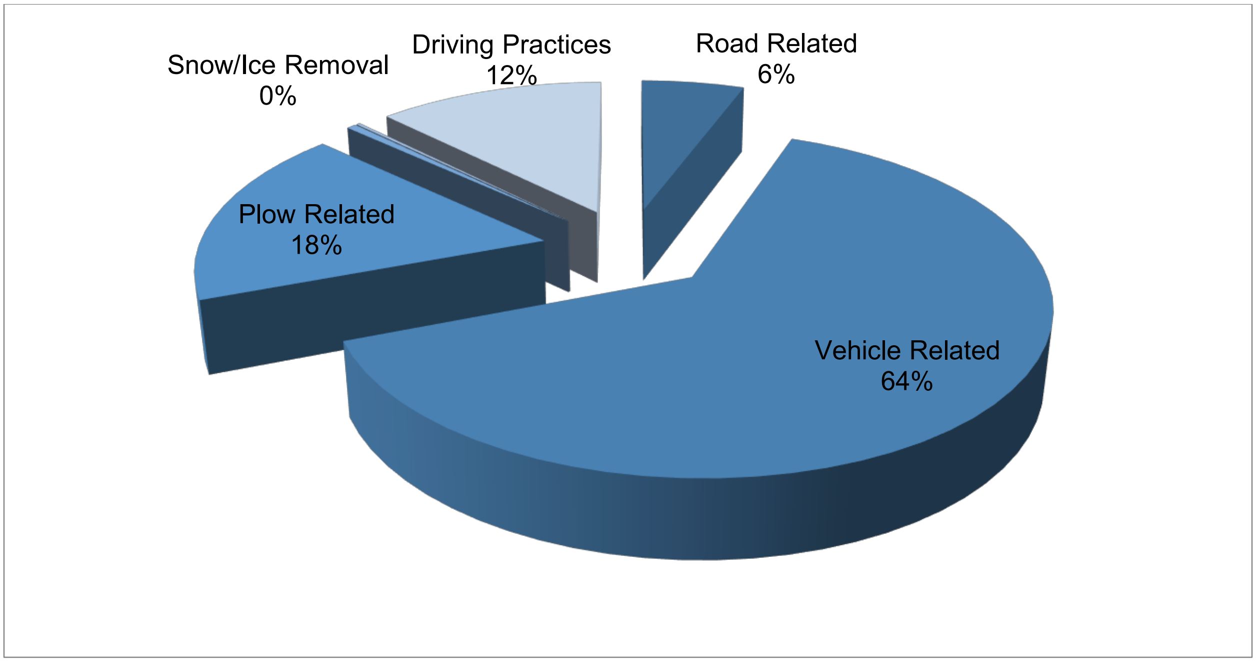


Figure 84. Best Ways to Reduce/Eliminate Noise, by Major Themes

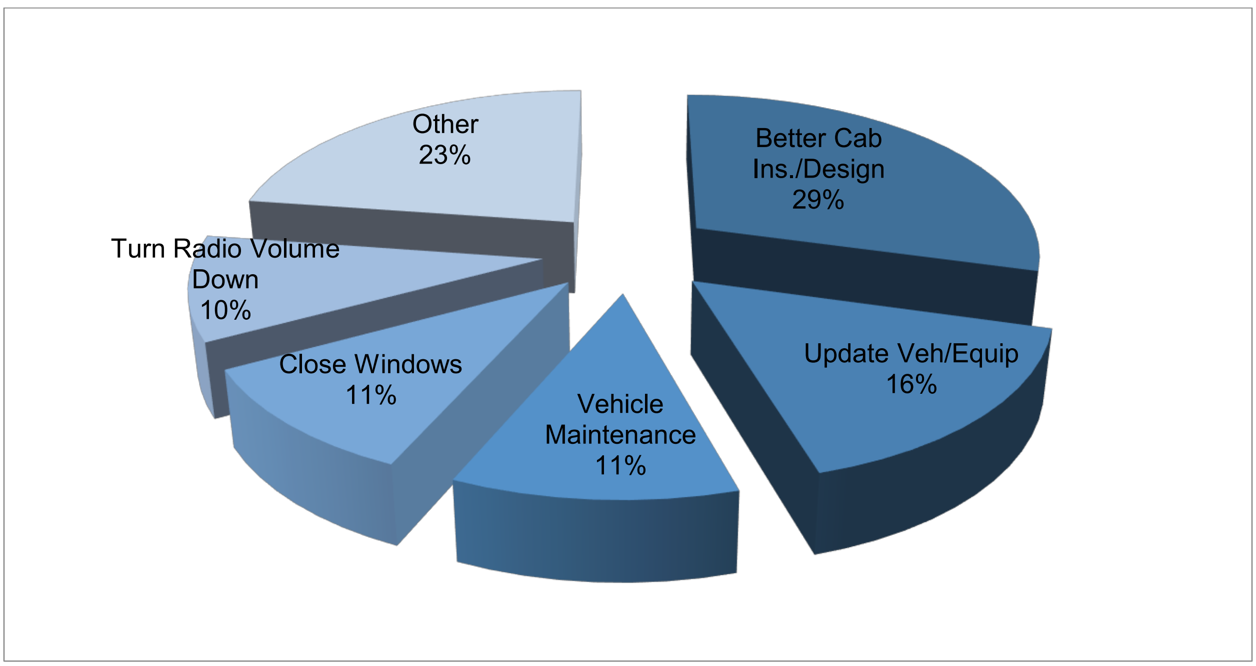


Figure 85. Best Vehicle-related Methods to Reduce/Eliminate Noise

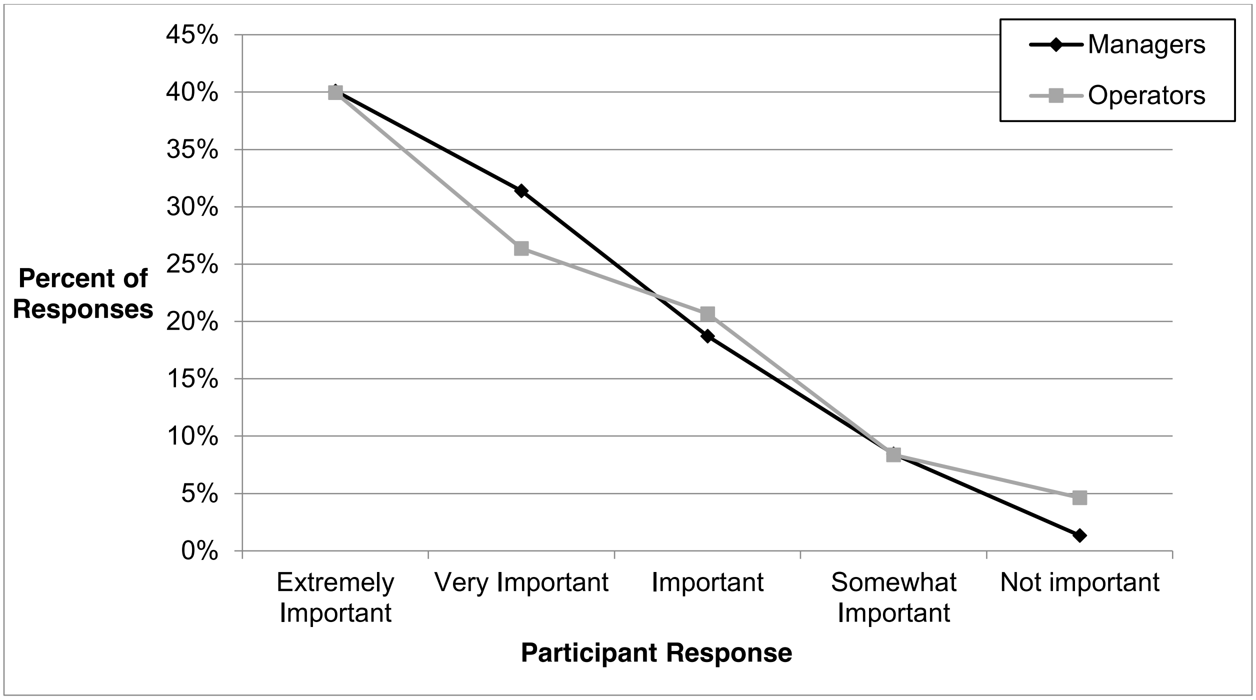


Figure 86. Traffic as a Source of Fatigue during Winter Emergencies

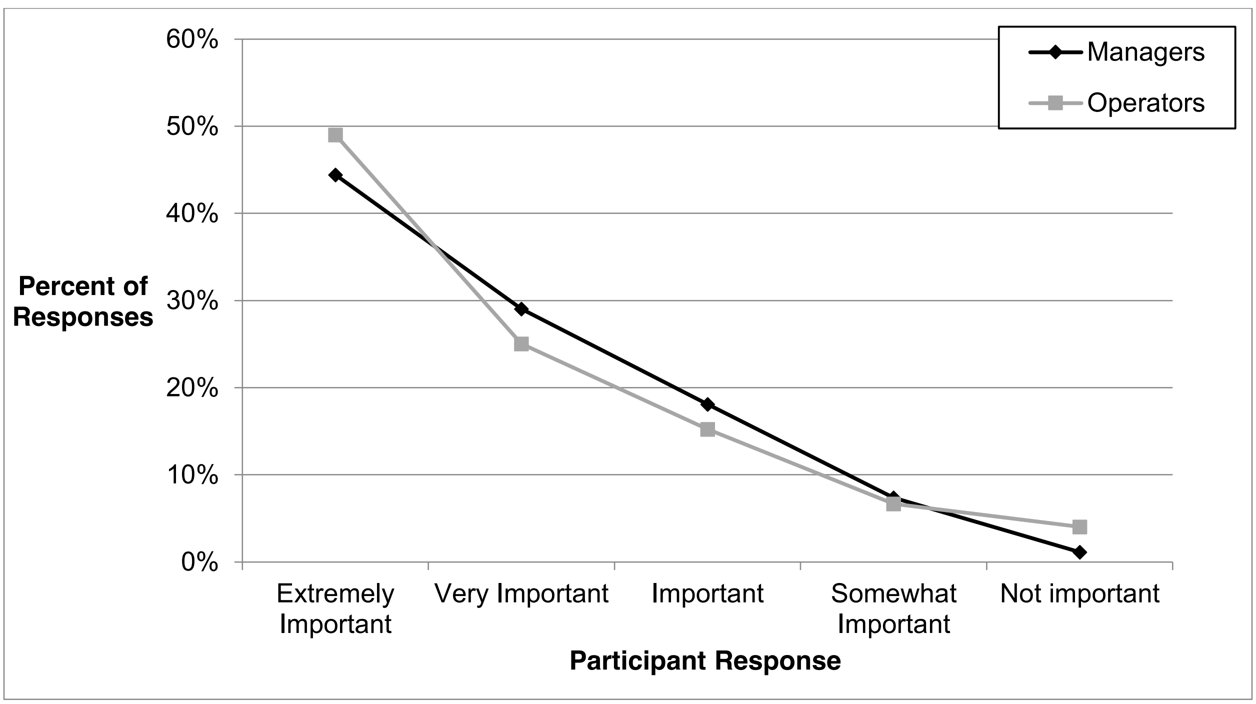


Figure 87. Light from Headlamps as a Source of Fatigue during Winter Emergencies

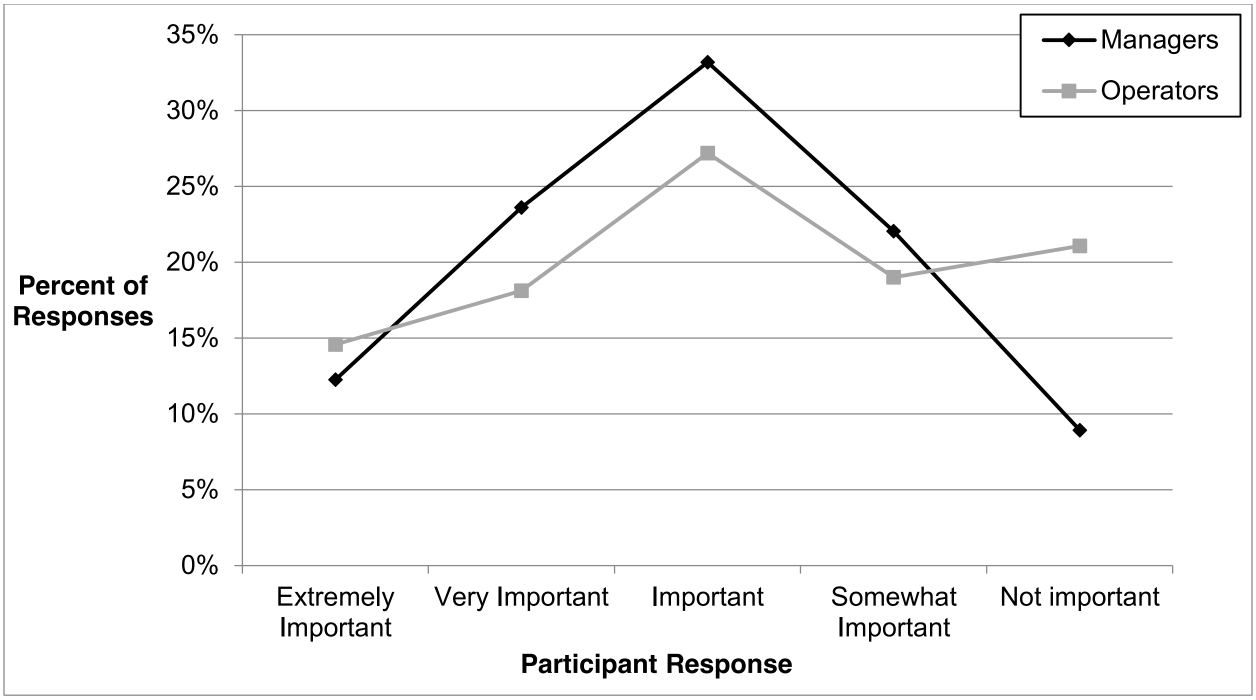


Figure 88. Too Much Technology inside Truck as a Source of Fatigue during Winter Emergencies

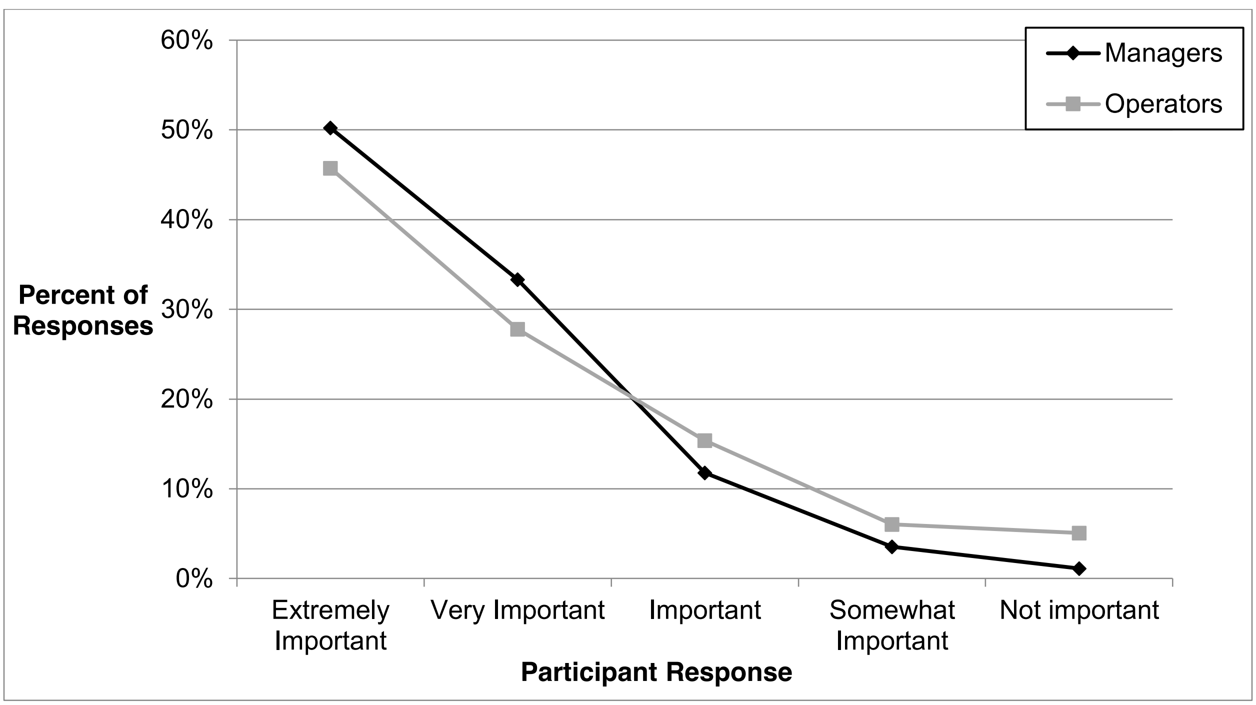


Figure 89. Nighttime Operations as a Source of Fatigue during Winter Emergencies

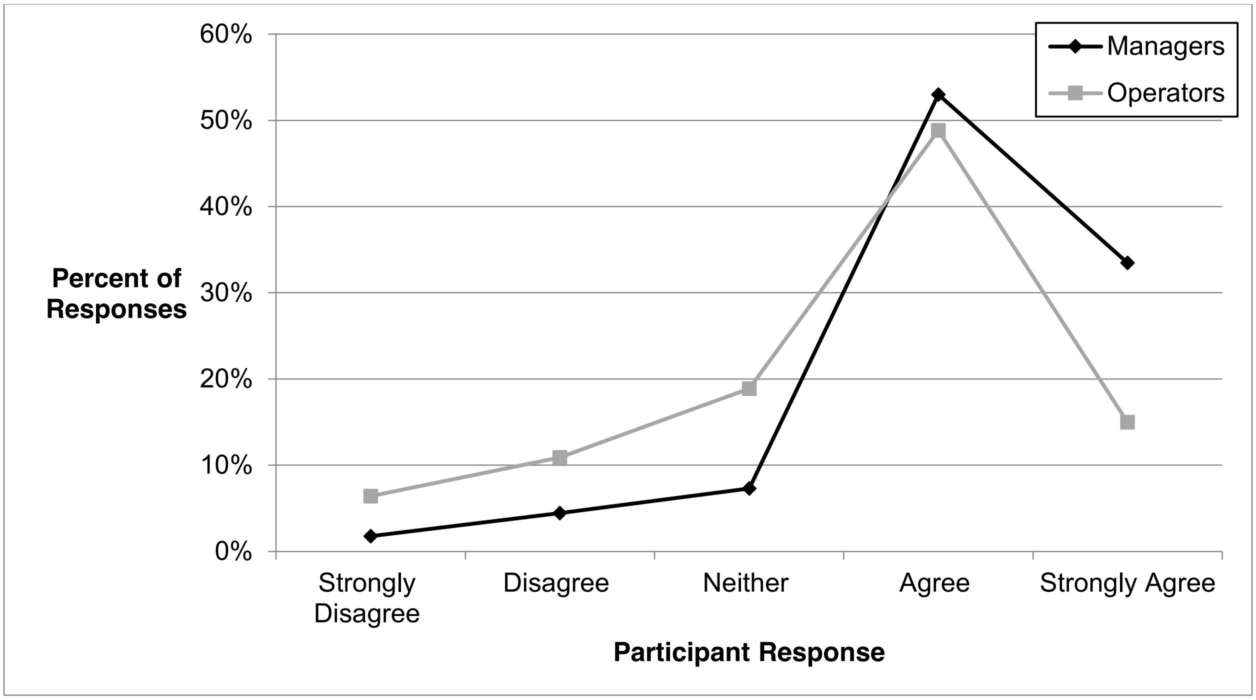


Figure 90. Responses to the Statement, "Management encourages snow plow operators to take breaks whenever they need to."

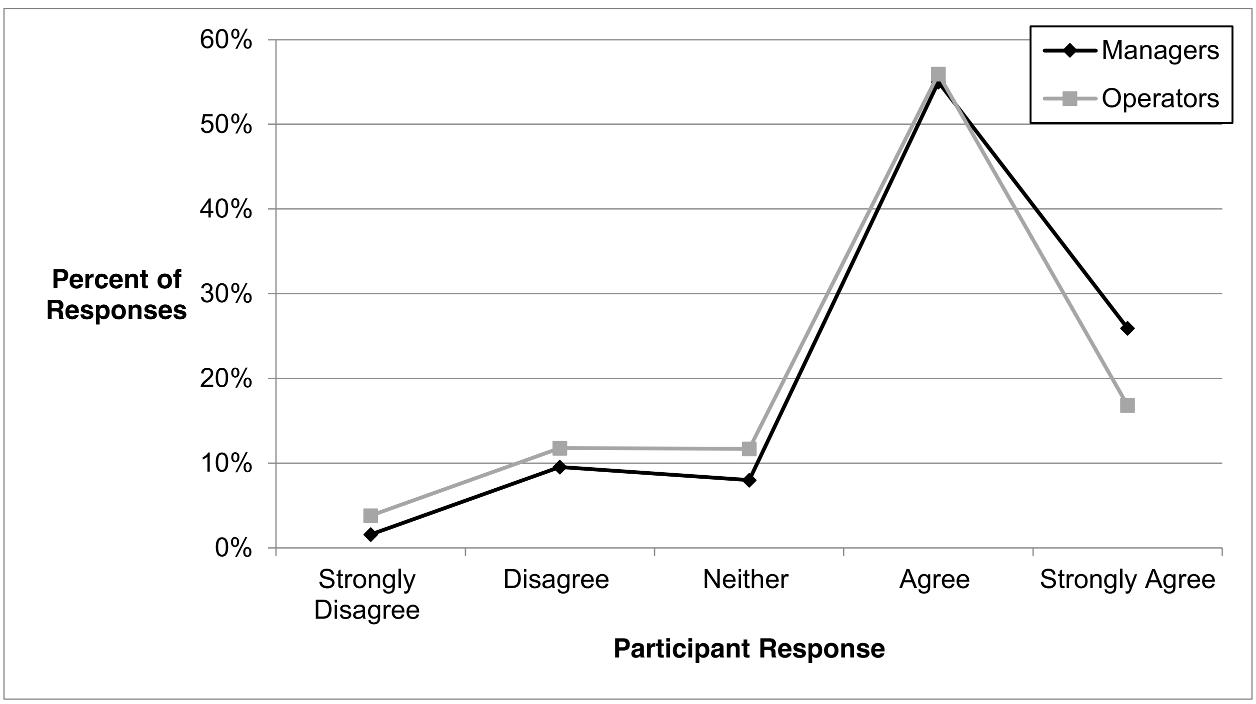


Figure 91. Responses to the Statement, "Snow plow operators are able to take breaks whenever they need to."

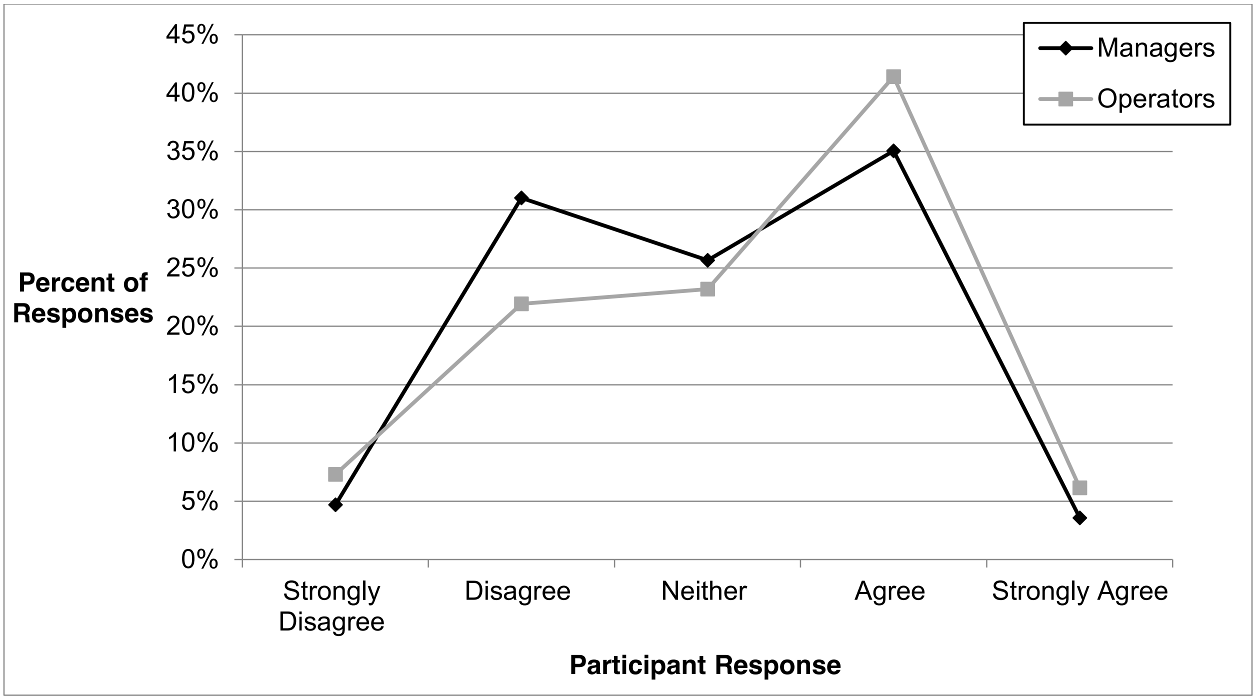


Figure 92. Responses to the Statement, "Snow plow operators always feel that they have enough time to do their work."

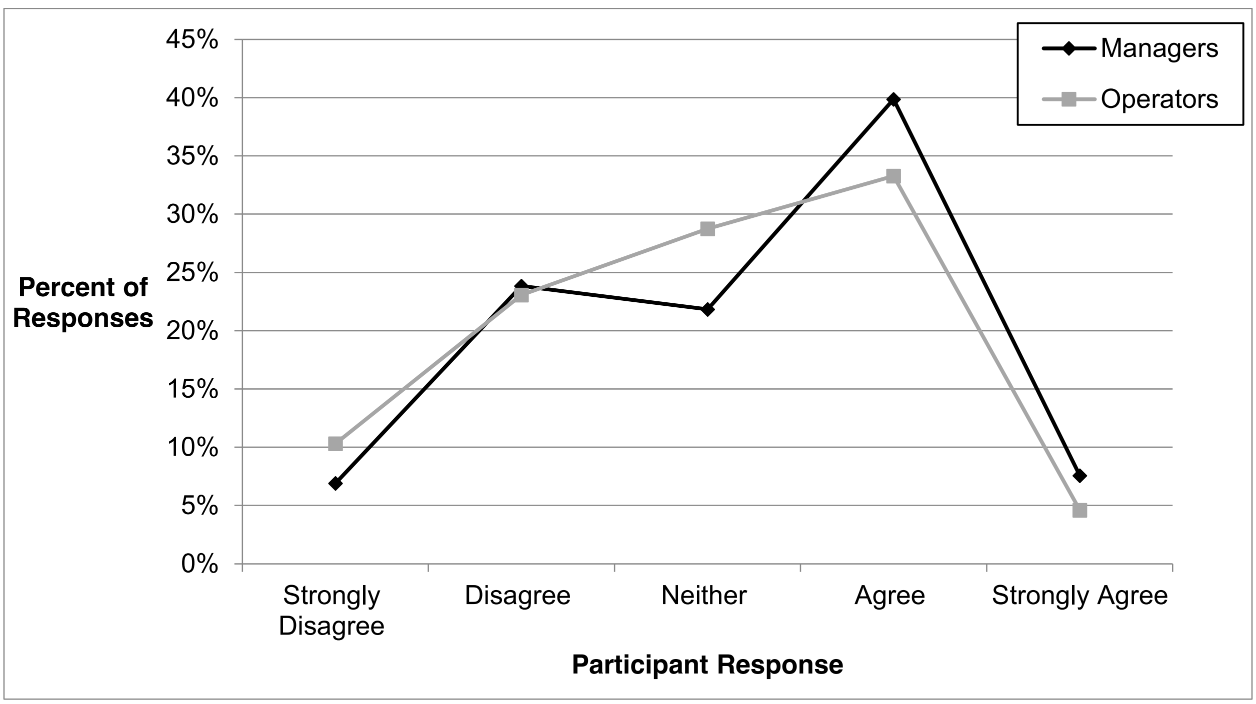


Figure 93. Responses to the Statement, "Snow operators received educational materials regarding fatigue."

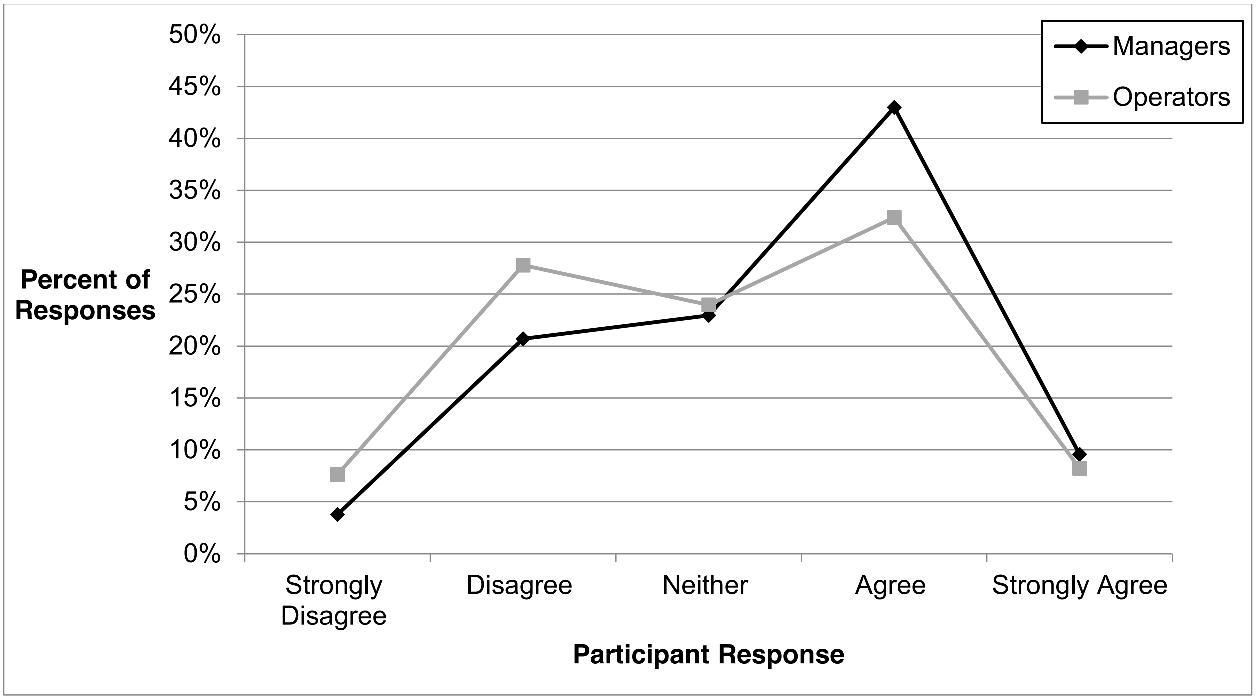


Figure 94. Responses to the Statement, "Snow plow operators prefer to continue driving the snow plow rather than taking a break during winter emergencies."

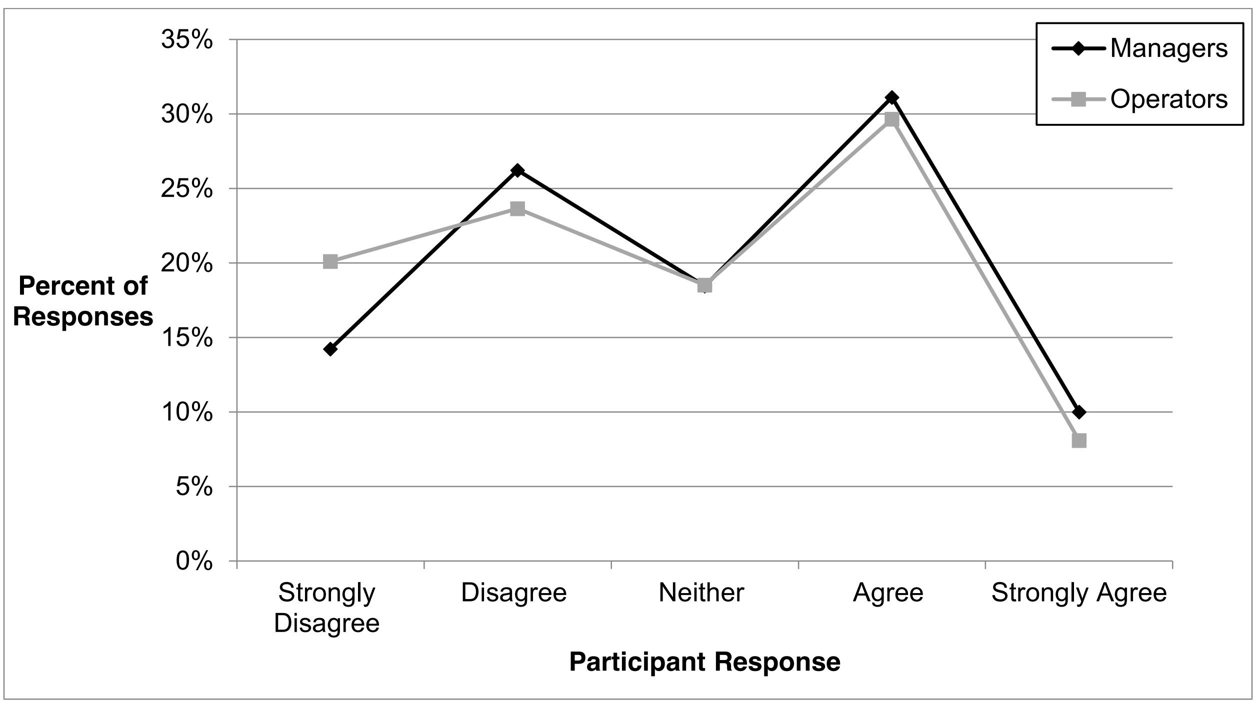


Figure 95. Responses to the Statement, "Snow plow operators can refuse work in a winter emergency if they feel tired and have not had enough sleep."

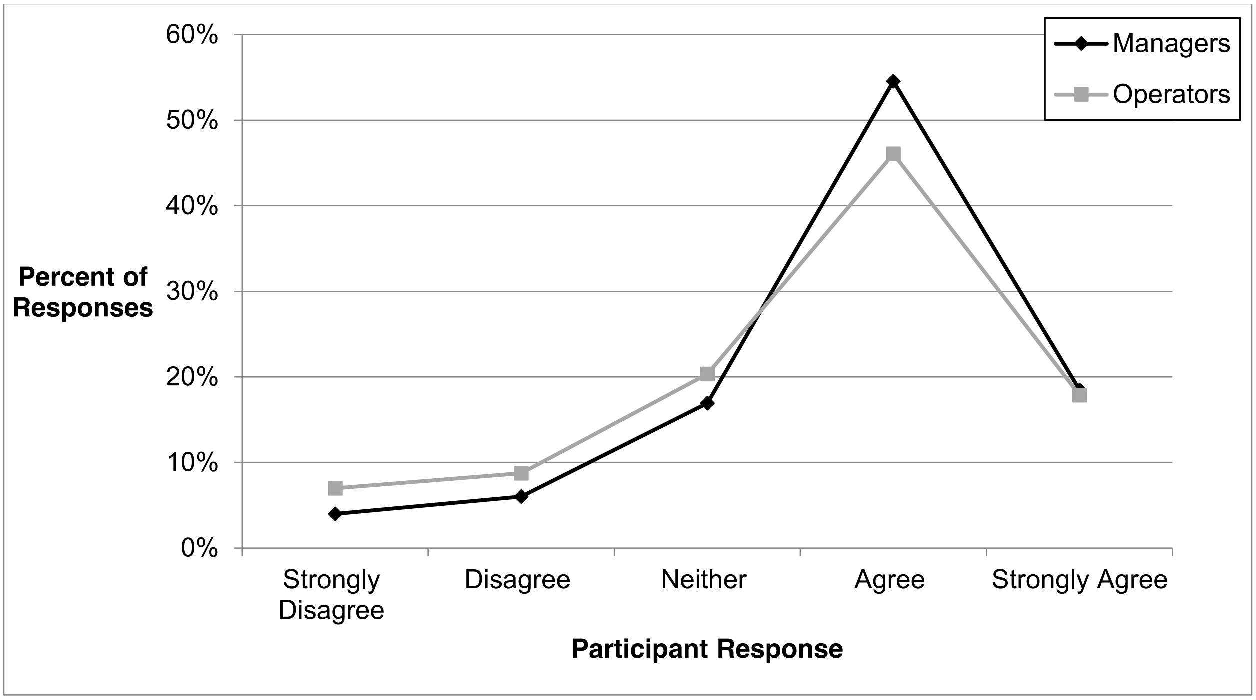


Figure 96. Responses to the Statement, "Management does a good job assigning shifts and hours."

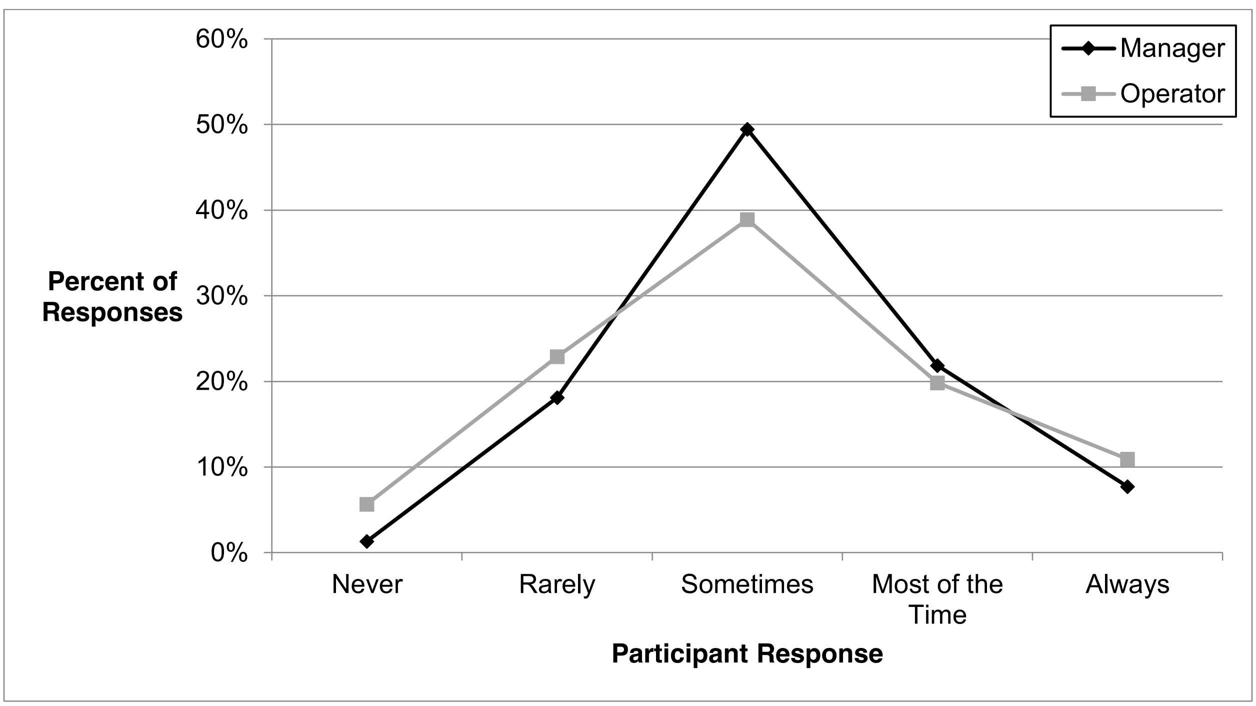


Figure 97. Responses to the Statement, "Operators are asked to operate a snow plow more than planned during a winter emergency."

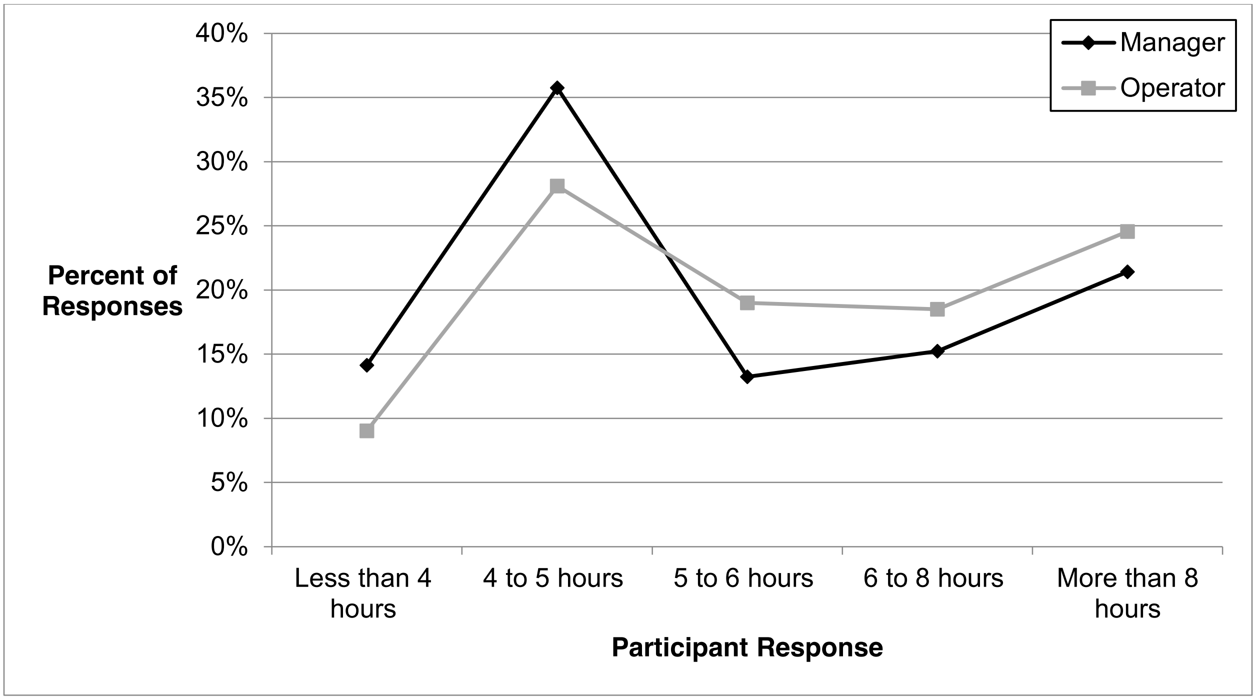


Figure 98. Responses to the Question, "How many hours are winter maintenance operators able to operate a snow plow without a break?"

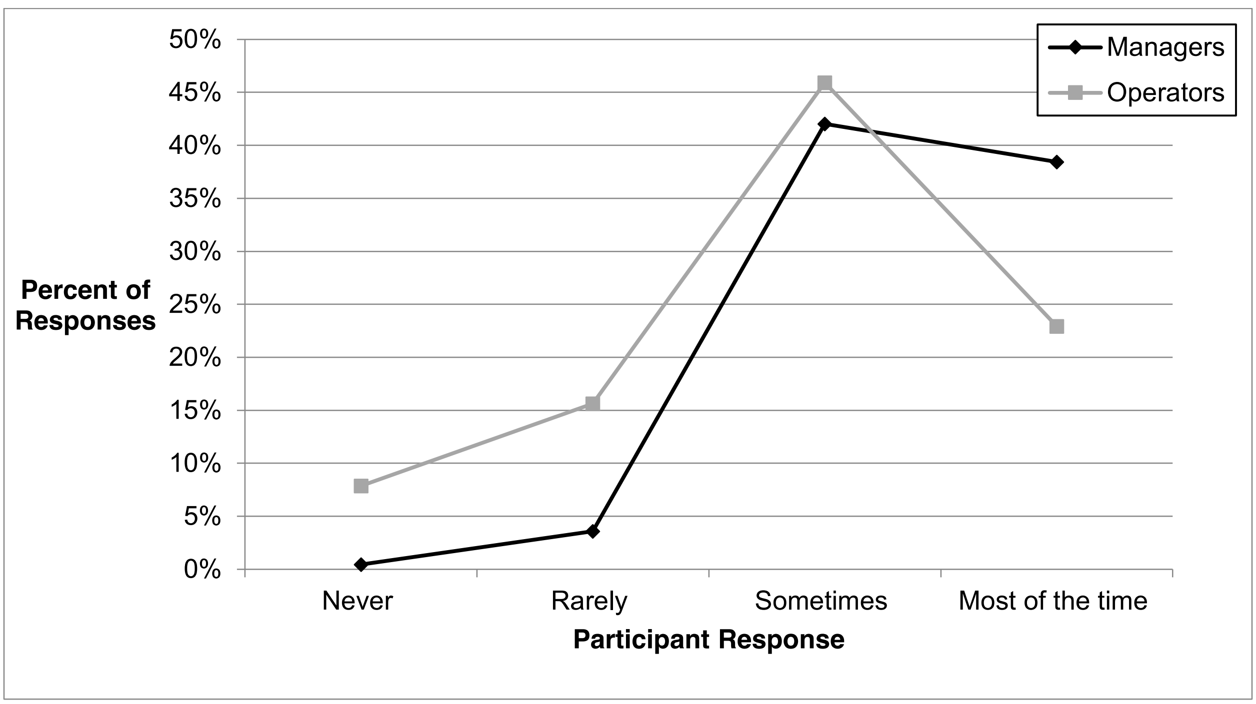


Figure 99. How Often Winter Maintenance Operators Experience Tense Muscles during Winter Emergencies

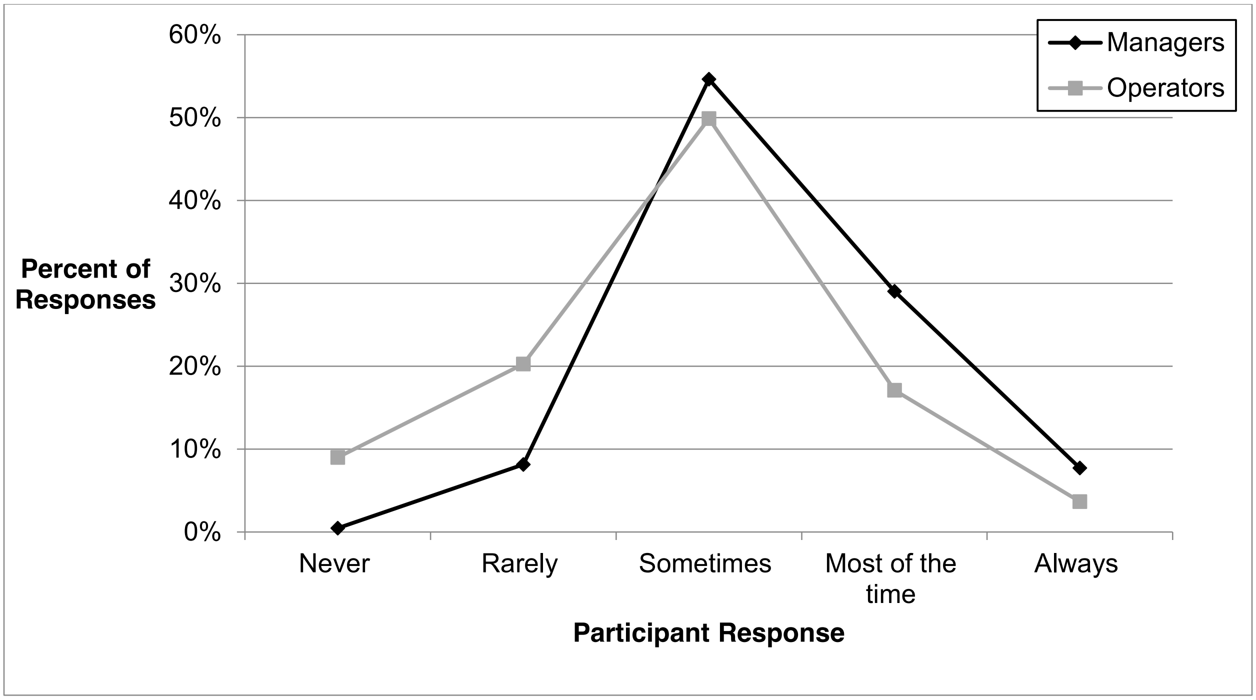


Figure 100. How Often Winter Maintenance Operators Experience an Aching Body during Winter Emergencies

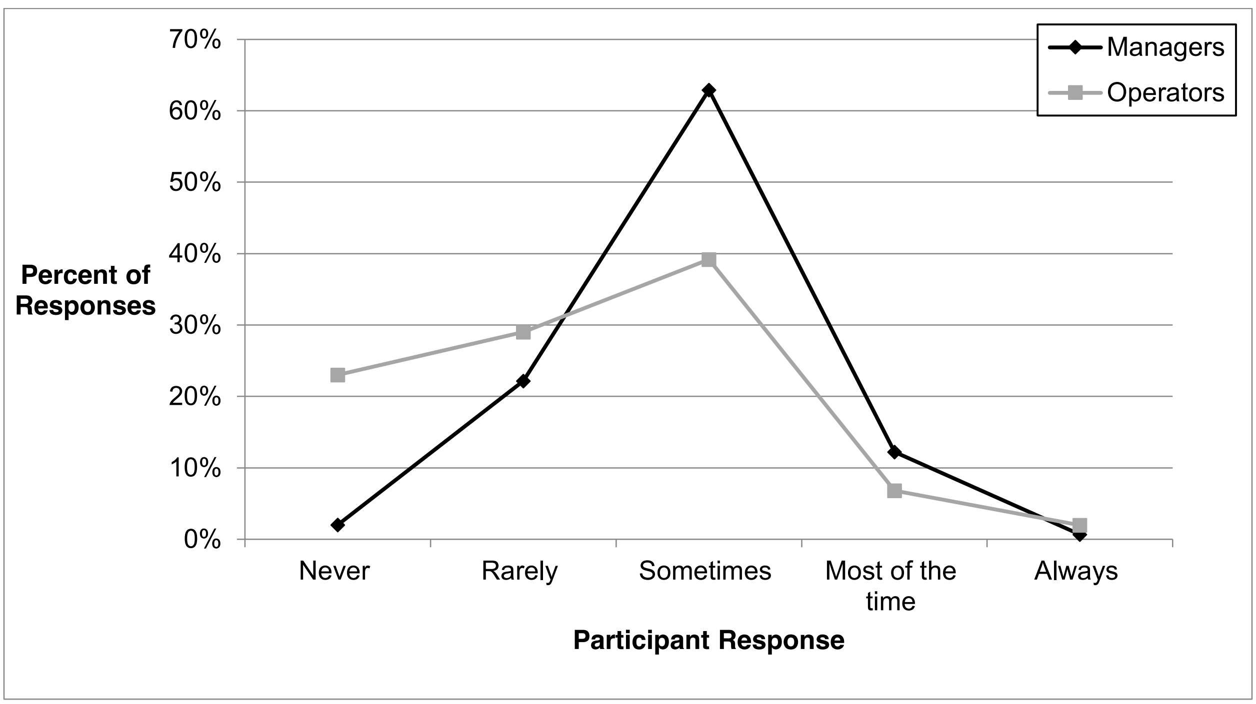


Figure 101. How Often Winter Maintenance Operators Experience Leg Numbness during Winter Emergencies

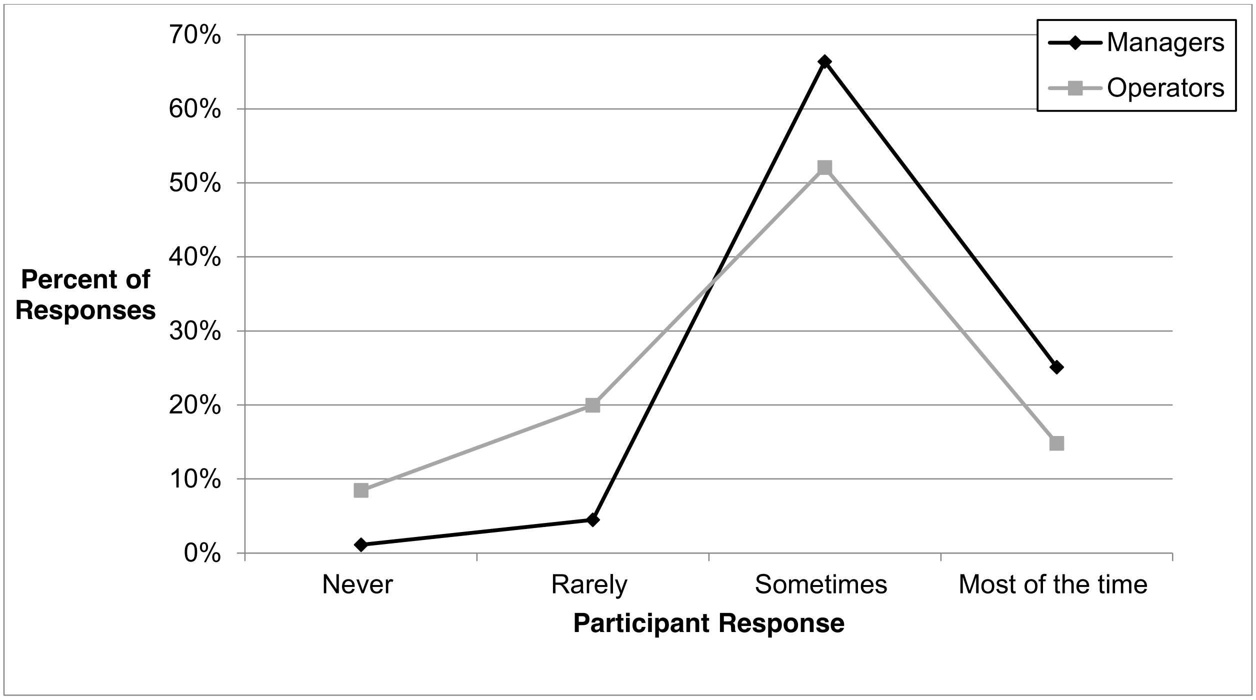


Figure 102. How Often Winter Maintenance Operators Experience Back Pain during Winter Emergencies

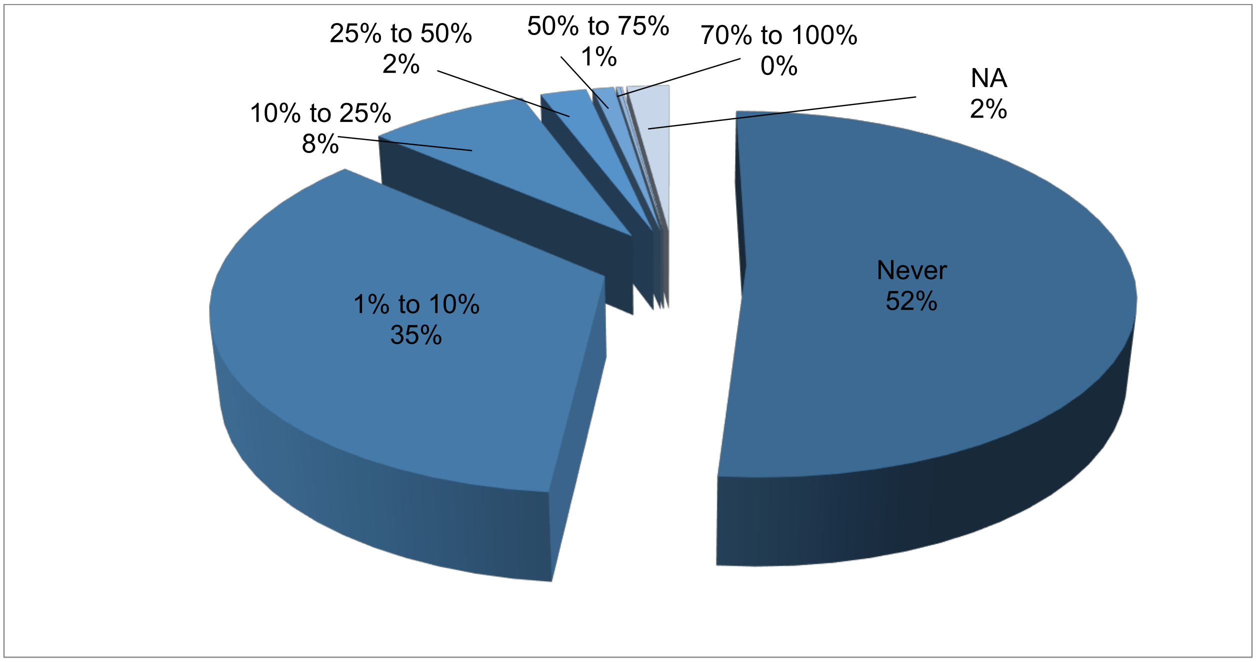


Figure 103. Percent of Time the Winter Maintenance Operator Dozed Off while Operating the Snow Plow during a Winter Emergency

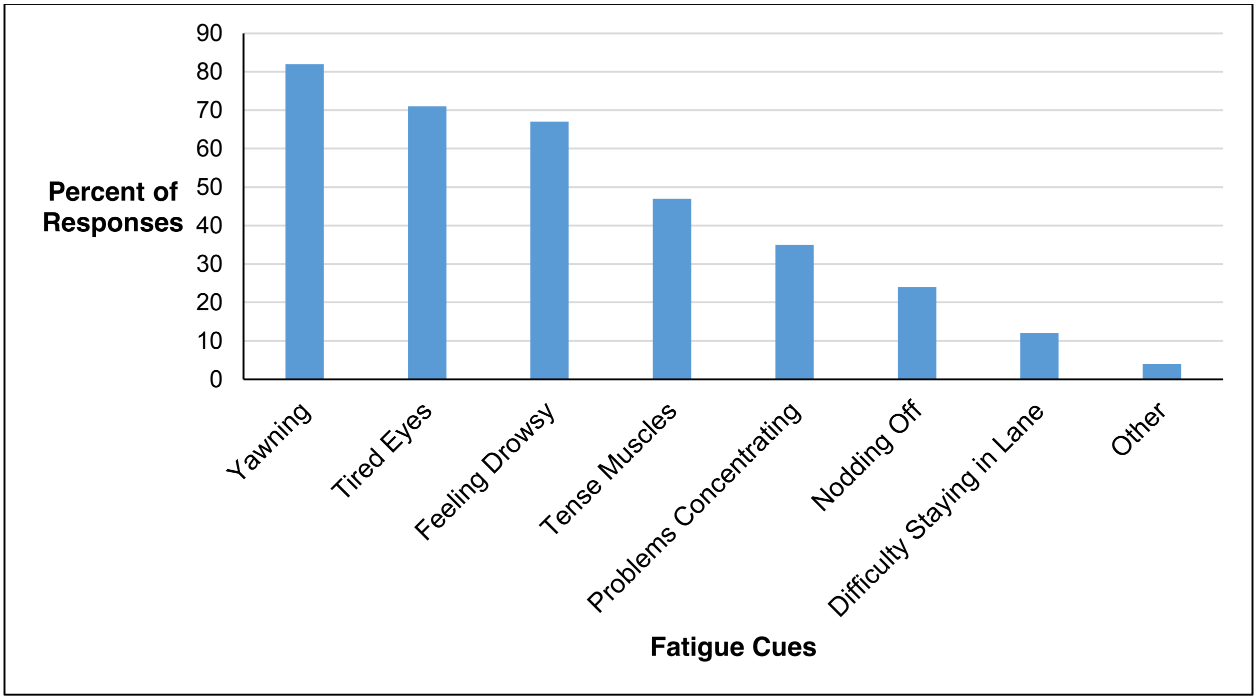


Figure 104. Cues Winter Maintenance Operators use to Realize They are Tired or Fatigued

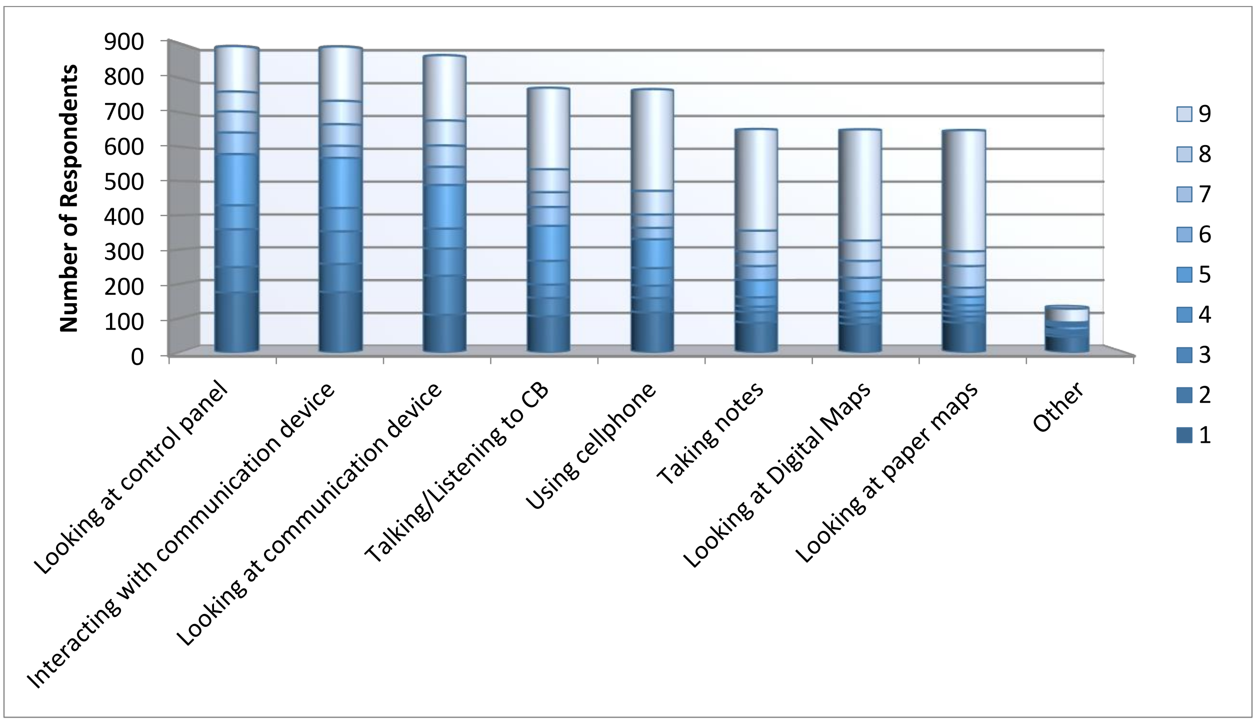


Figure 105. Major Distractions, Ranked 1 to 9 (1 = most important; 9 = least important)

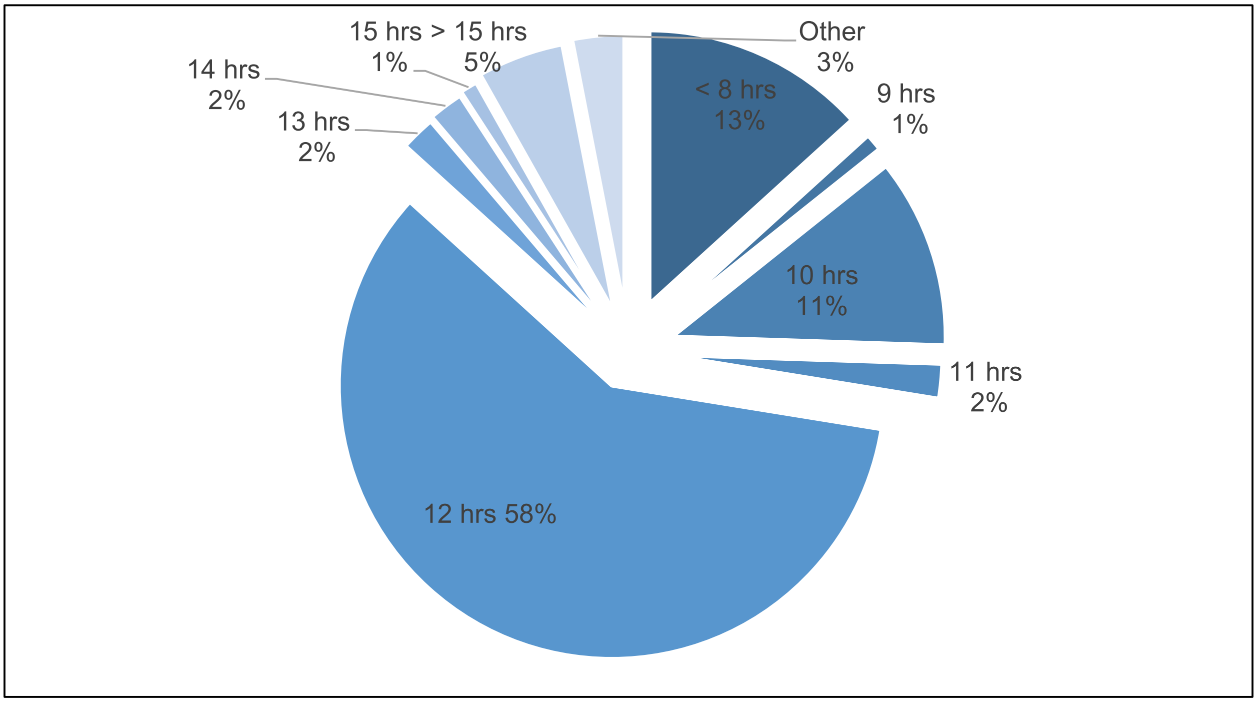


Figure 106. Length in Hours of a "Normal Shift" during a Winter Emergency

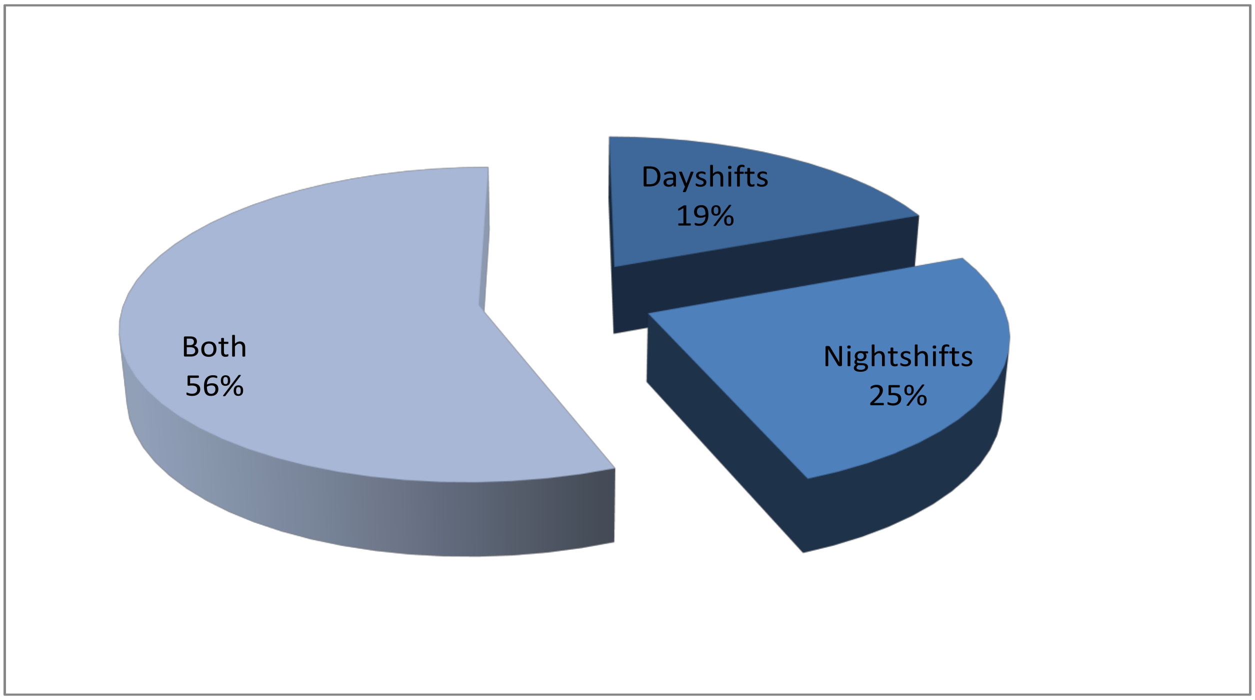


Figure 107. Type of Shift Worked by Winter Maintenance Operators

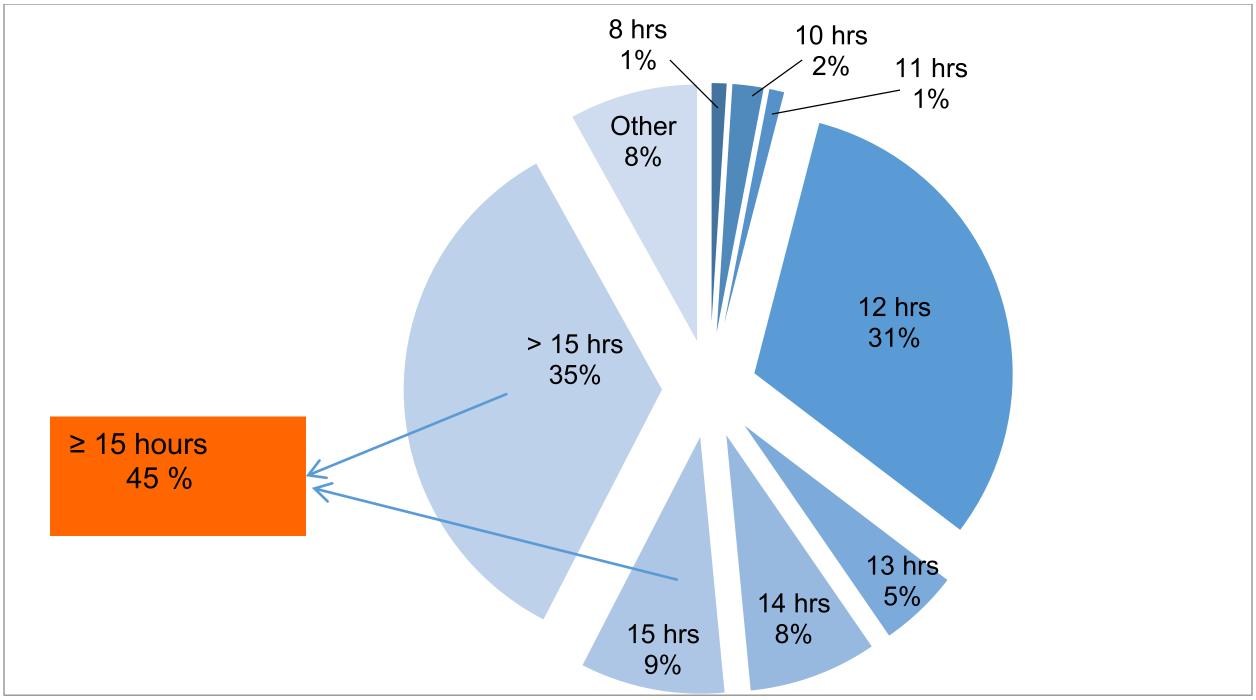


Figure 108. Maximum Hours Worked during a Winter Emergency

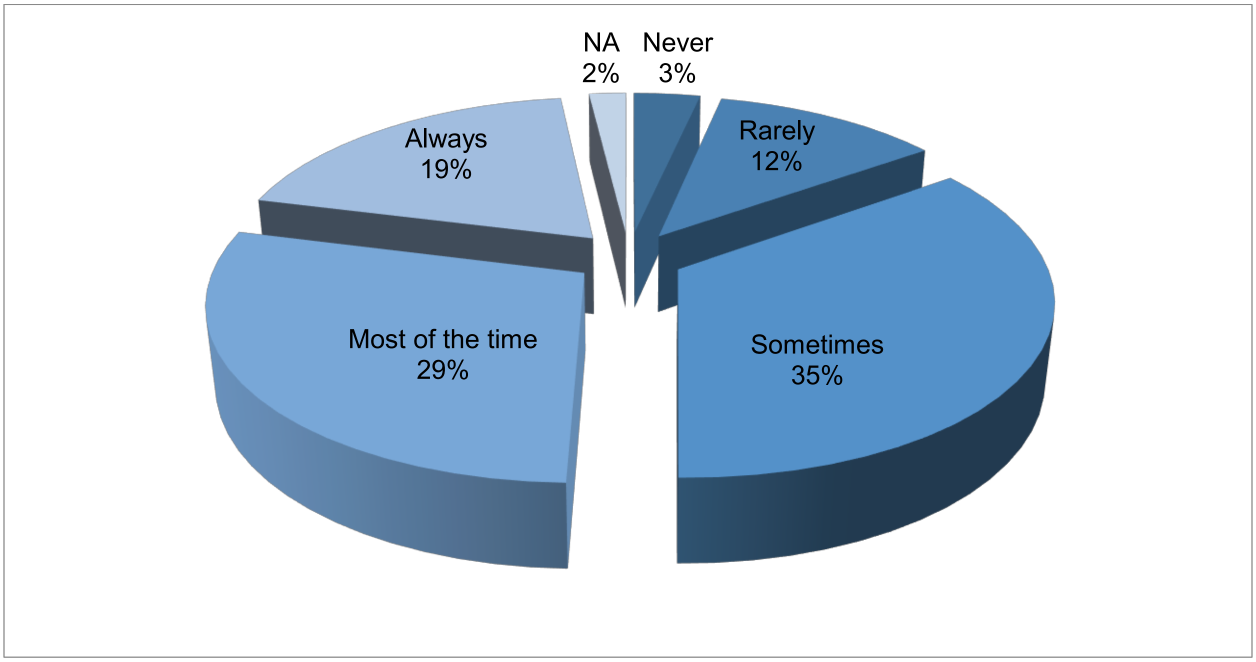


Figure 109. Frequency with which Winter Maintenance Operator is Asked to Work on Less than 8 Hours' Notice

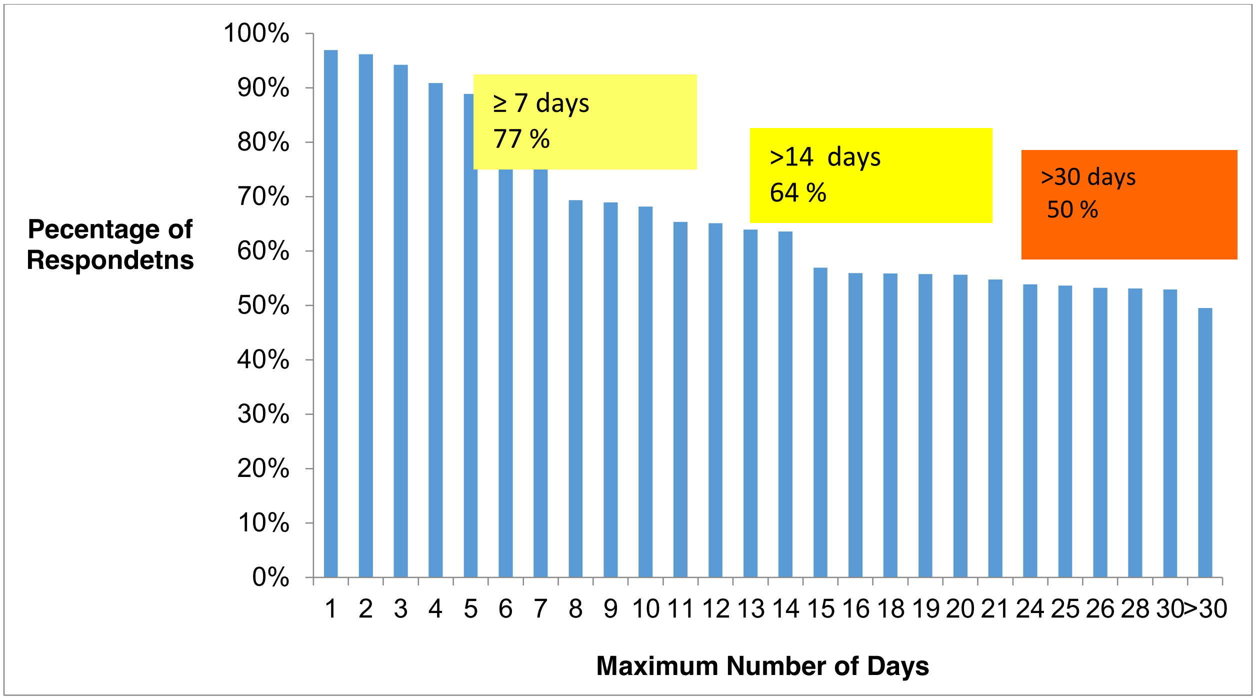


Figure 110. Maximum Number of Days Winter Maintenance Operators can Work before Taking a Day Off

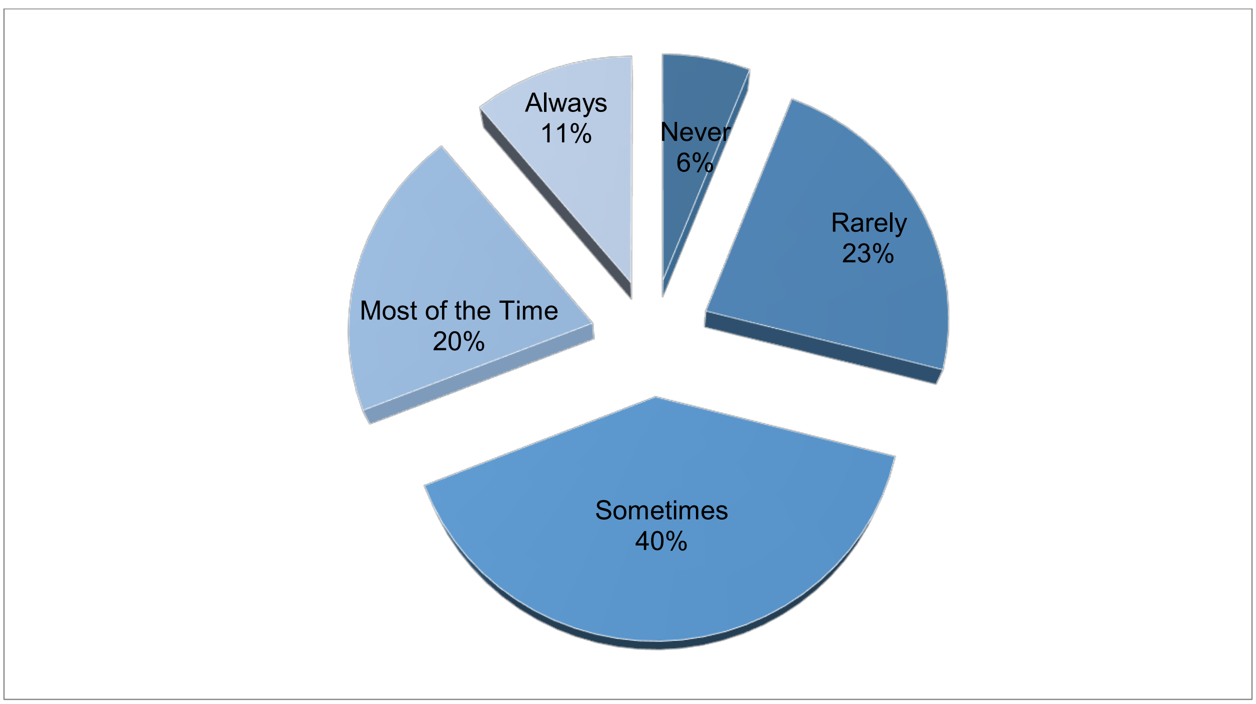


Figure 111. How Often a Winter Maintenance Operator Was Asked to Work More than Planned during Winter Emergencies

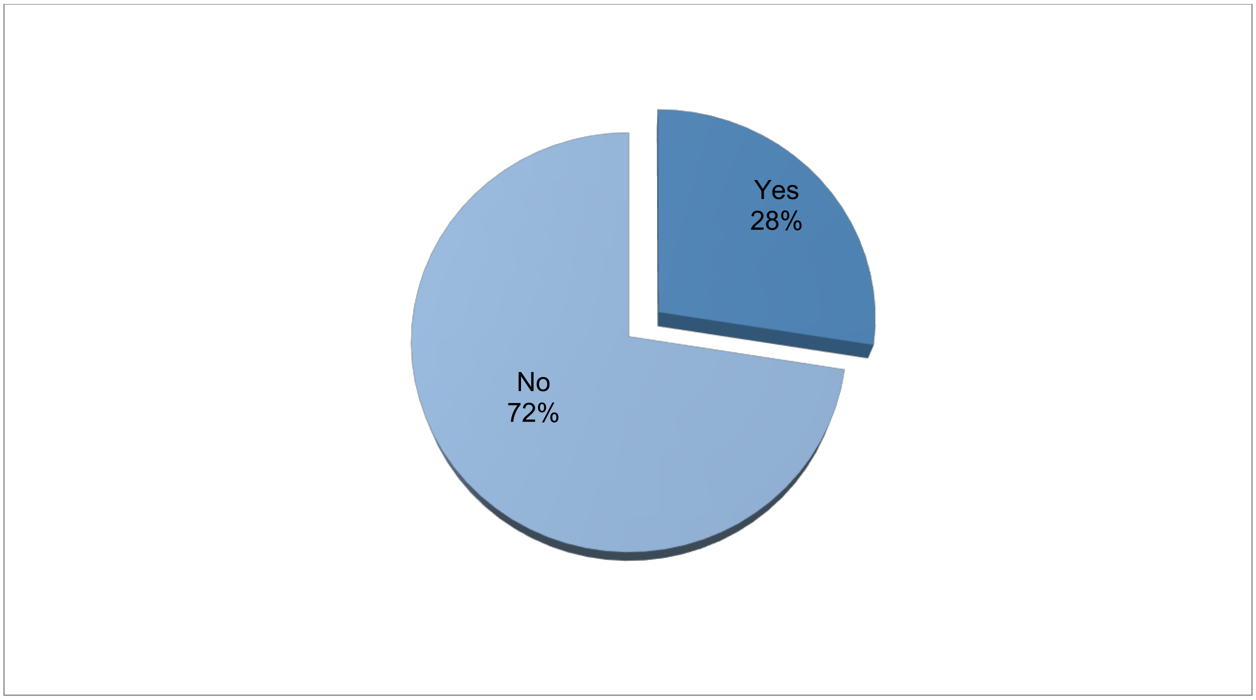


Figure 112. Percentage of Winter Maintenance Operators Required to Take Regular Breaks

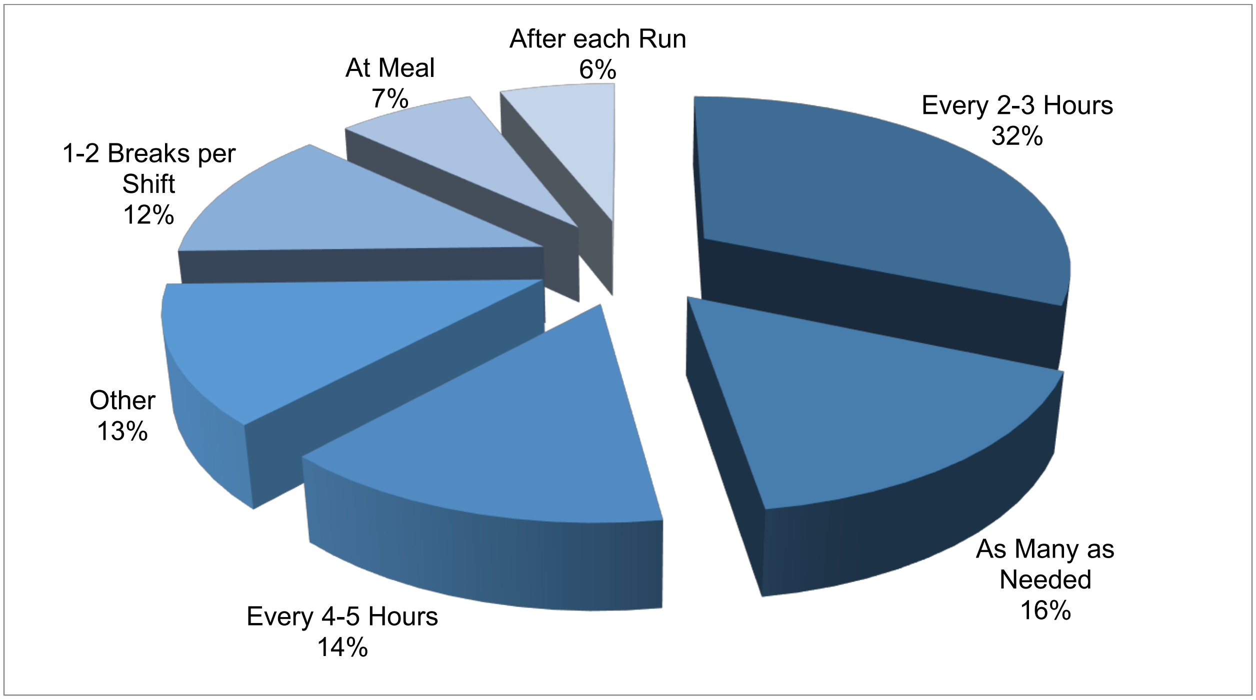


Figure 113. Distribution of Times Winter Maintenance Operators are Required to Take Regular Breaks during a Winter Emergency

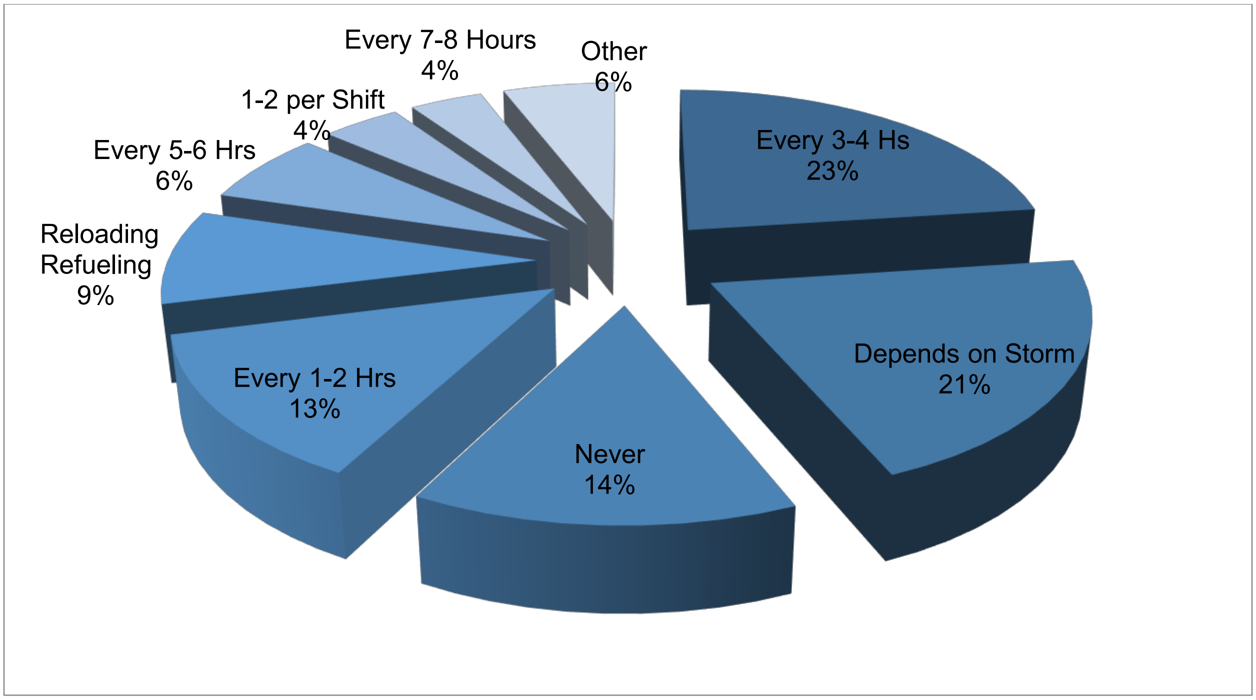


Figure 114. How Often Winter Maintenance Operators Actually Take a Break from Driving during a Winter Emergency

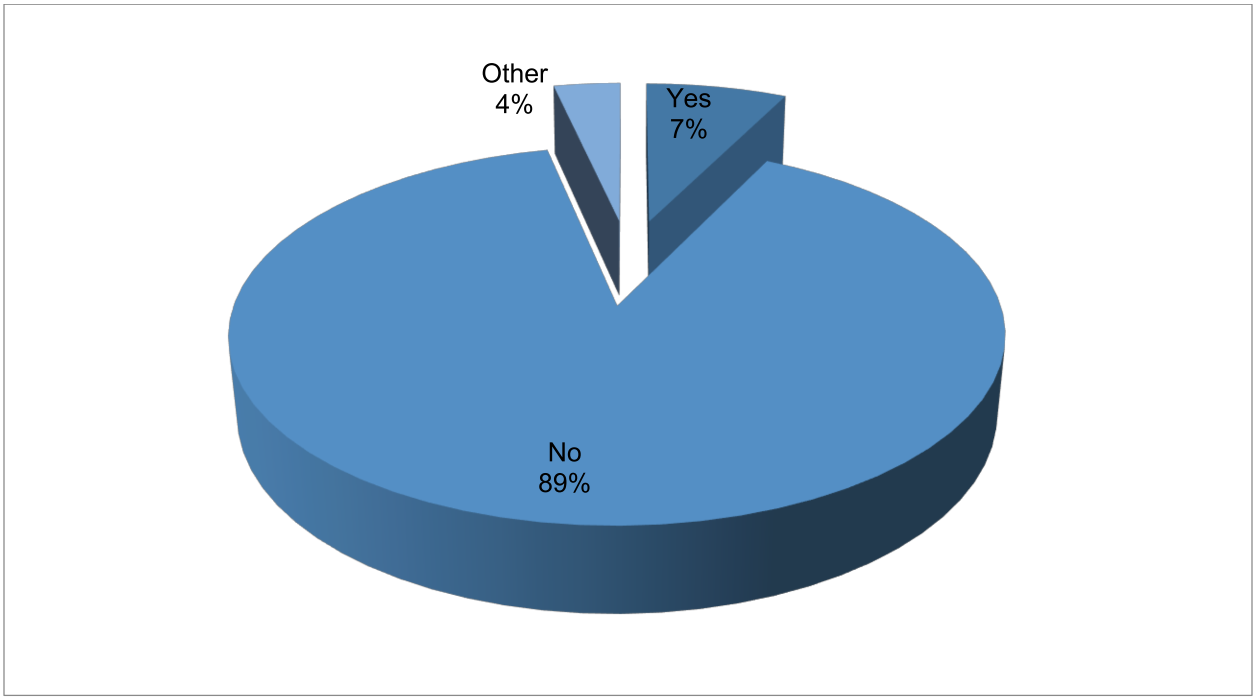


Figure 115. Are There Procedures in Place to Test if the Winter Maintenance Operator is Fit to Begin Work?

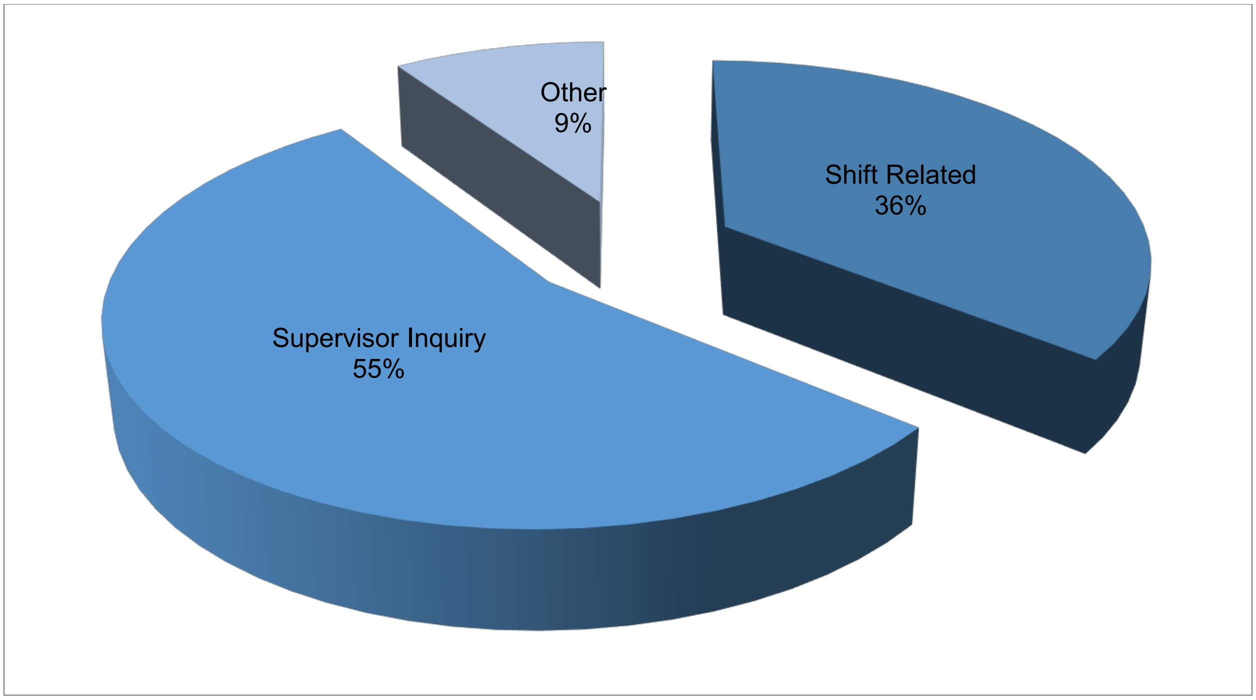


Figure 116. Procedures to Check if a Winter Maintenance Operator is Fit to Begin Work during Winter Emergencies, by Theme

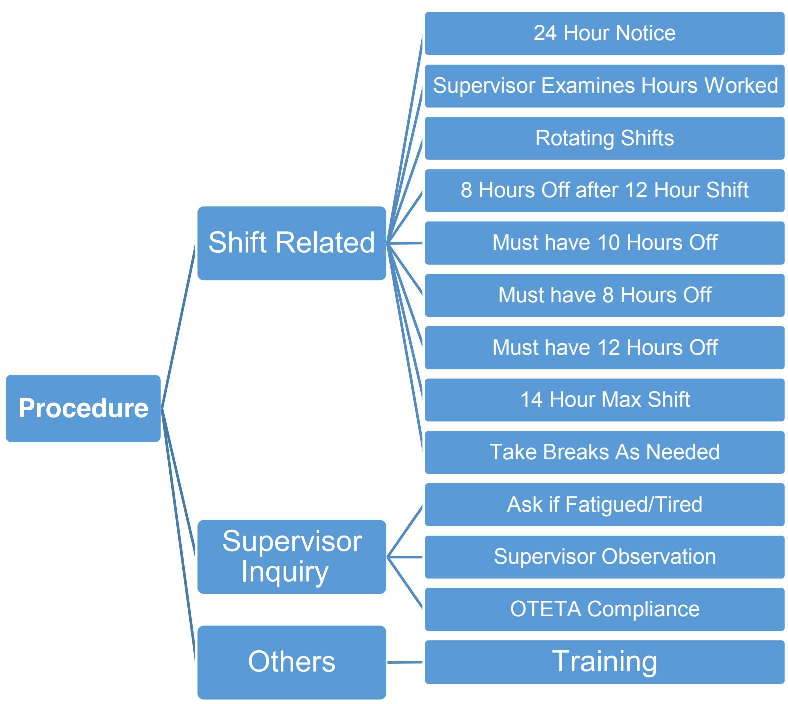


Figure 117. Prodecures in Place to Ensure Winter Maintenance Operator is Fit to Begin Operating a Snow Plow

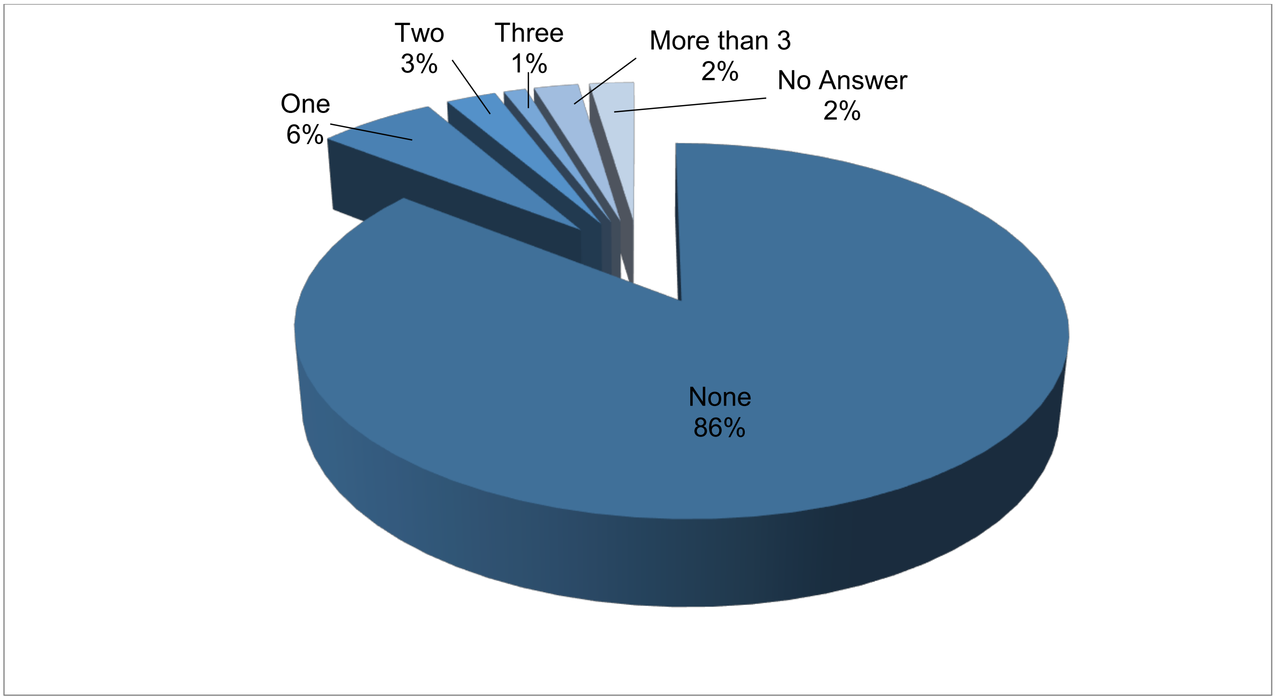


Figure 118. Number of Crashes Winter Maintenance Operators Reported in the Past Year

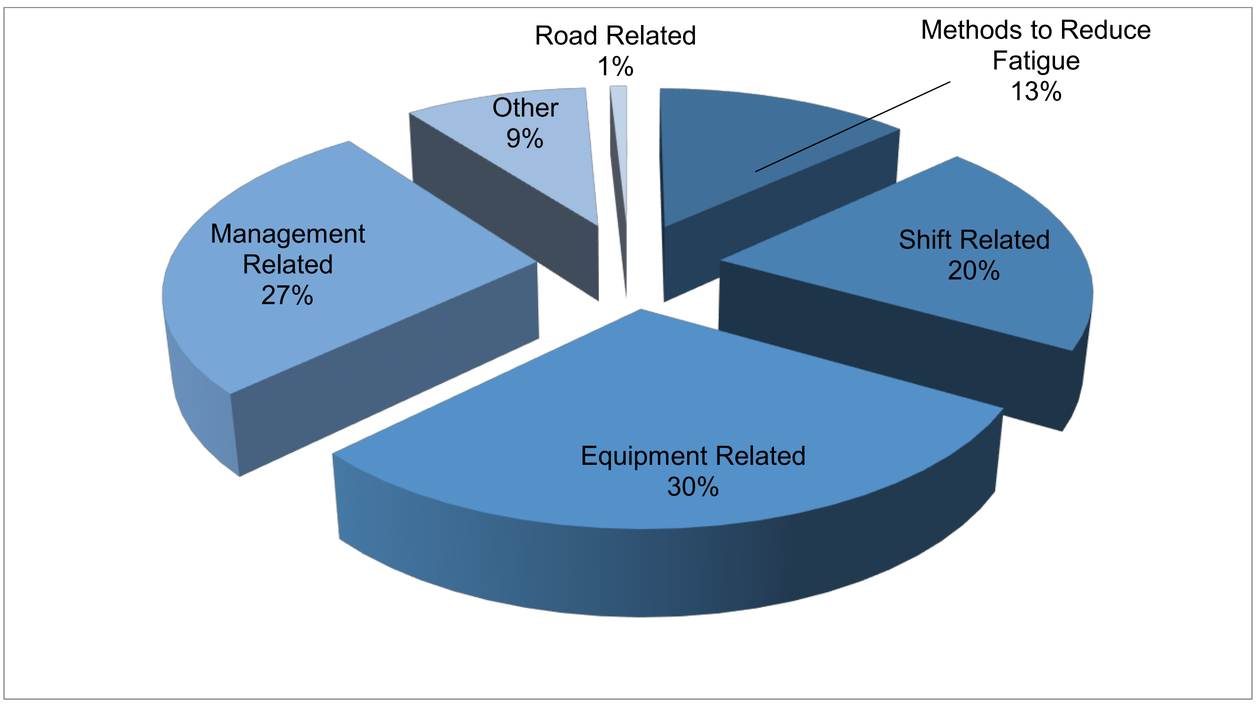


Figure 119. Suggestions to Improve Winter Maintenance Operations, by Theme

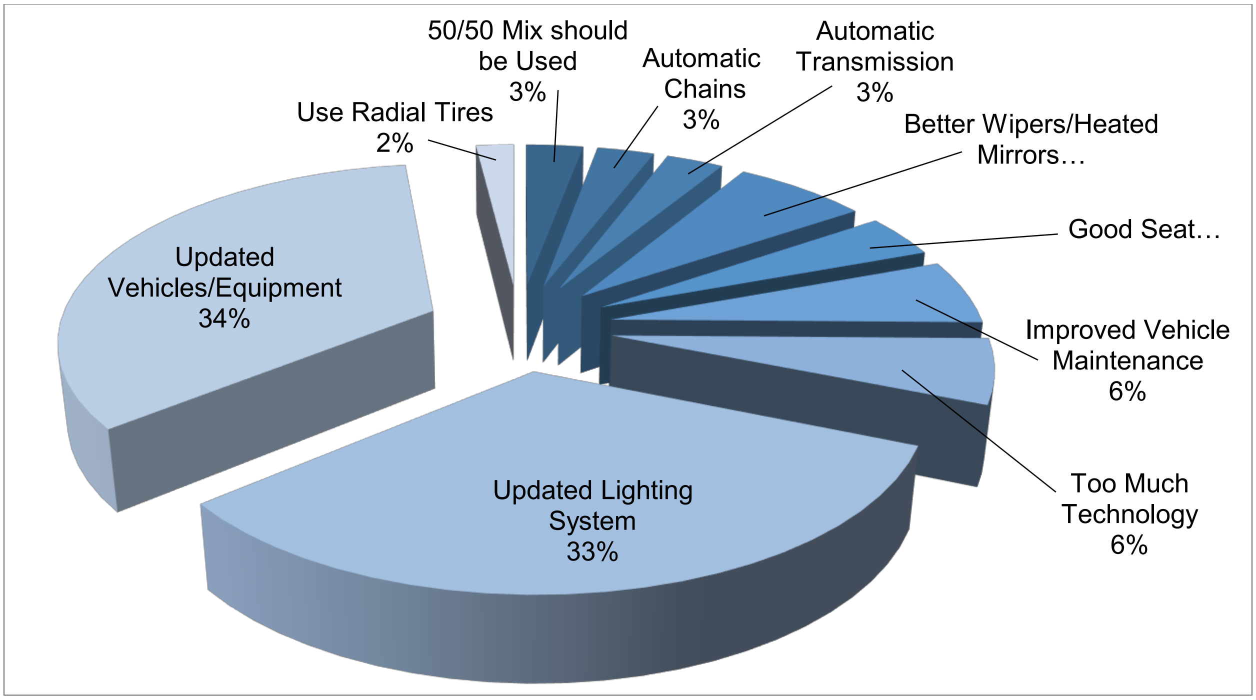


Figure 120. Equipment-related Suggestions to Improve Winter Maintenance Operations

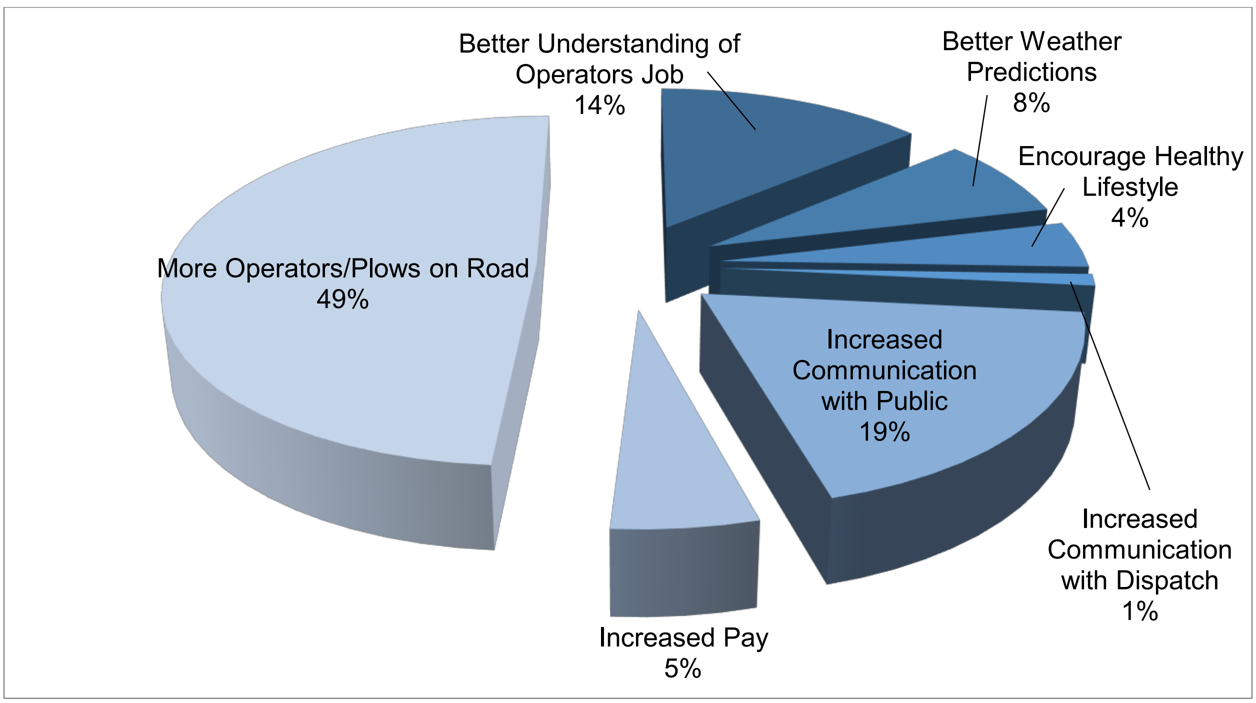


Figure 121. Management-related Suggestions to Improve Winter Maintenance Operations

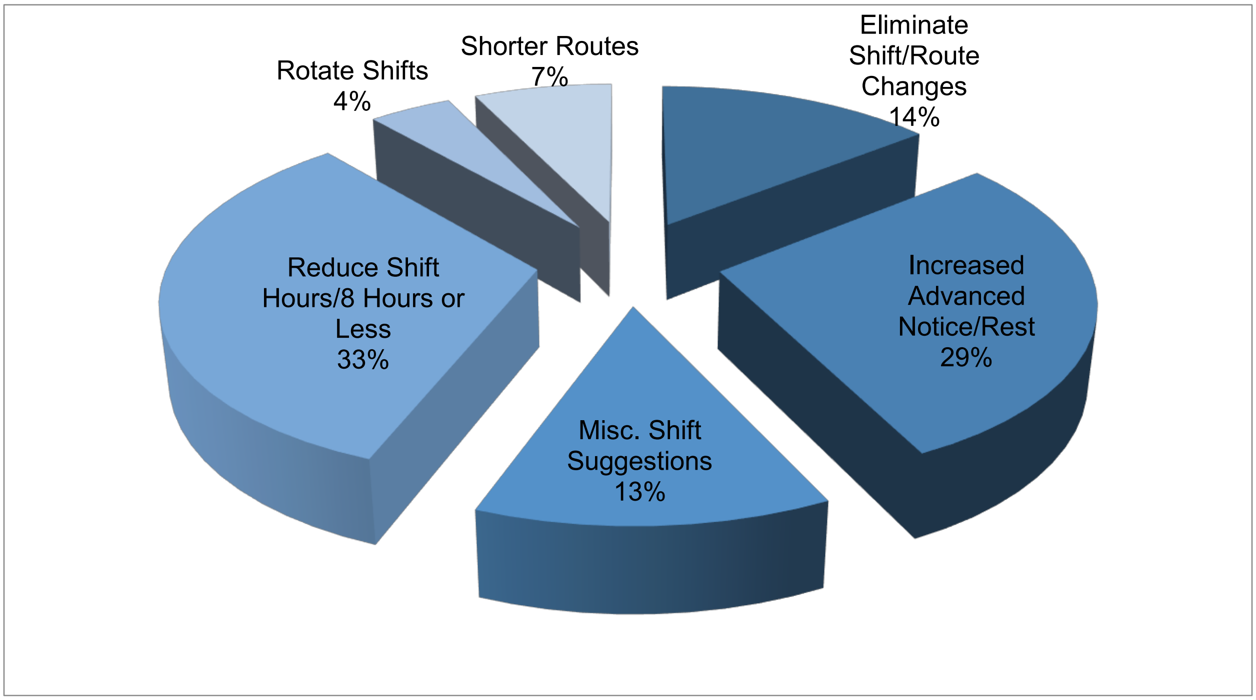


Figure 122. Shift-related Suggestions to Improve Winter Maintenance Operations

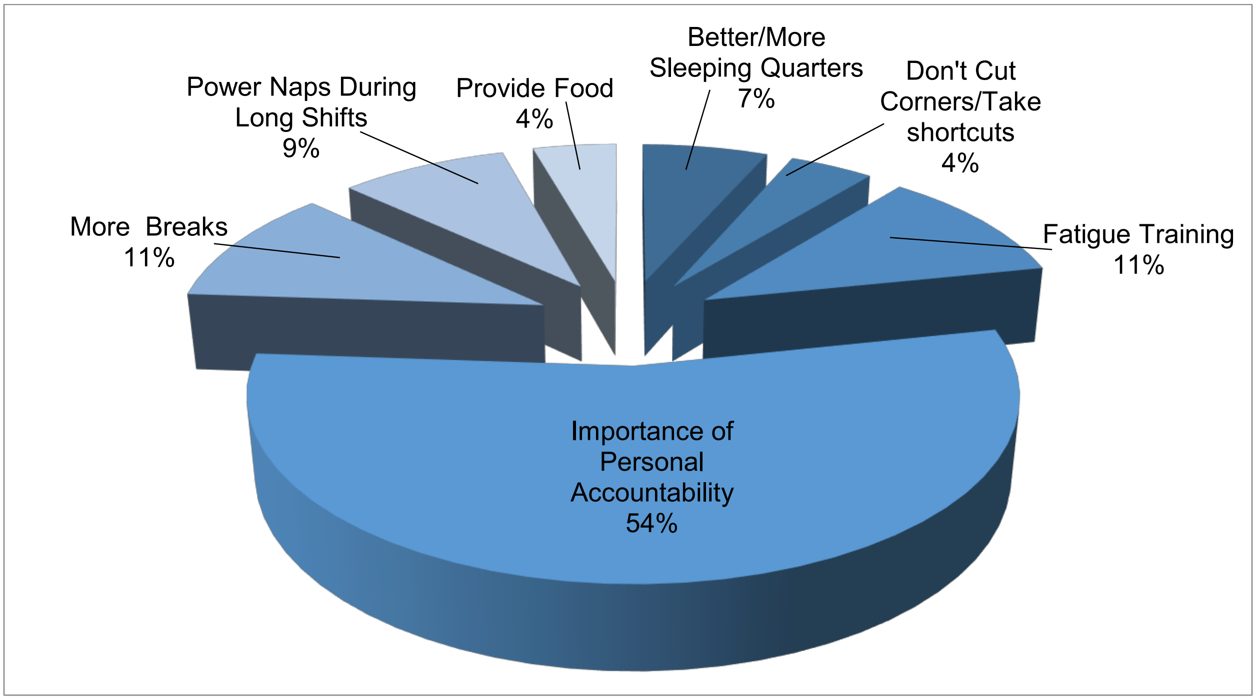


Figure 123. Suggestions to Reduce Fatigue in Winter Maintenance Operations

APPENDIX K – WINTER MAINTENANCE MANAGER QUESTIONNAIRE RESULTS

Figure 124. Managers' Responsibilities

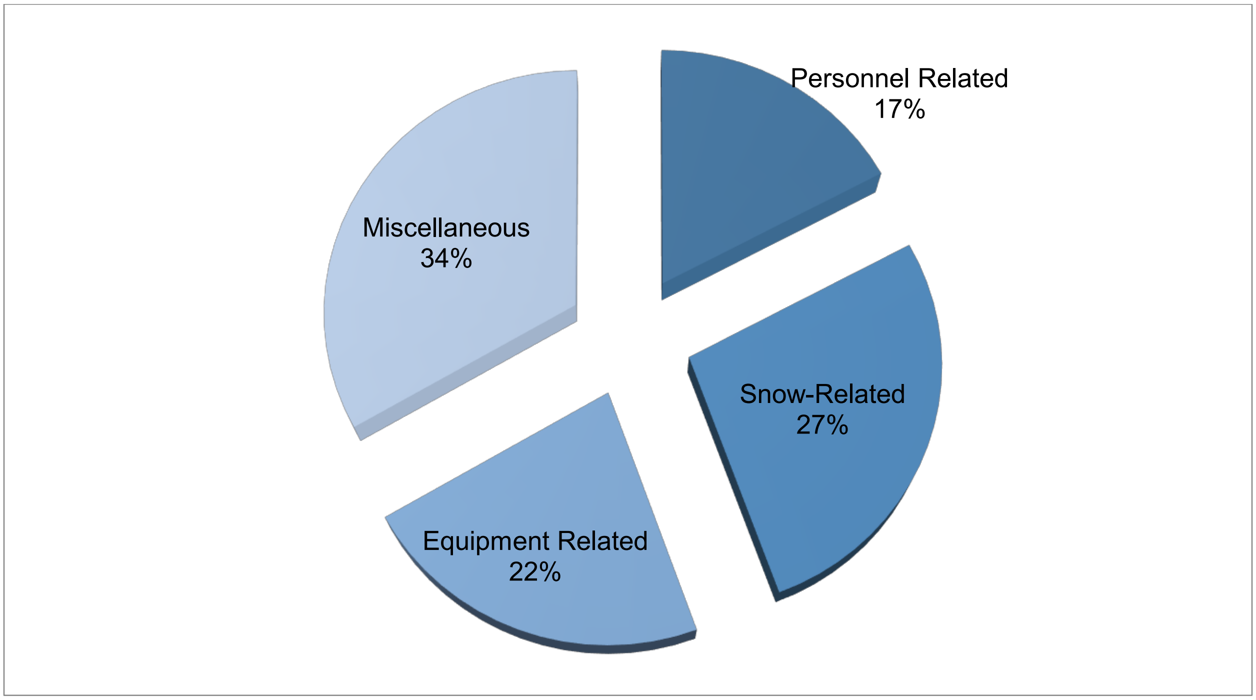


Figure 125. Other Manager Duties, by Themes

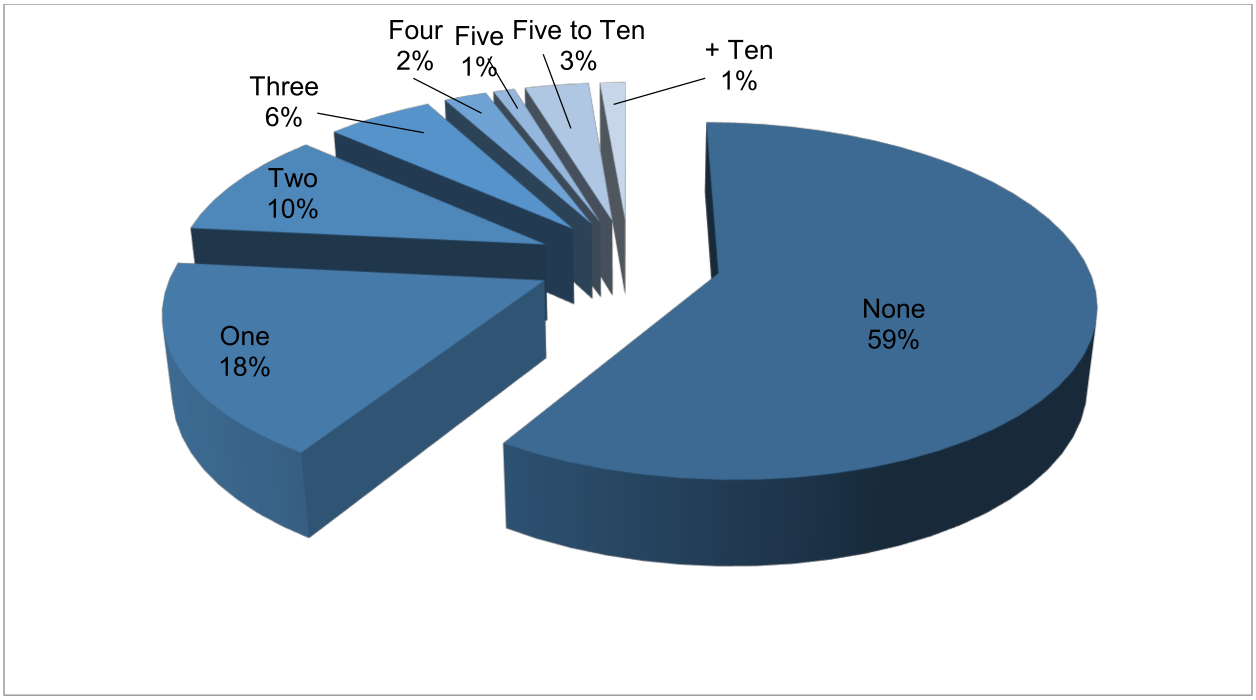


Figure 126. Percent of Managers Reporting a Crash during the Last Year

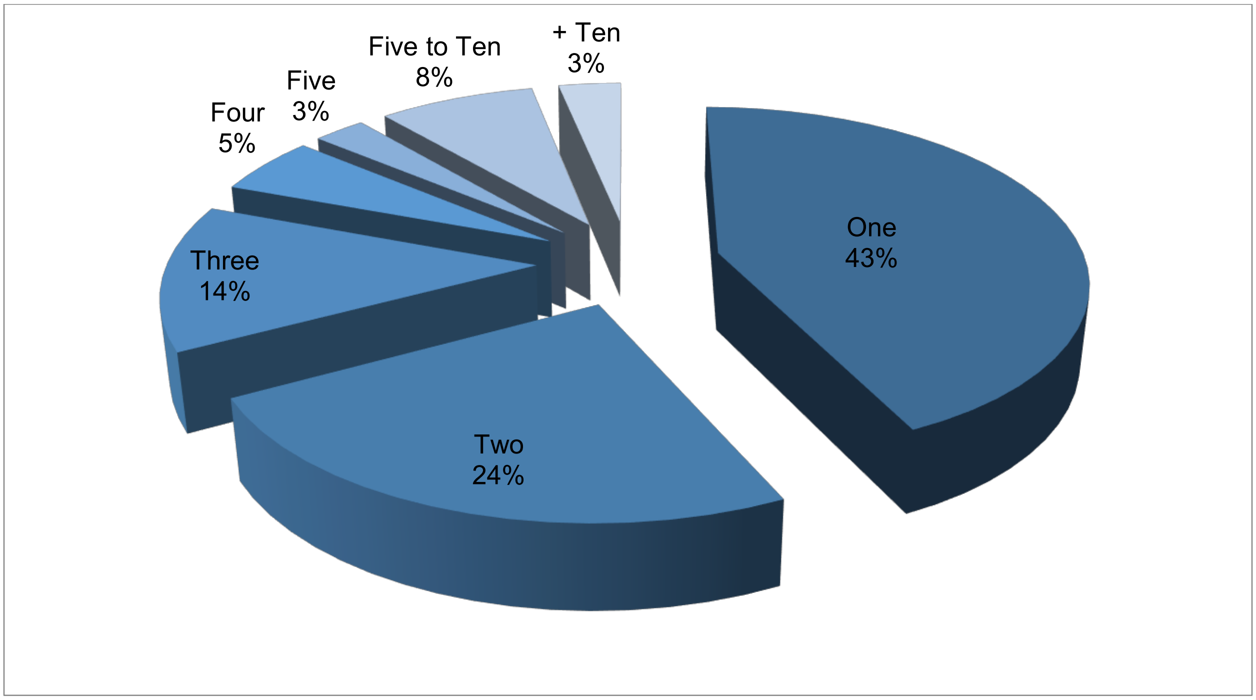


Figure 127. Number of Crashes Reported by Managers

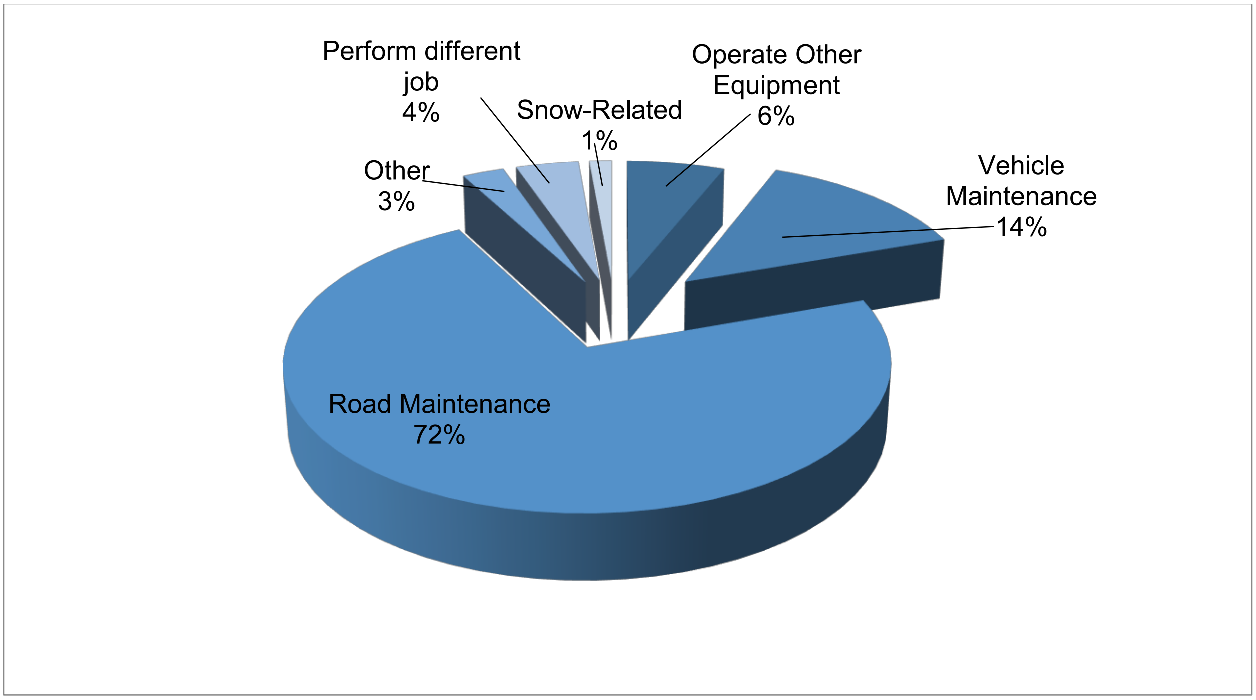


Figure 128. Winter Maintenance Operator Activities When Not involved in Snow Plow Operations

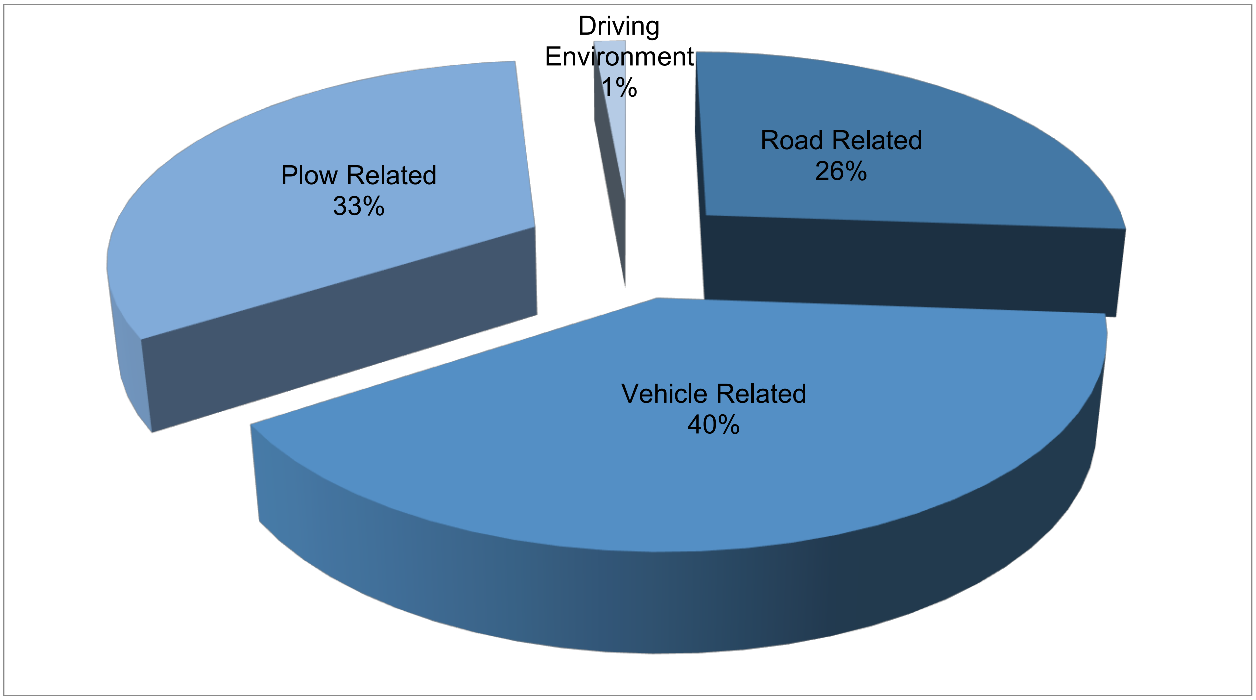


Figure 129 Major Sources of Vibration during Winter Emergencies

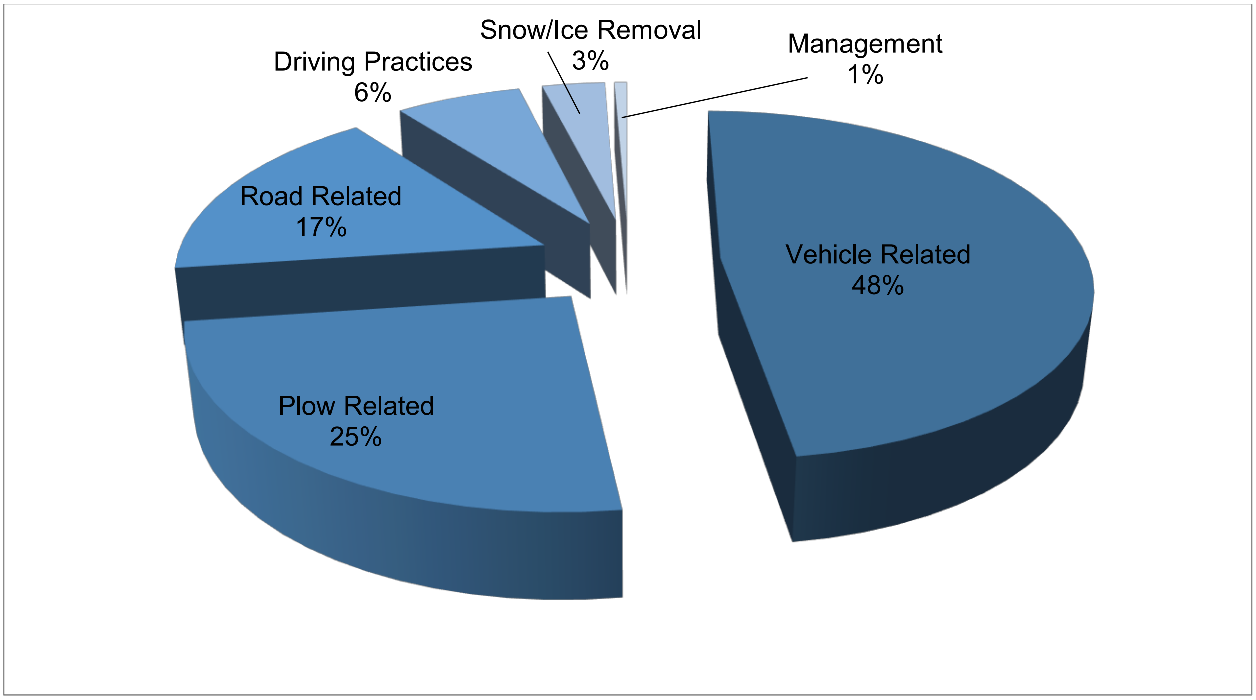


Figure 130. Best Ways to Eliminate Vibration Sources, by Theme

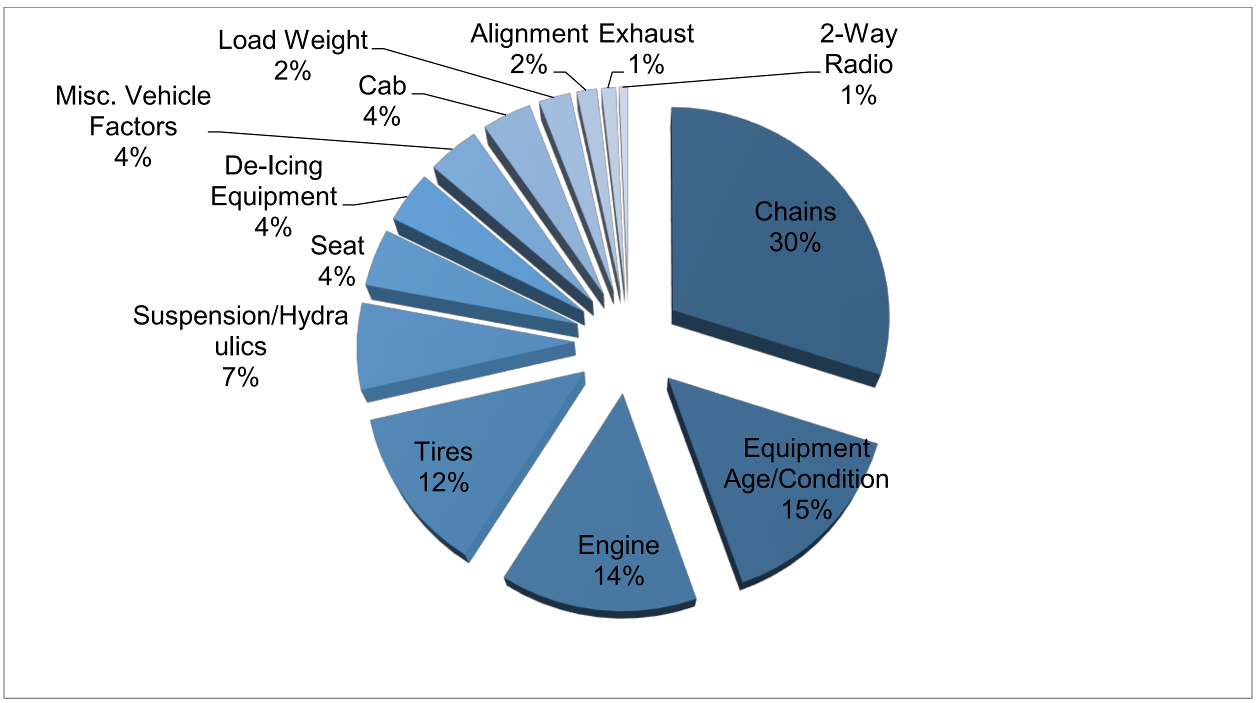


Figure 131. Vehicle-related Sources of Vibration

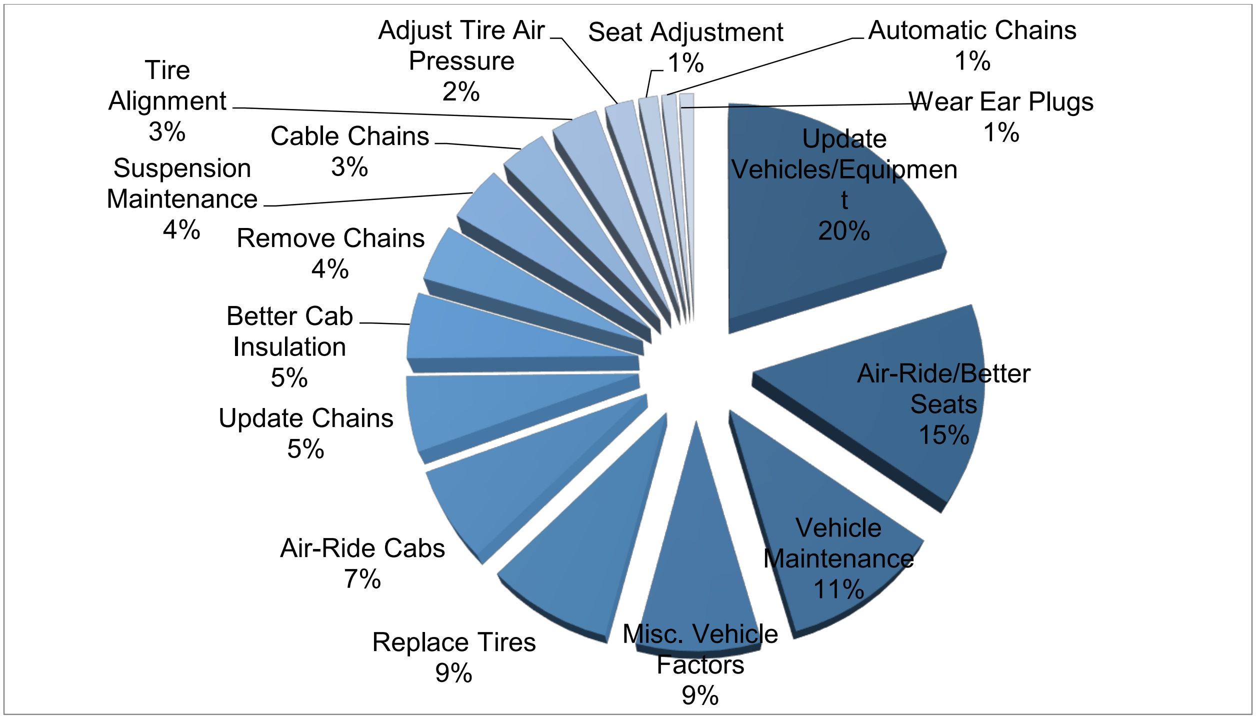


Figure 132. Vehicle-related Ways to Eliminate Vibration

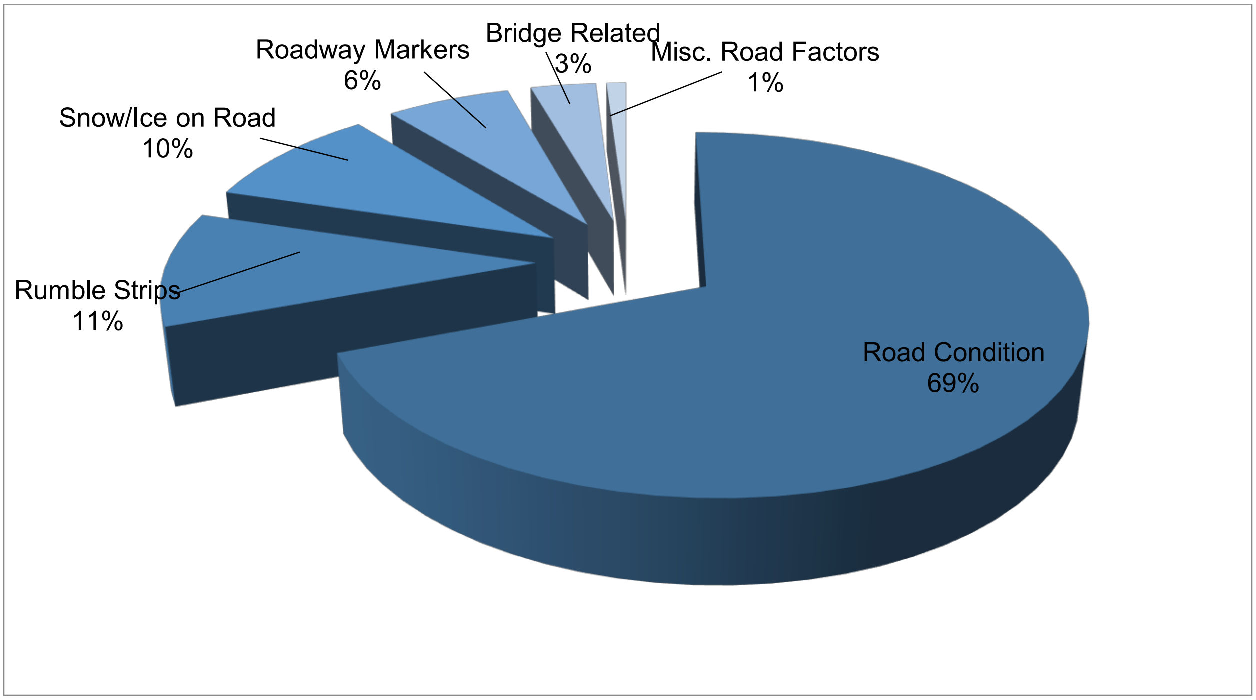


Figure 133. Roadway-related Sources of Vibration

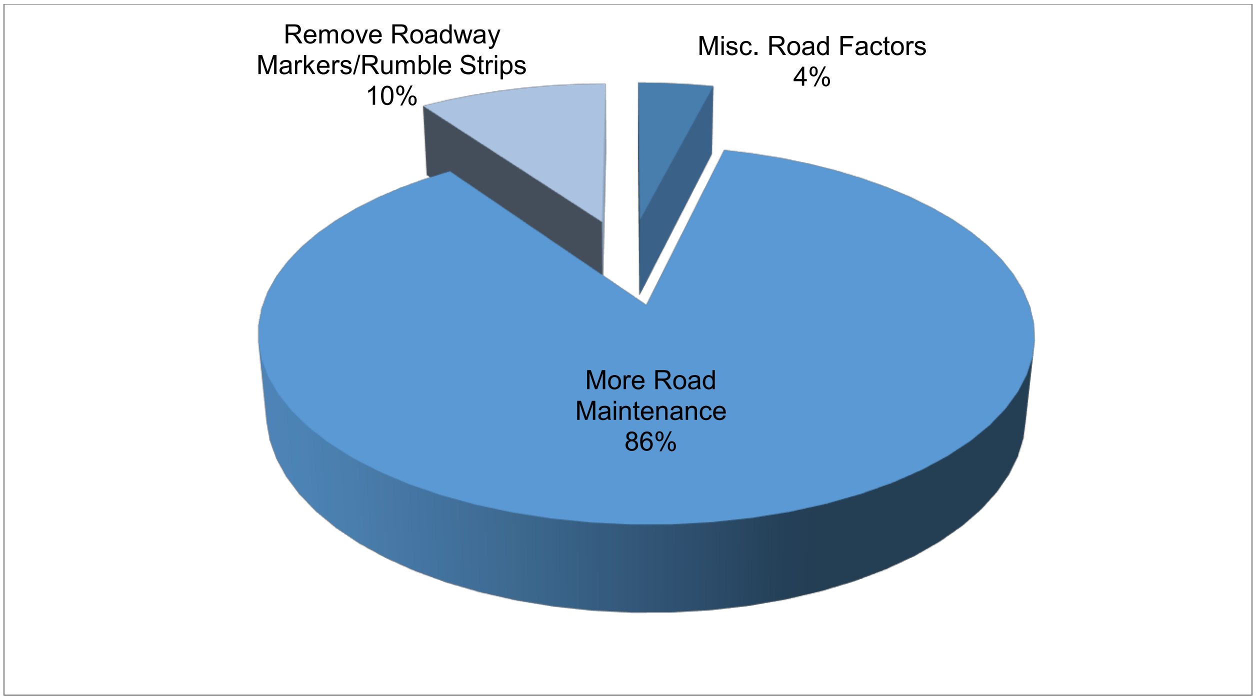


Figure 134. Roadway-related Ways to Eliminate Vibration

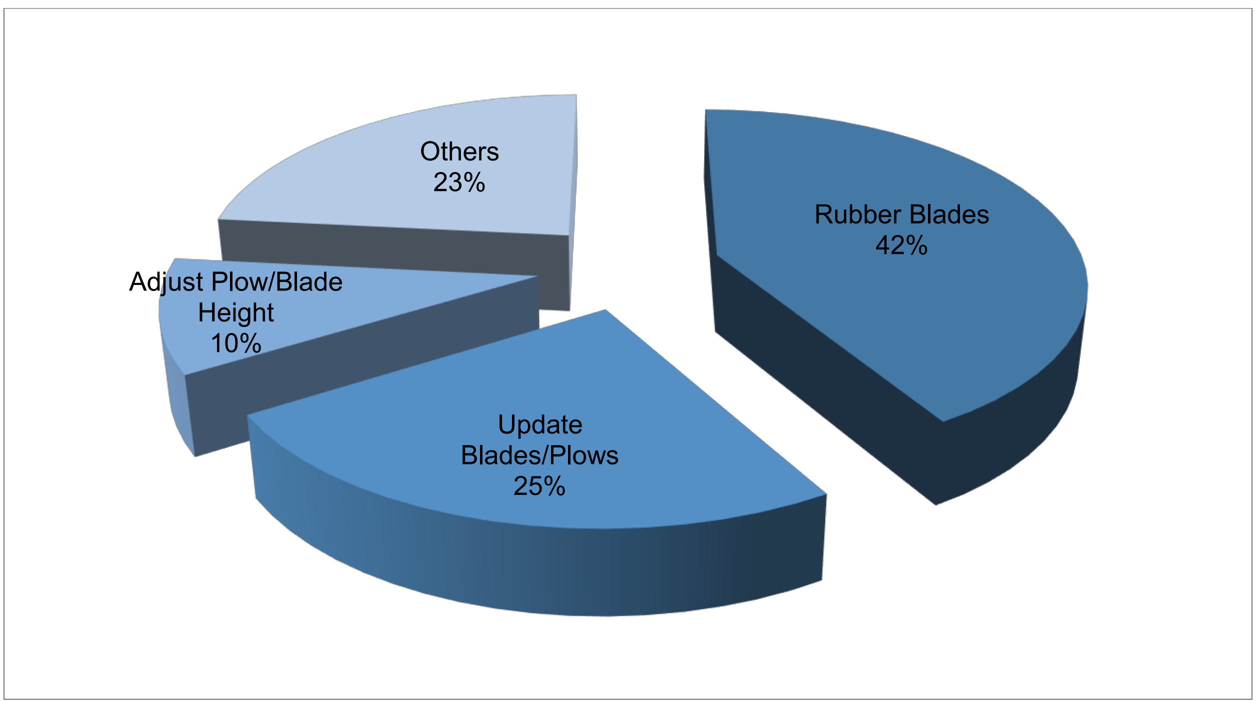


Figure 135. Plow-related Ways to Eliminate Vibration

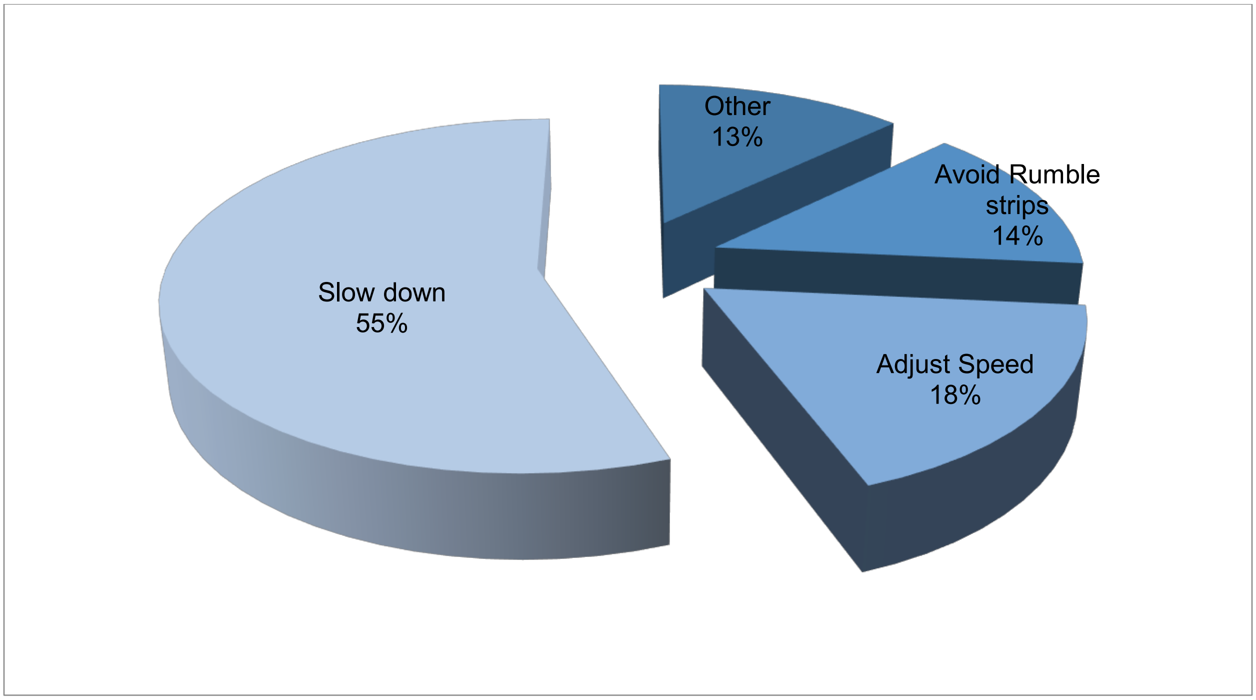


Figure 136. Driving Practices to Eliminate Vibration

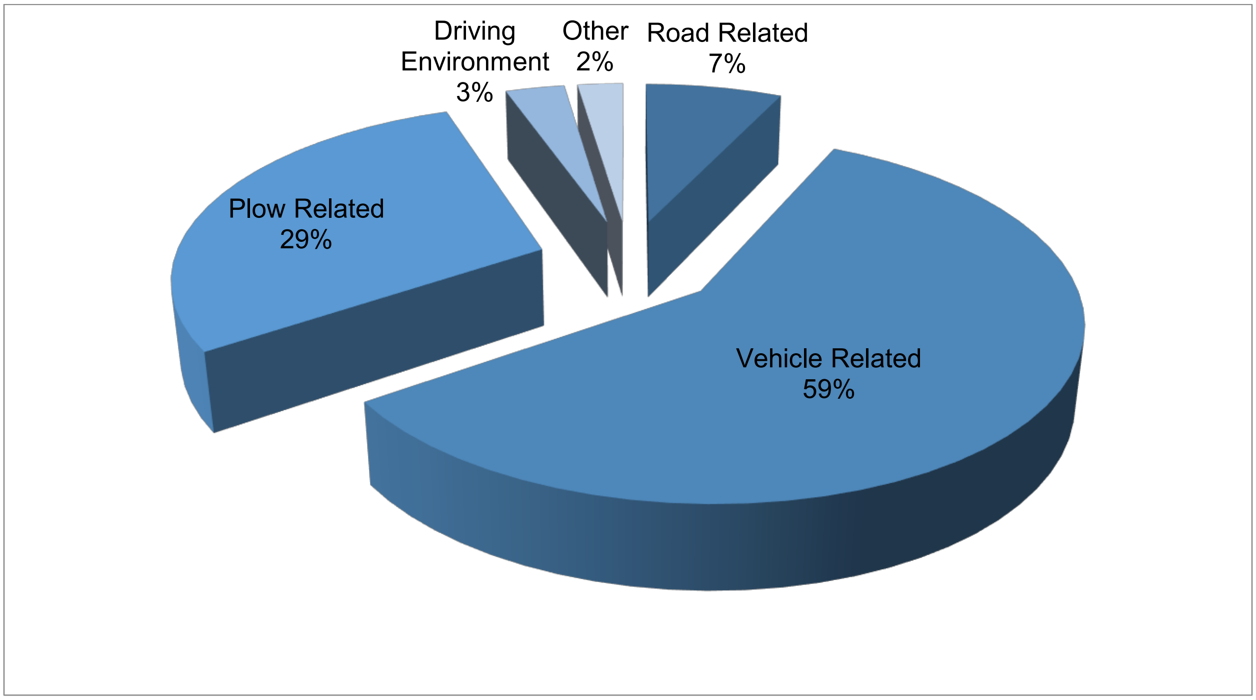


Figure 137. Major Sources of Noise, by Theme

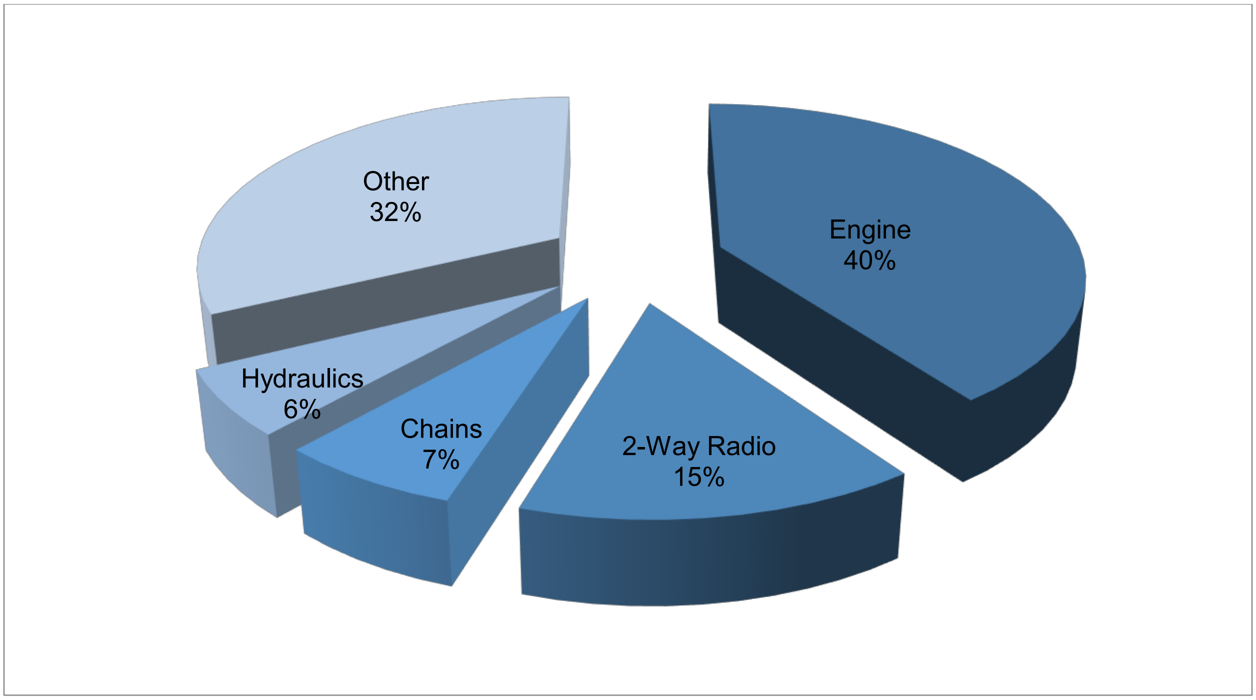


Figure 138. Vehicle-related Sources of Noise

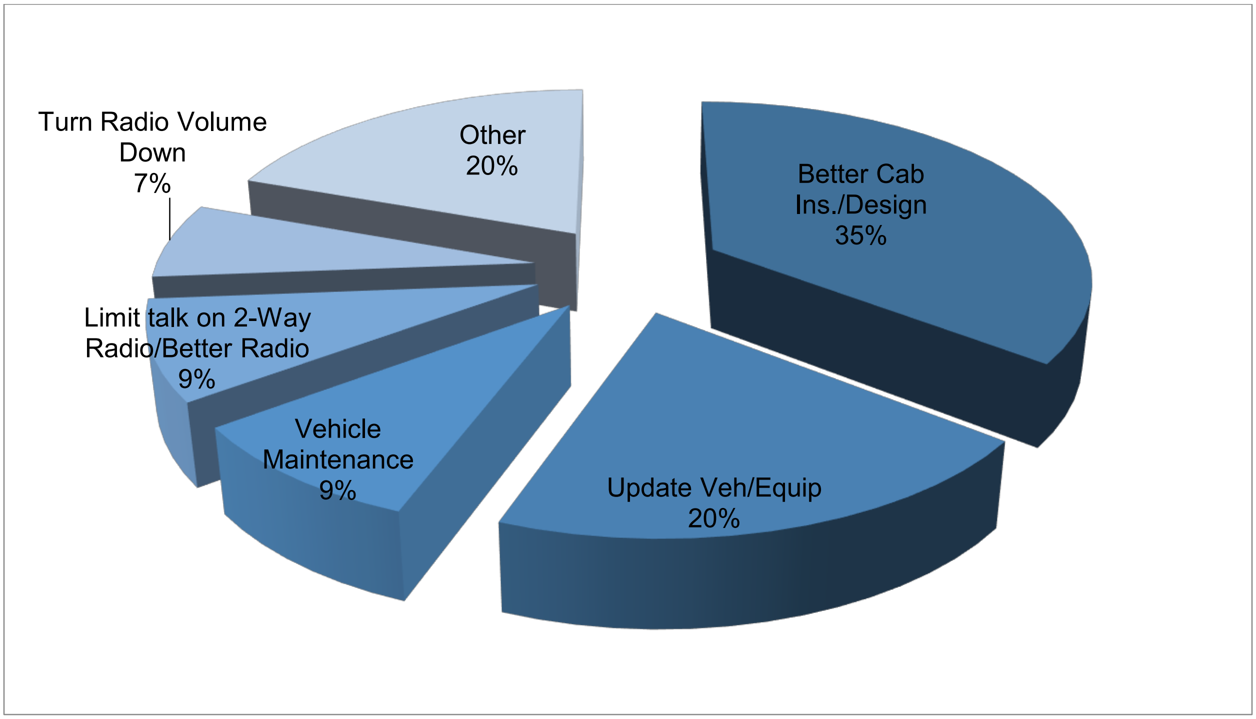


Figure 139. Vehicle-based Methods to Reduce/Eliminate Noise

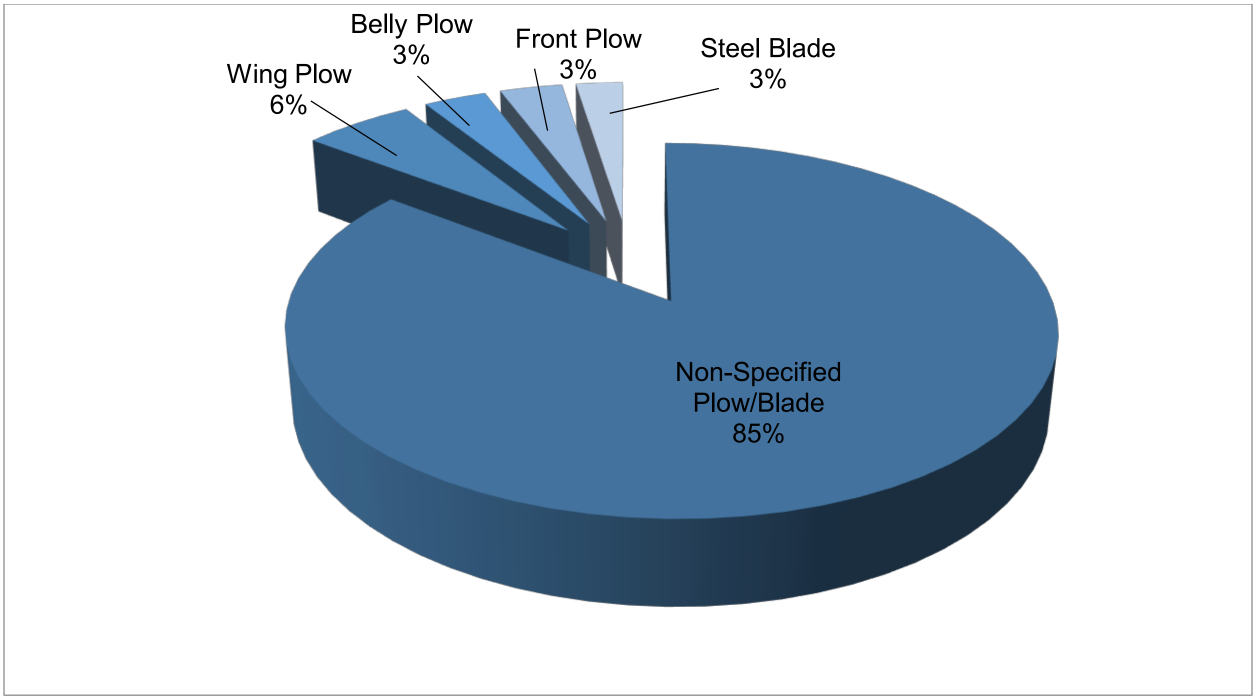


Figure 140. Plow-related Sources of Noise

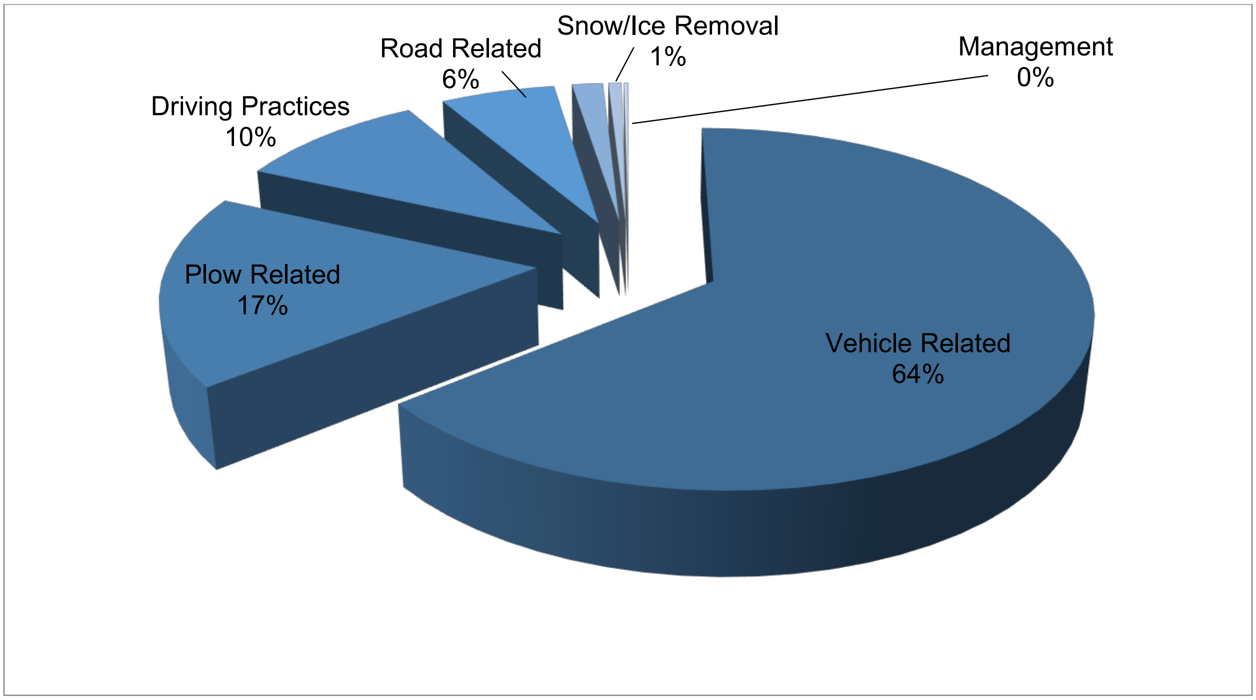


Figure 141. Best Methods to Reduce/Eliminate Noise, by Theme

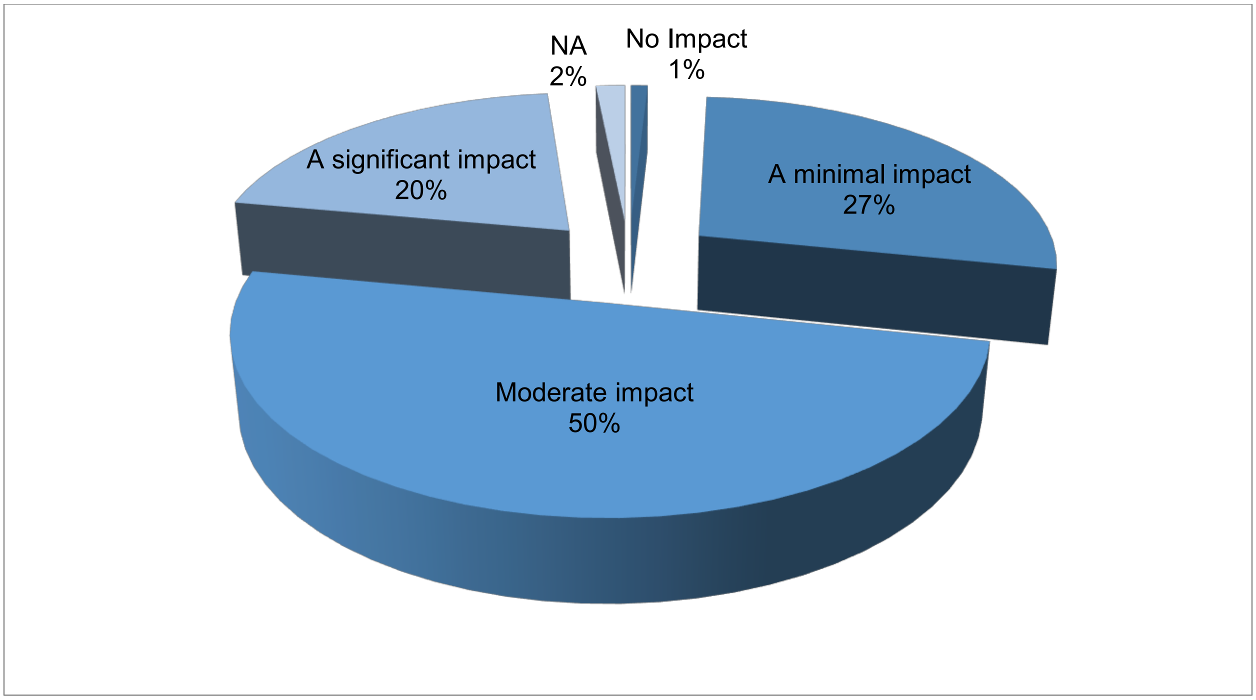


Figure 142. Impact of Fatigue on Winter Maintenance Operations

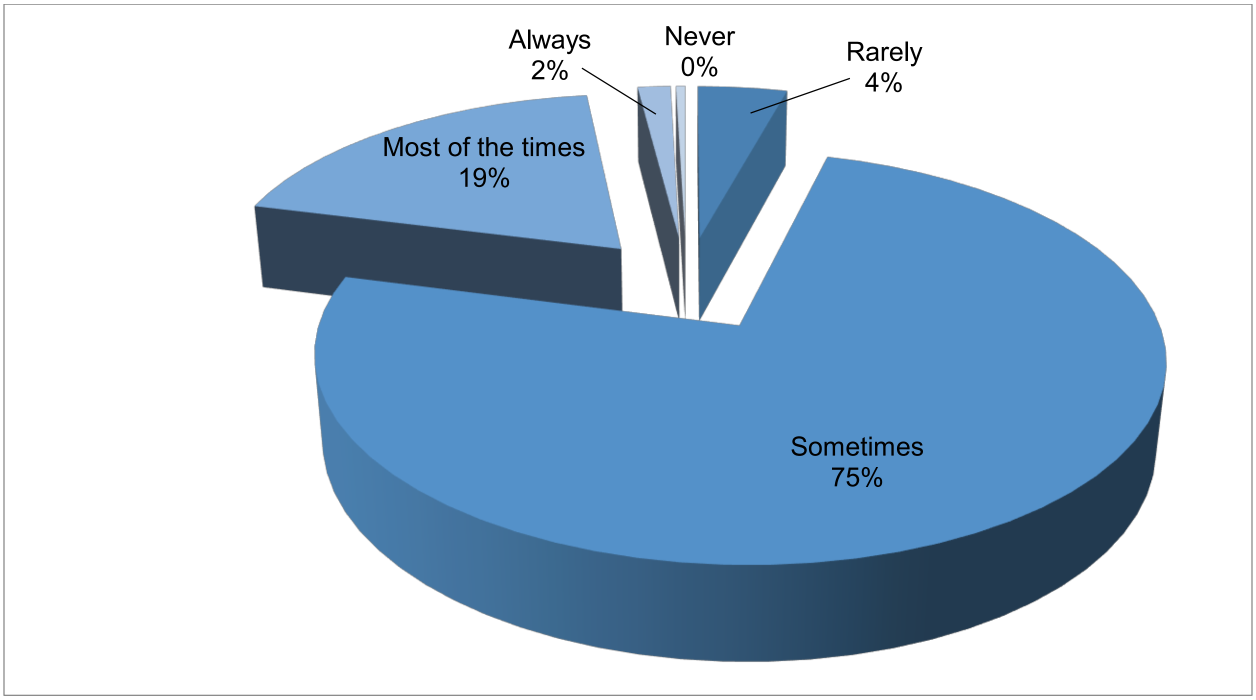


Figure 143. Managers' Estimated Frequency of Winter Maintenance Operators Feeling Tired when Operating a Snow Plow during Winter Emergencies

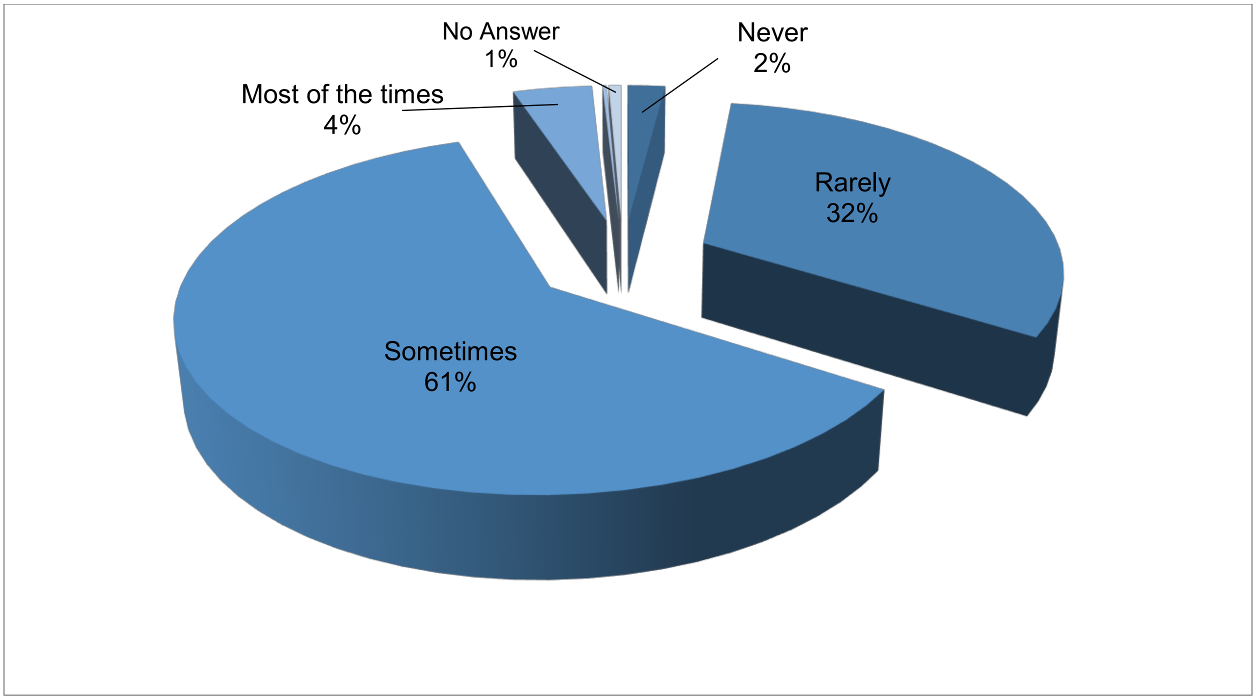


Figure 144. Managers' Estimated Frequency of Winter Maintenance Operators Experiencing a Lapse of Concentration when Operating a Snow Plow during Winter Emergencies

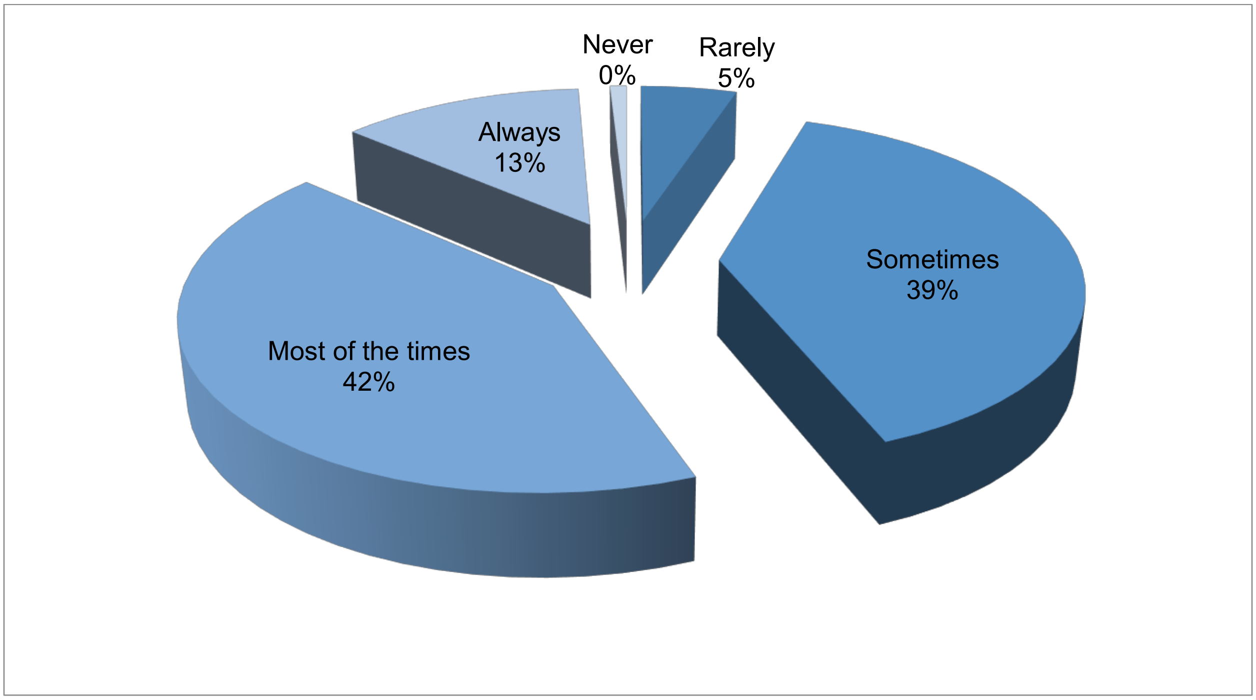


Figure 145. Managers' Estimated Frequency of Winter Maintenance Operators Feeling Extremely Tired after Completing Winter Emergency Shift

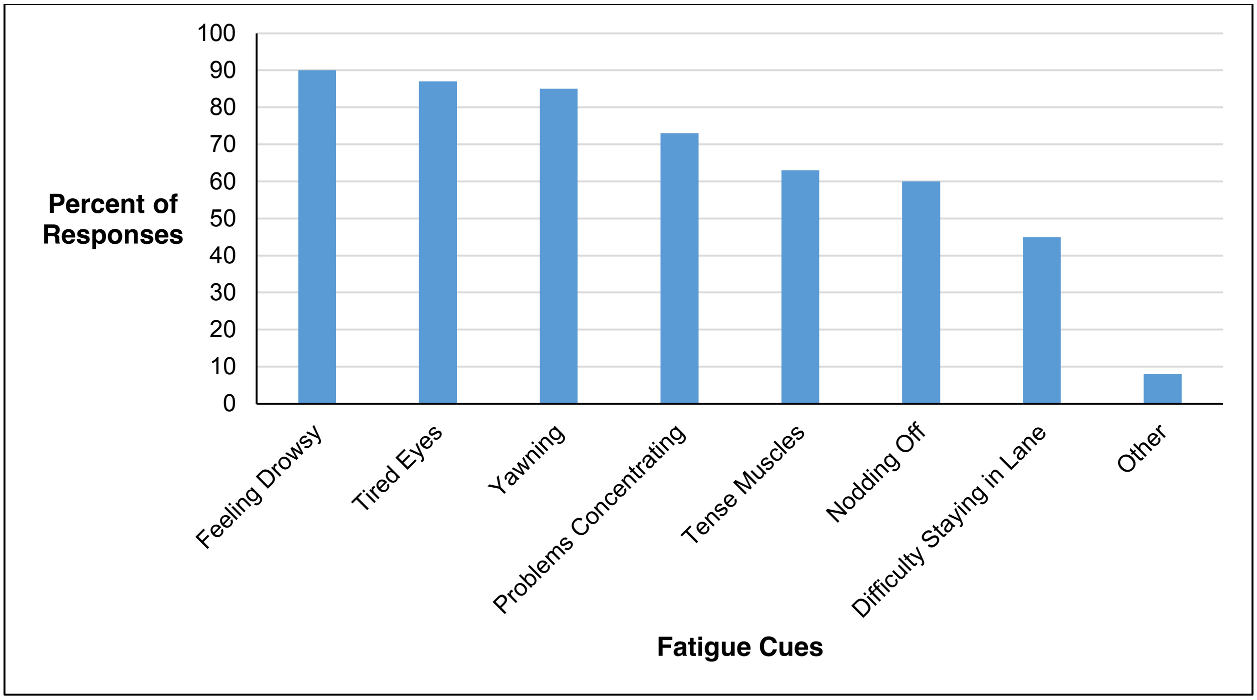


Figure 146. Managers' Opinions of How Winter Maintenance Drivers Know They are Tired

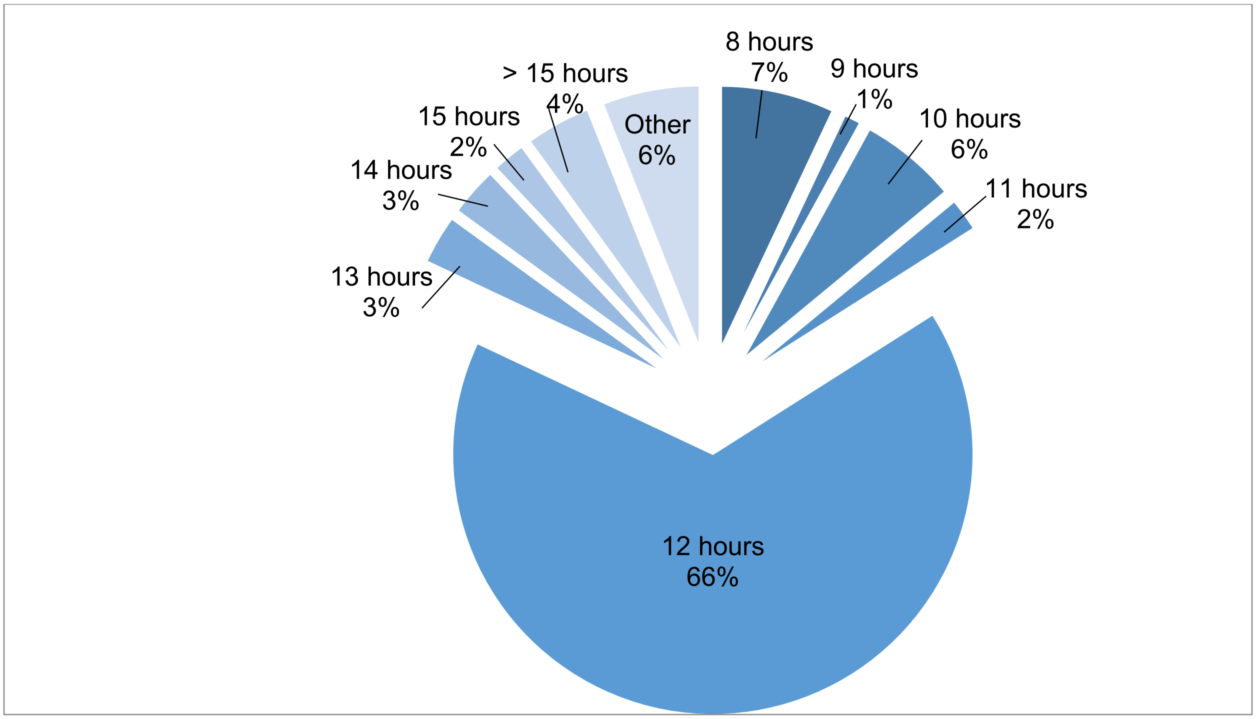


Figure 147. Length in Hours of a "Normal Shift" during a Winter Emergency

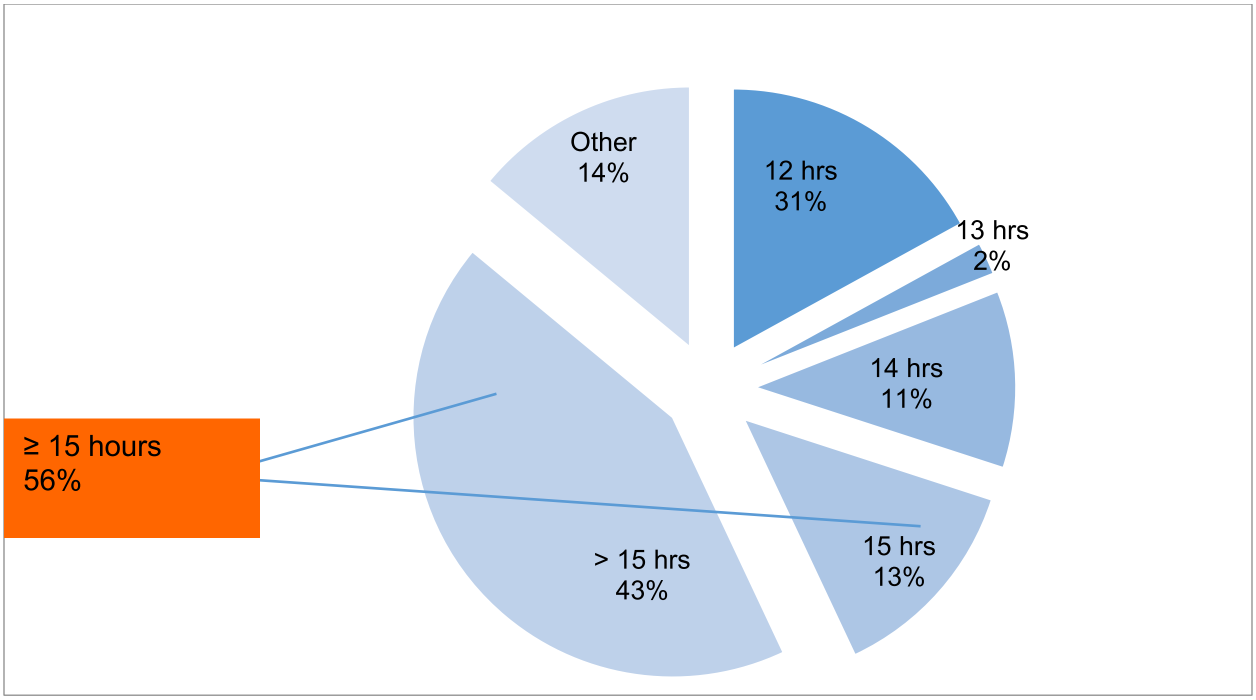


Figure 148. Maximum Number of Hours a Winter Maintenance Operator Worked during a Winter Emergency

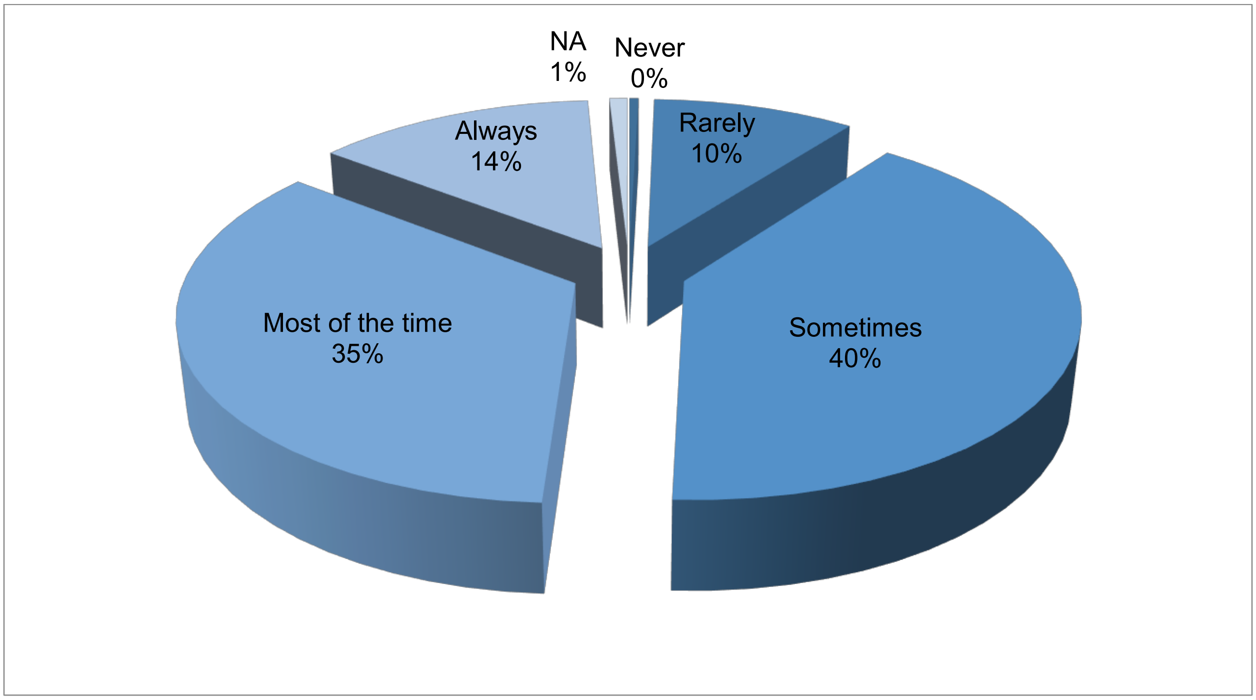


Figure 149. How Often a Winter Maintenance Operator is Asked to Work on Less Than 8 Hours' Notice

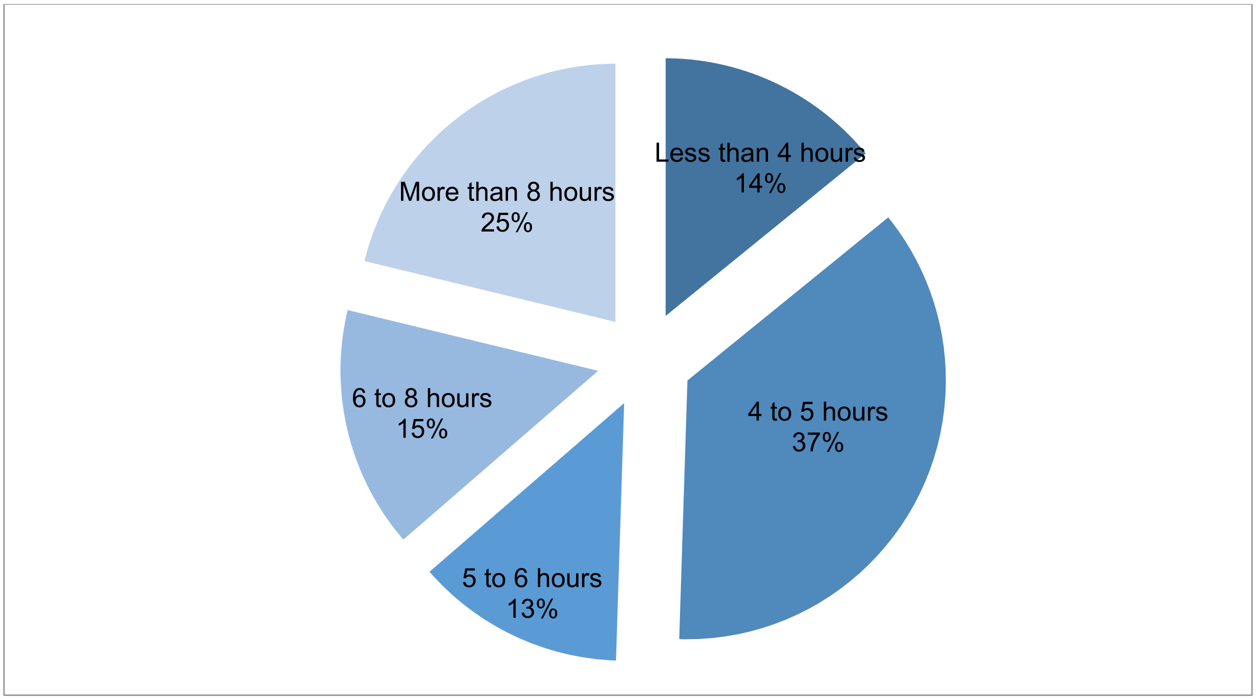


Figure 150. Maximum Number of Hours a Winter Maintenance Operator Can Drive during Winter Emergencies before Taking a Break

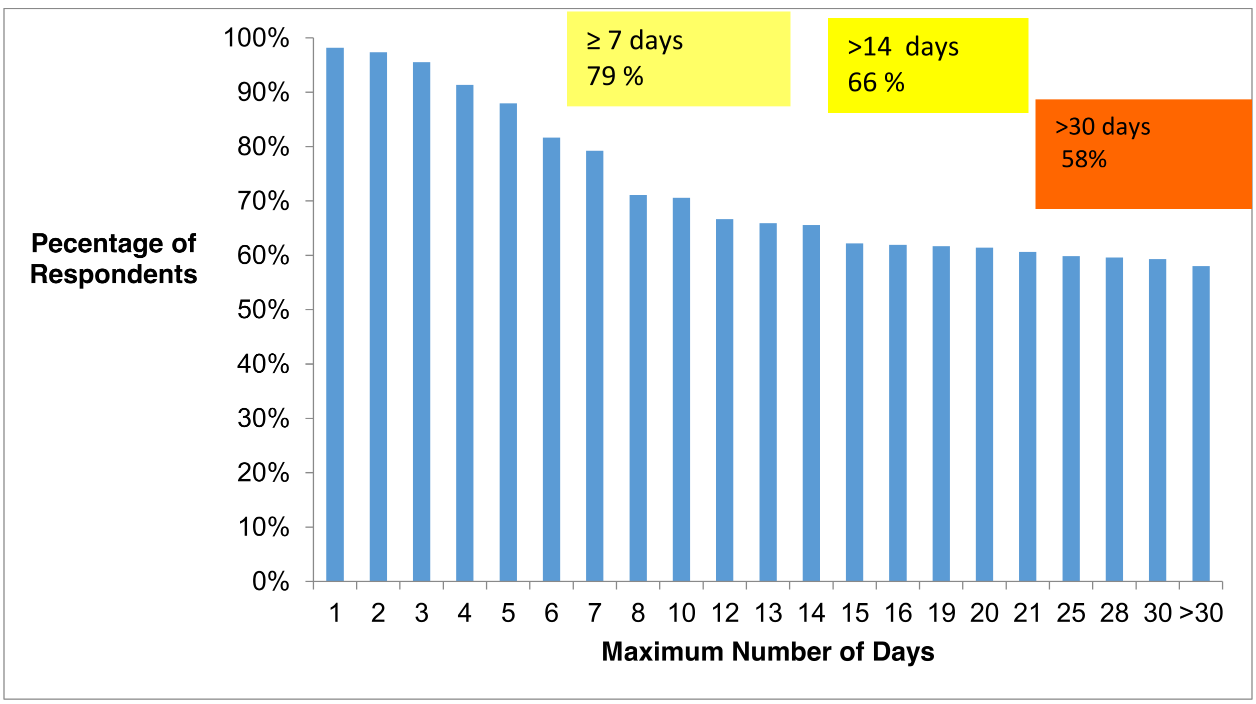


Figure 151. Number of Continuous Days a Winter Maintenance Operator Can Work Before Taking a Day Off during Winter Emergencies

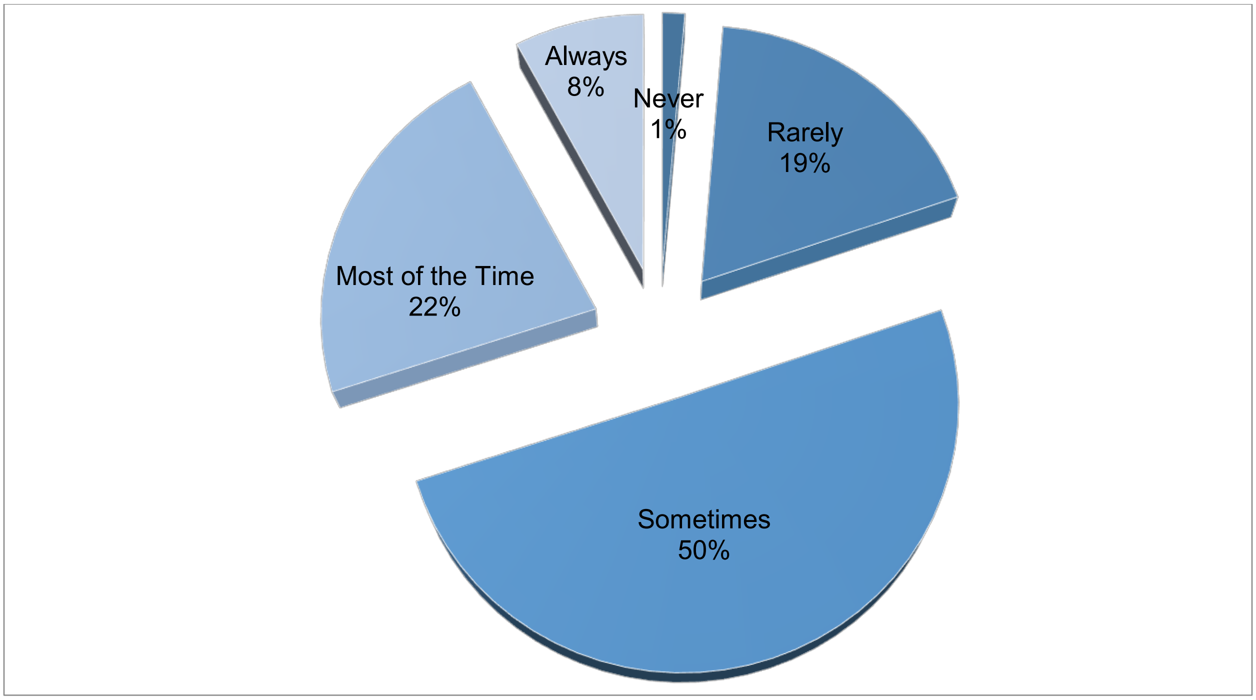


Figure 152. Maximum Number of Hours a Winter Maintenance Operator Can Drive during Winter Emergencies before Taking a Break

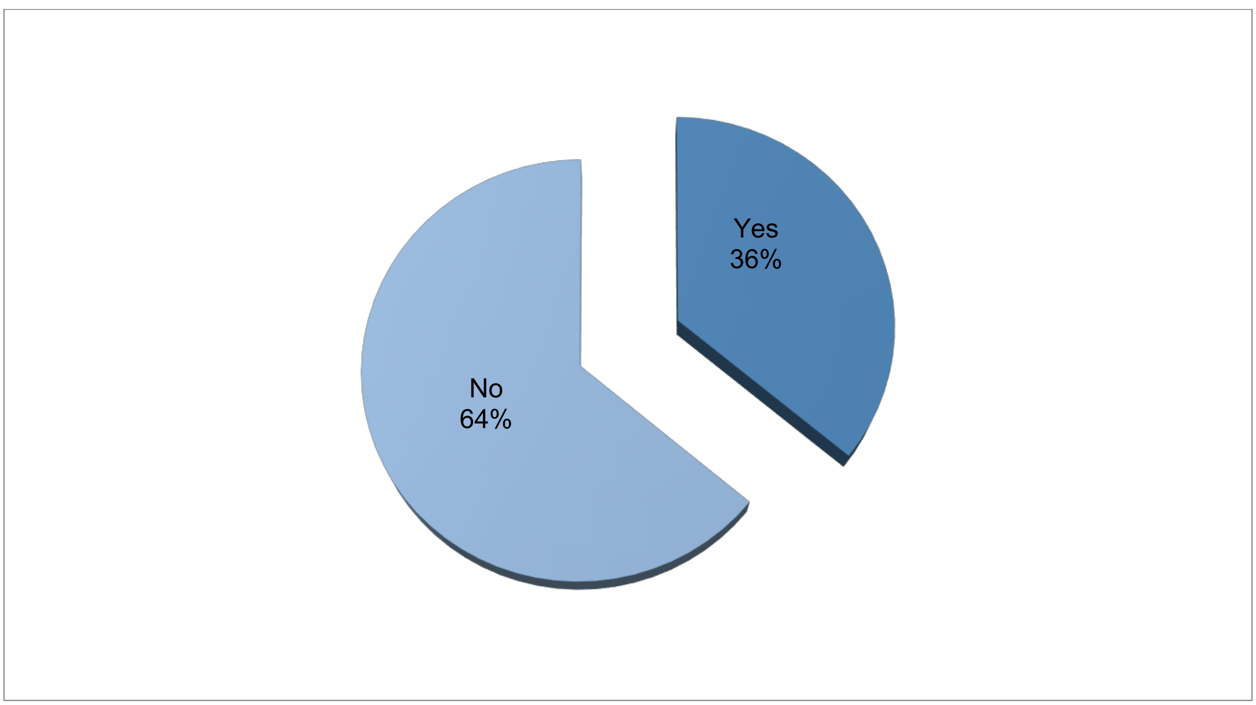


Figure 153. Are Winter Maintenance Operators Required to Take Regular Breaks during Winter Emergencies?

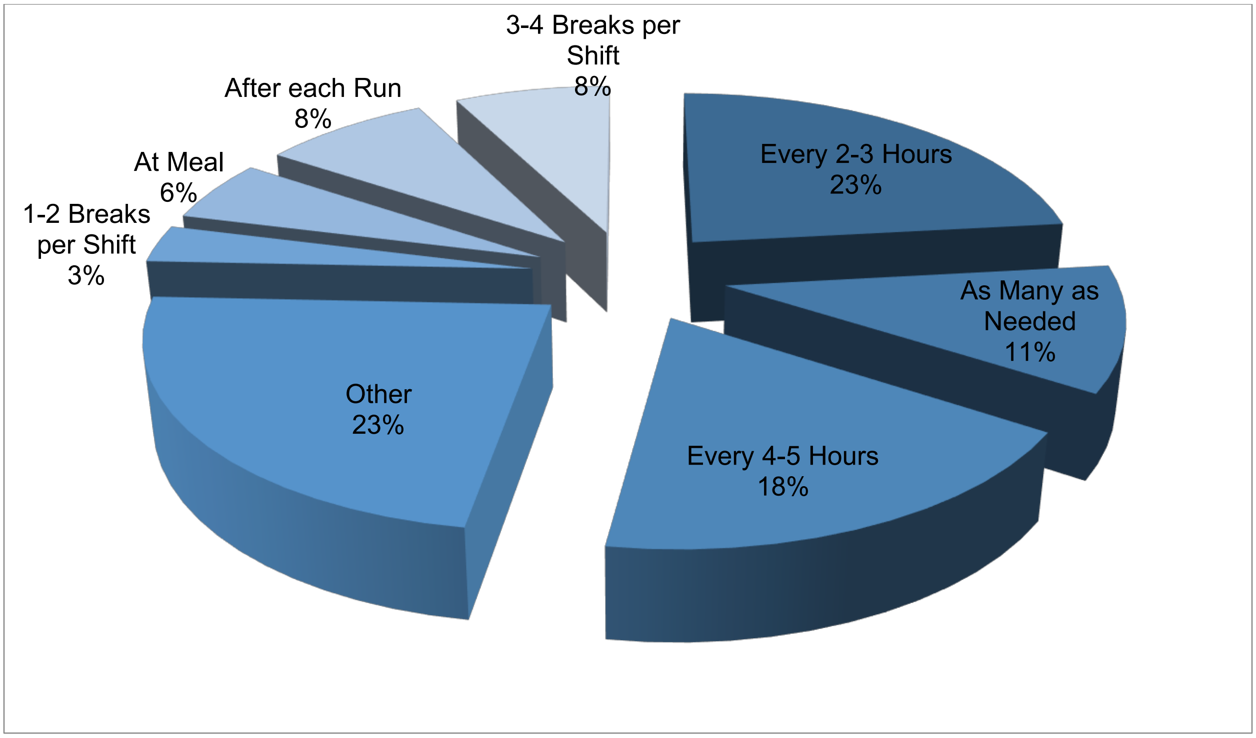


Figure 154. How Often Winter Maintenance Operators are Required to Take Regular Breaks during Winter Emergencies

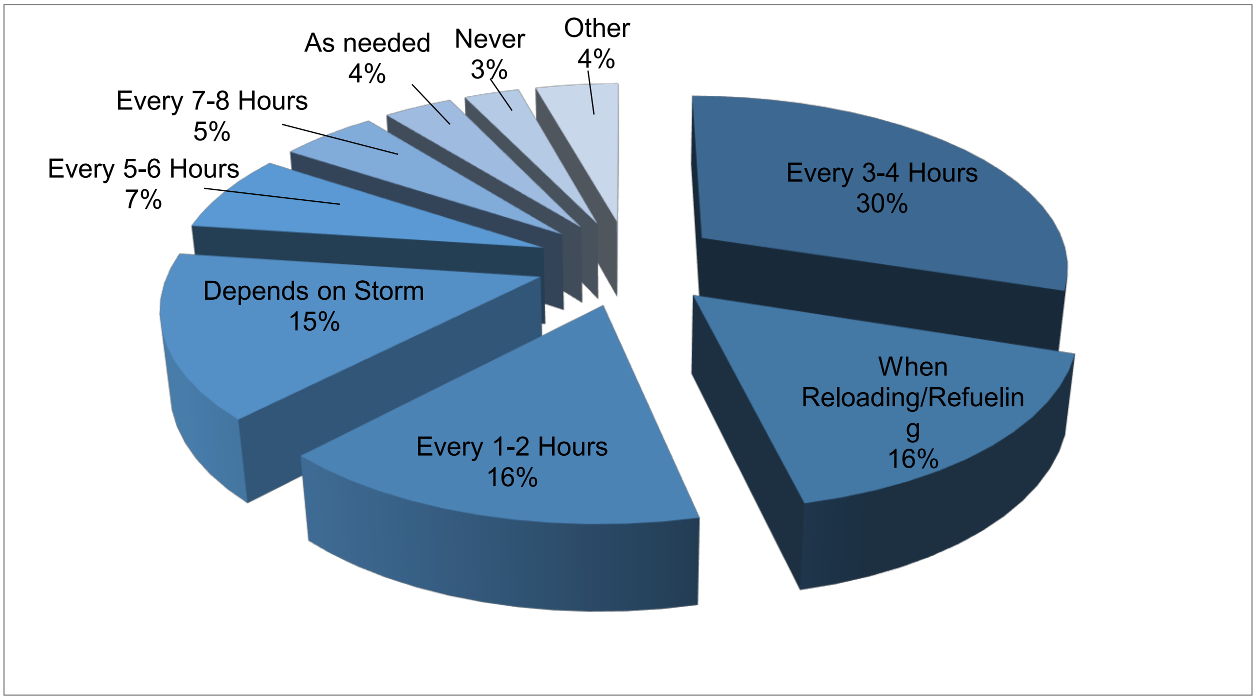


Figure 155. How Often Winter Maintenance Operators Actually Take a Break during Winter Emergencies

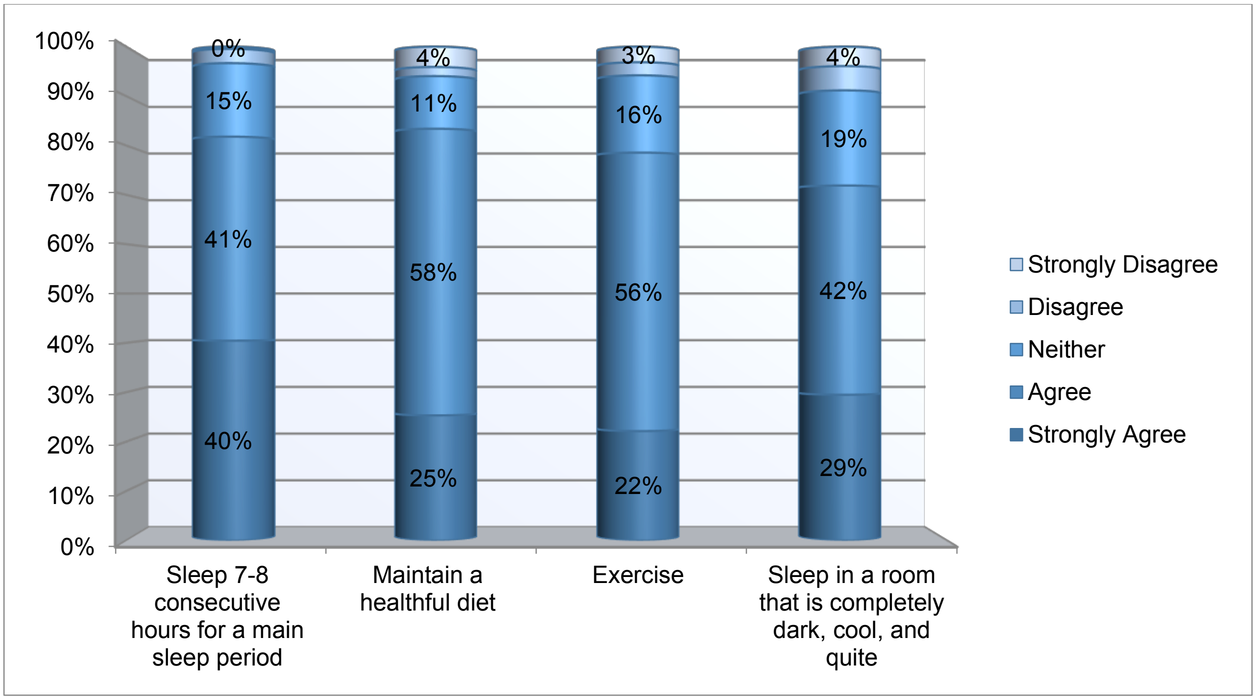


Figure 156. Opinions Regarding Ability to Prevent Winter Maintenance Operators from Becoming Fatigued while Driving

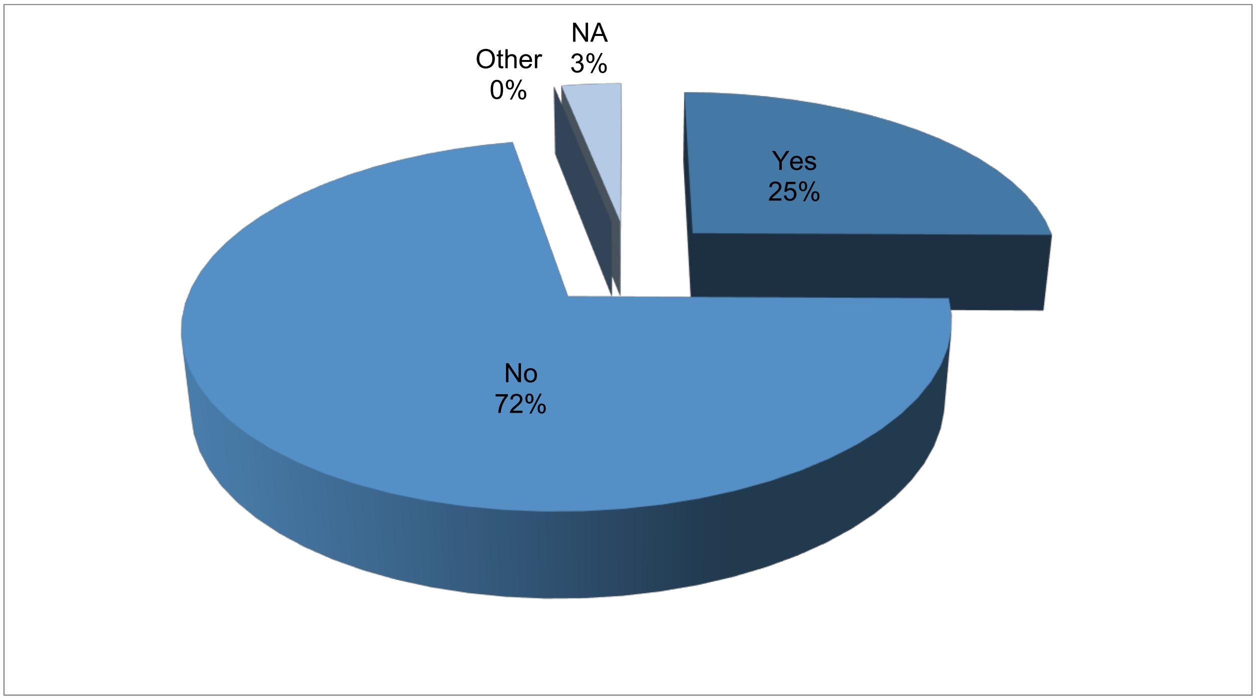


Figure 157. Are Procedures in Place to Test if the Winter Maintenance Operator is Fit to Begin Work?

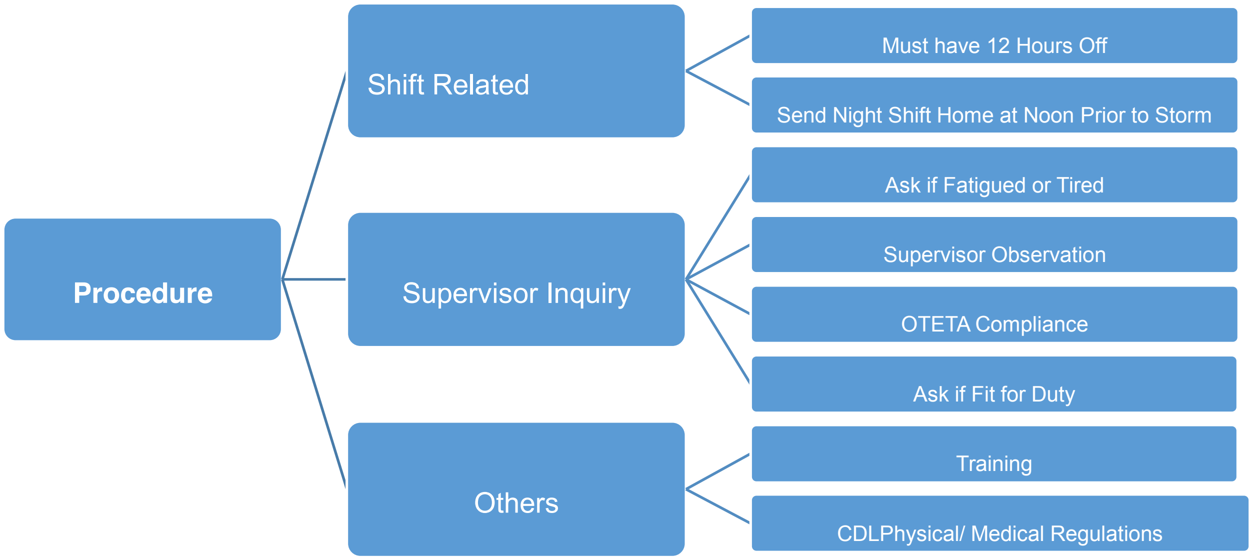


Figure 158. Procedures in Place to Determine Fitness for Duty

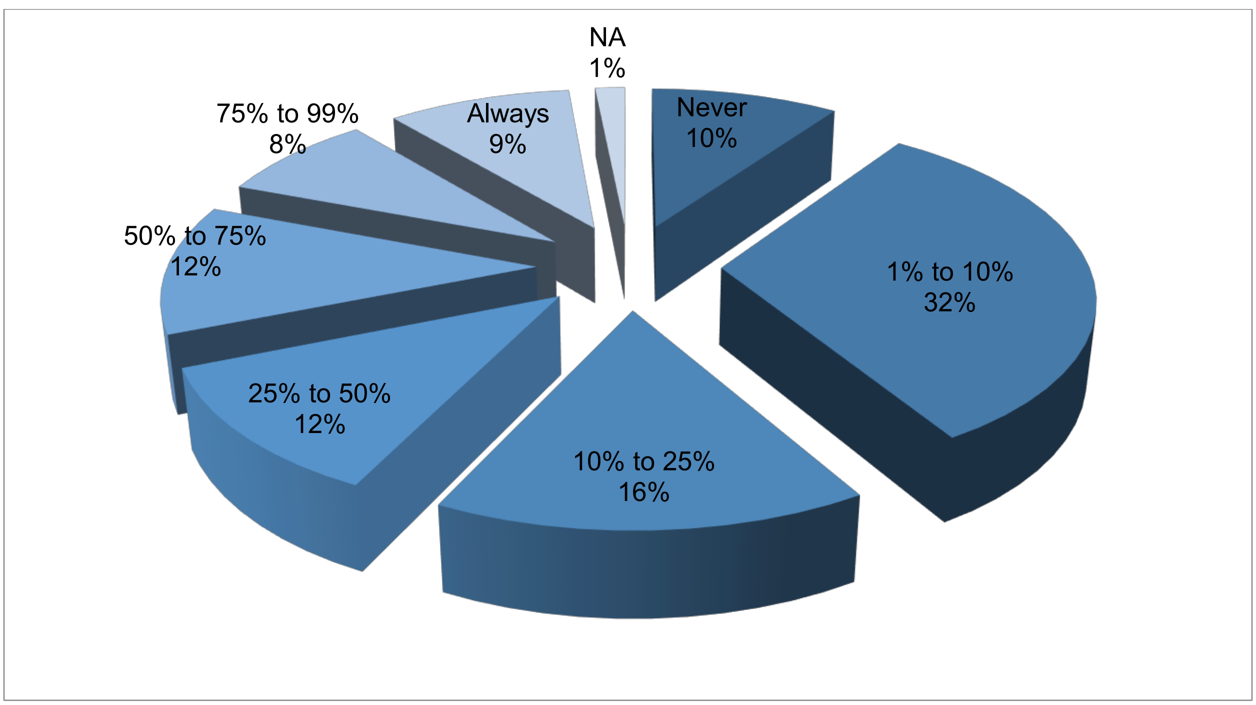


Figure 159. Percent of Time a Winter Maintenance Operator has Dozed Off while Operating a Snow Plow during Winter Emergencies

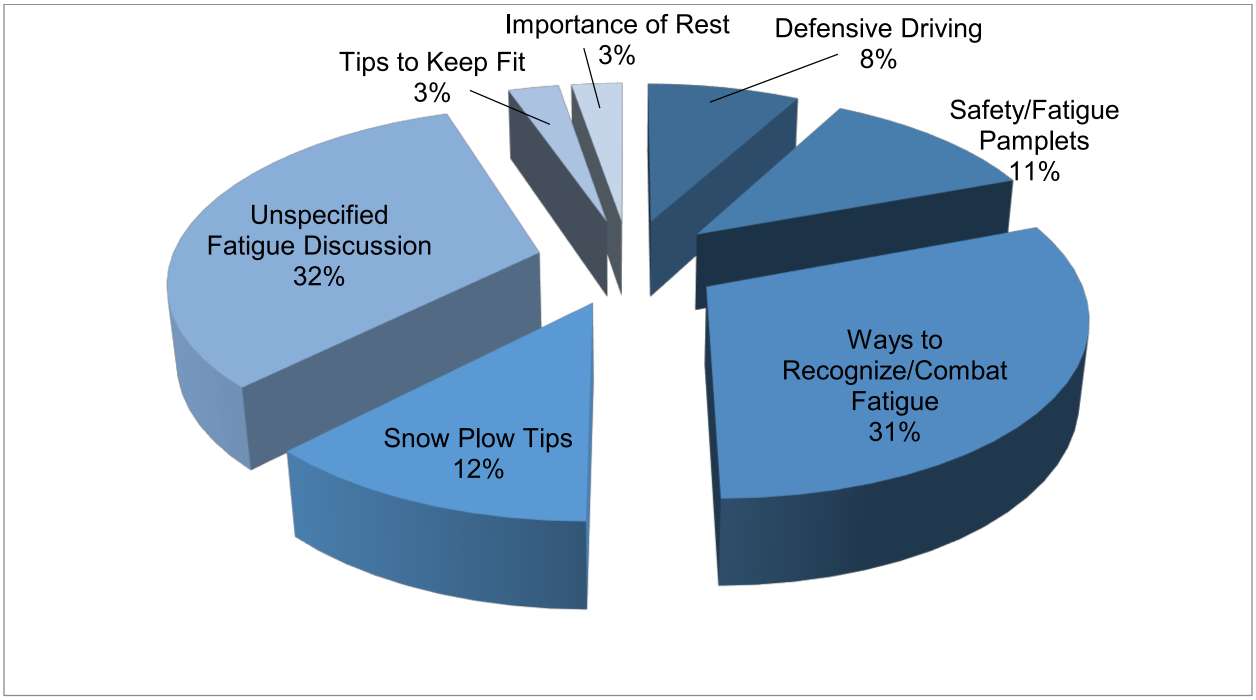


Figure 160. Training Topics

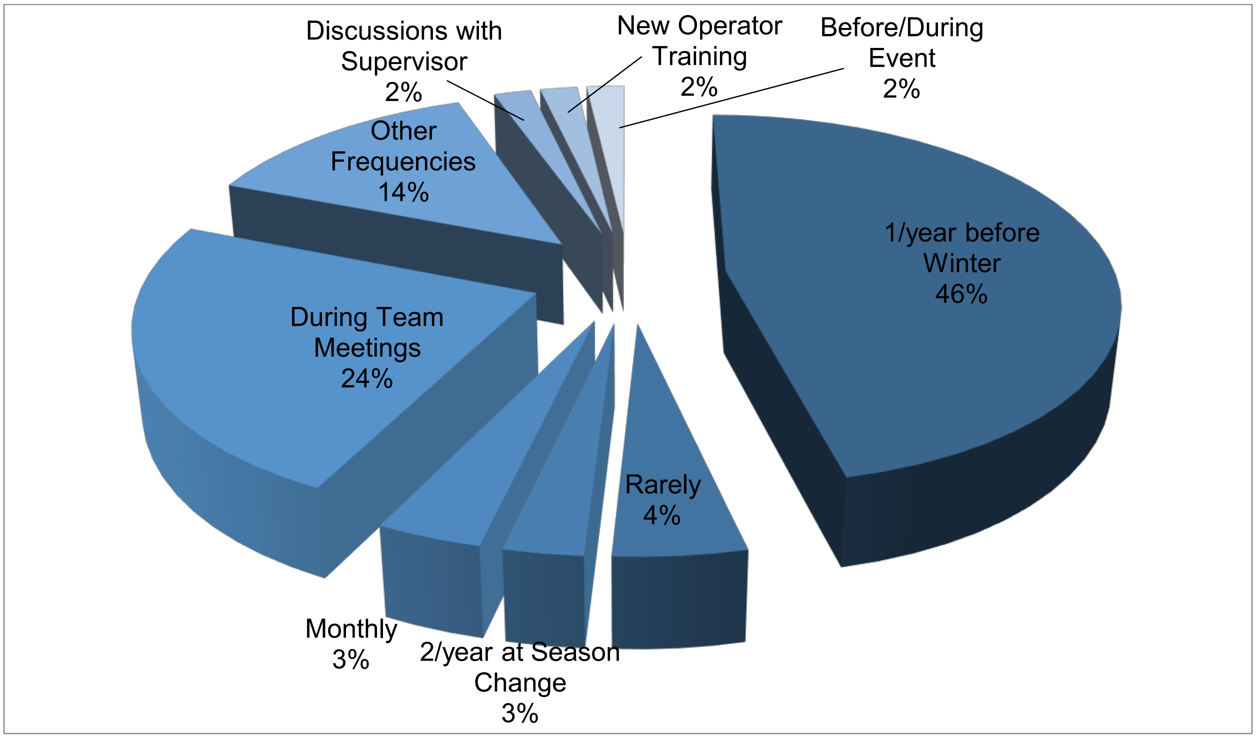


Figure 161. Fatigue Training Frequencies

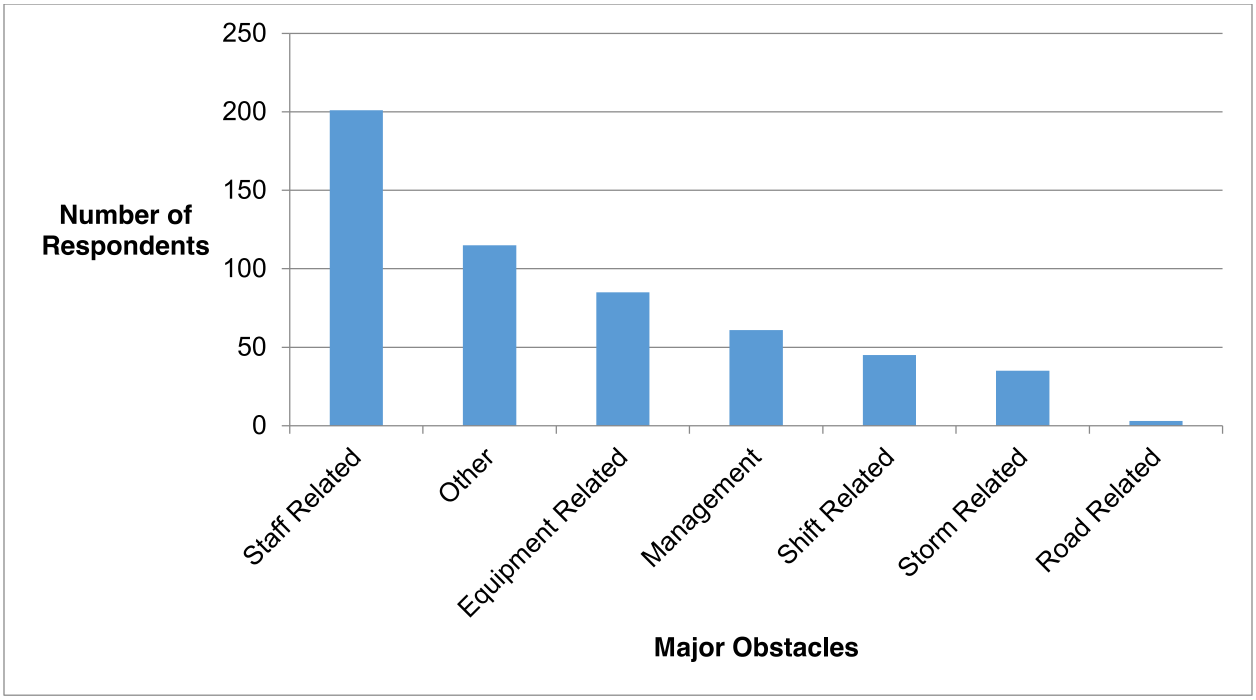


Figure 162. Major Obstacles to Combat Fatigue

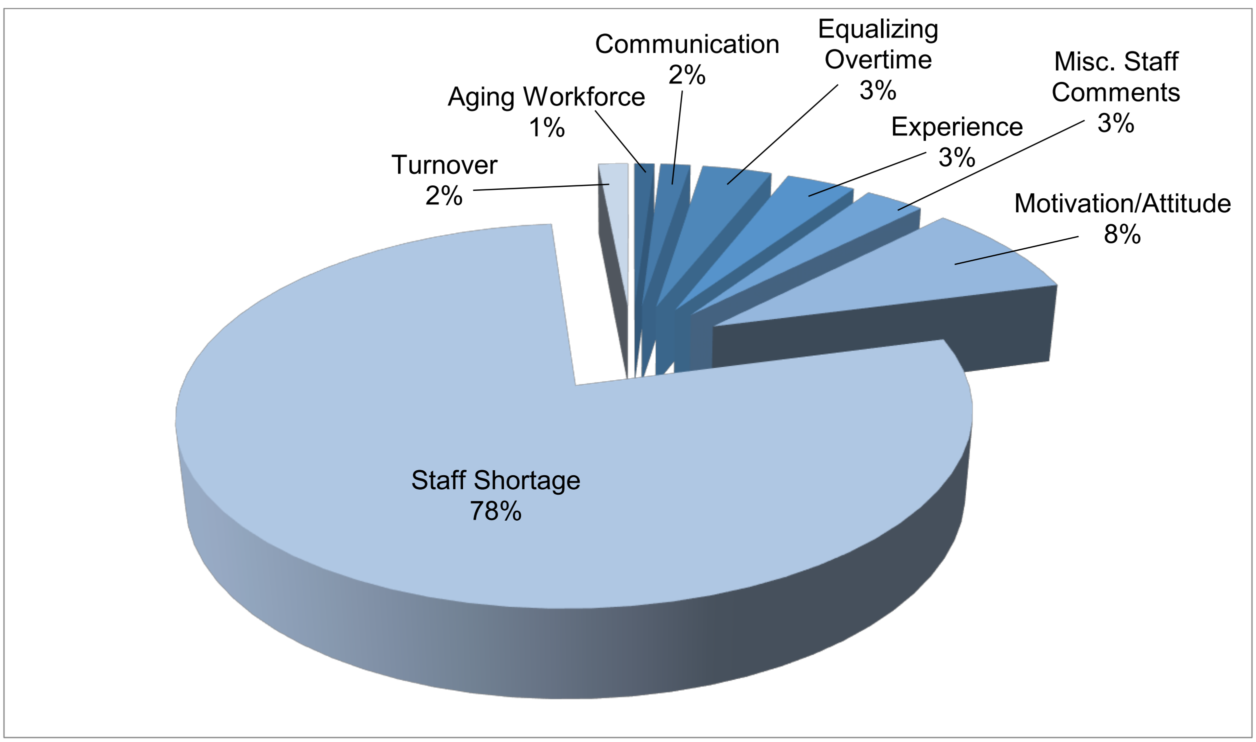


Figure 163. Staff-related Obstacles to Combat Fatigue

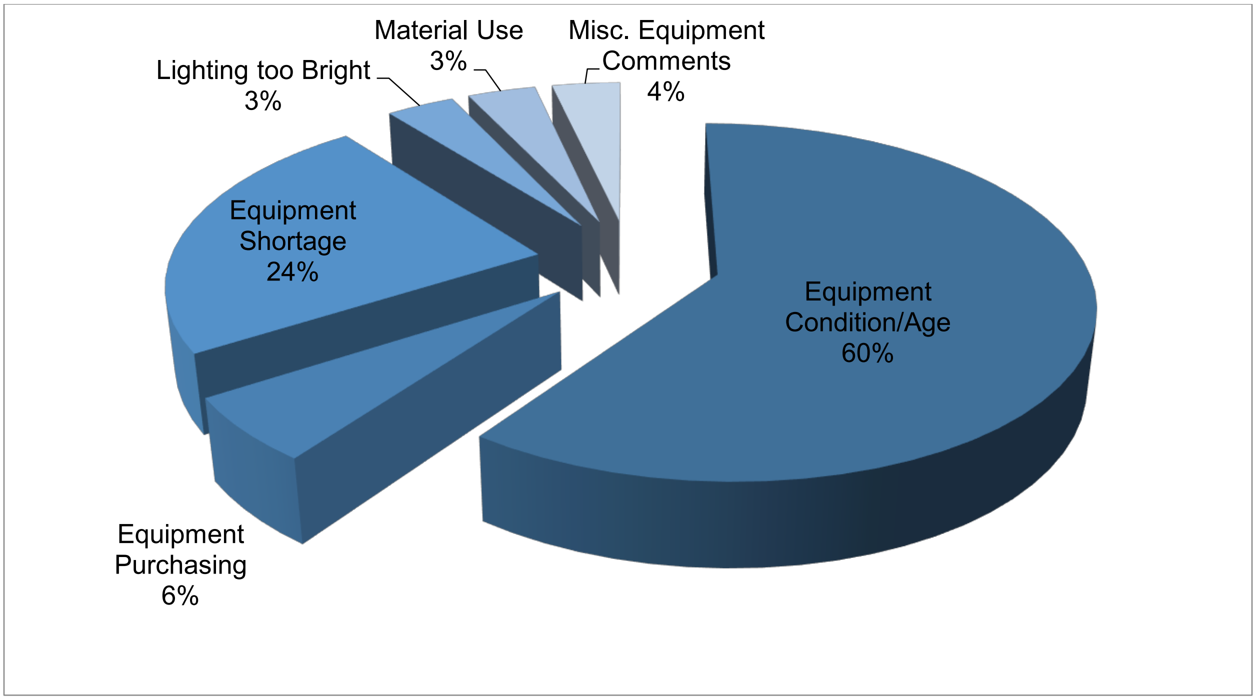


Figure 164. Equipment-related Obstacles to Combat Fatigue

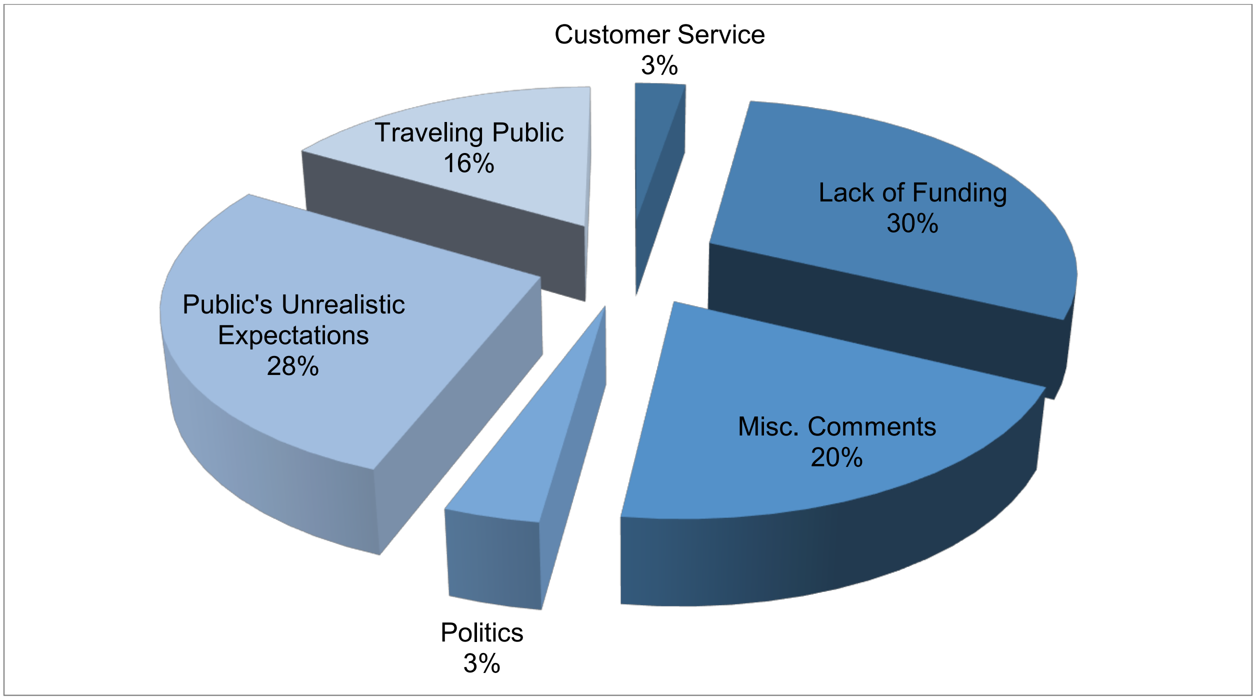


Figure 165. Other Obstacles to Combat Fatigue

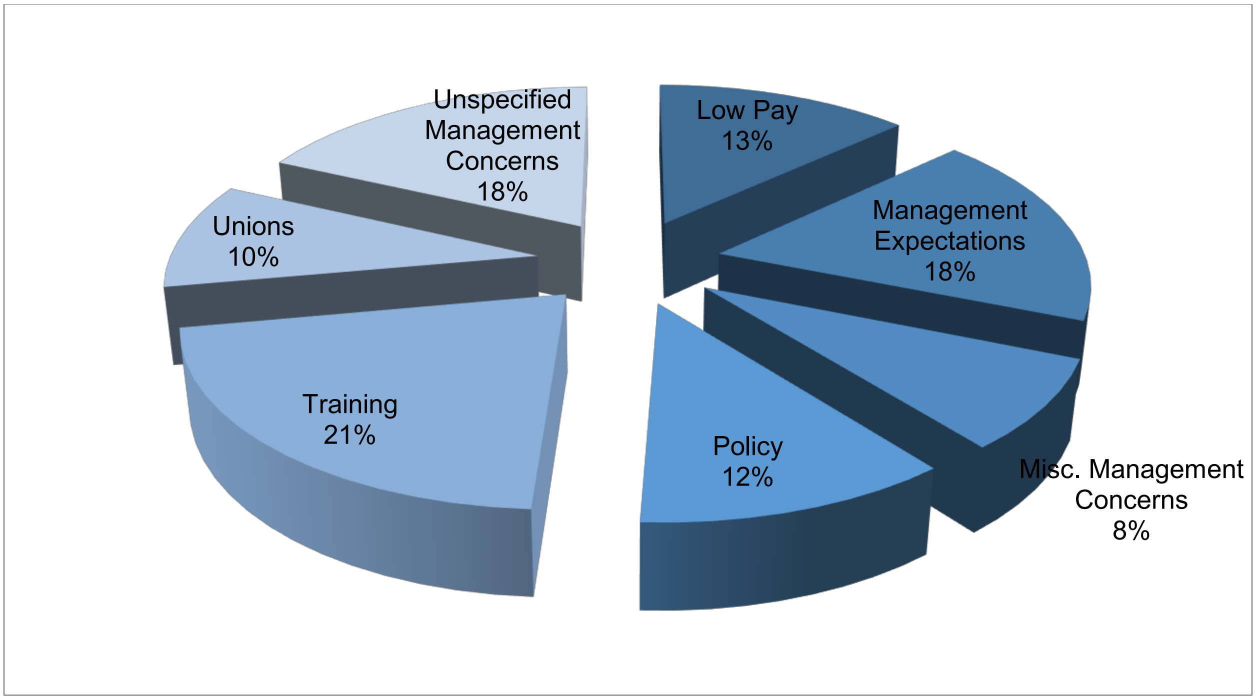


Figure 166. Management-related Obstacles to Combat Fatigue

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