Crash Risk and Mobile Device Use Based on Fatigue and Drowsiness Factors in Truck Drivers

Laura M. Toole

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Tonya L. Smith-Jackson, Co-chair
Richard J. Hanowski, Co-chair
Woodrow W. Winchester III

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ABSTRACT

Driver distraction has become a major concern for the U.S. Department of Transportation (US DOT). Performance decrements are typically the result of driver distraction because attentional resources are limited, which are limited; fatigue and drowsiness limit attentional resources further. The purpose of the current research is to gain an understanding of the relationship between mobile device use (MDU), fatigue, through driving time and time on duty, and drowsiness, through time of day and amount of sleep, for commercial motor vehicle drivers. A re-analysis of naturalistic driving data was used to obtain information about the factors, MDU, safety-critical events (SCE), and normal driving epochs. Odds ratios were used to calculate SCE risk for 6 mobile device use subtasks and each of the factors, which were divided into smaller bins of hours for more specific information. A generalized linear mixed model and chi-square test were used to assess MDU for each factor and the associated bins. Results indicated visually demanding subtasks were associated with an increase in SCE risk, but conversation on a hands-free cell phone decreased SCE risk. There was an increase in SCE risk for visual manual subtasks for all bins in which analyses were possible. Drivers had a higher proportion of MDU in the early morning (circadian low period) than all other times of day that were analyzed. These results will be used to create recommended training and evaluate policy and technology and will help explain the relationship between MDU, fatigue, and drowsiness.

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Introduction

Motivation

The most recent commercial motor vehicle (CMV) data published by the Federal Motor Carrier Safety Administration (FMCSA) noted that 33,808 people were killed in 2009 and 3,619 (11%) of them lost their lives in crashes involving a bus or large truck ("Commercial motor", 2011). A large truck is defined as having a gross vehicle weight rating of 10,000 lb or more ("Commercial motor", 2011). The data also indicated that the number of large trucks involved in fatal crashes decreased by 1,497 from 2007 to 2009. This decrease can, in part, be attributed to the creation of rules and regulations by FMCSA and other organizations. FMCSA indicates the aim of enacting the rules and regulations is to support the Administration's mission of decreasing the number of crashes and fatalities involving CMVs (Federal Motor Carrier Safety Administration, n.d.a).

A CMV, as defined by the Virginia Department of Motor Vehicles (n.d.), can be categorized as one of the following:

- A single vehicle with a gross vehicle weight rating (GVWR) of 26,001 lb or more
- A combination of vehicles with a gross combination weight rating (GCWR) of 26,001 lb or more if the vehicle(s) being towed has a GVWR of more than 10,000 lb
- Vehicles that carry 16 or more passengers, including the driver
- Any size vehicle that transports hazardous materials and that requires federal placarding. (p. 1)

In 2009, driver distraction became a major focal point of the U.S. Department of Transportation (US DOT) and the general public; so much so that it was Webster's New World College Dictionary "word of the year" ("Webster's New", 2009). The definition was, "[w]hat many are guilty of when they use digital devices on the go" (p. 1). The Driver Distraction in Commercial Vehicle Operations (CVO) study by Olson, Hanowski, Hickman, and Bocanegra (2009) examined the types of tasks conducted by CMV drivers prior to safety-critical events (SCE), defined in the Definition of a SCE subsection, and their SCE risk. The results of this study motivated public awareness and policy regarding driver distraction (details discussed in the Past Research on Mobile Device Use subsection).

Shortly after the Olson et al. (2009) study was released, U.S. Transportation Secretary Ray LaHood held a summit, which brought together safety experts, researchers, industry representatives, elected officials and members of the public to share their knowledge and ideas about how to address the growing trend of driver distraction (US Department of Transportation, 2009). During the summit, Secretary LaHood announced that President Obama had issued Executive Order No. 13,513 that banned government employees from text messaging while driving a government vehicle, text messaging while driving their personal car on official government business, and text messaging on a government owned cell phone while driving. This executive order encouraged other contractors and companies that work with the government to ban their employees from text messaging while using company vehicles (Executive Order No. 13,513, 2009). The order defined texting messaging as "reading from or entering data into any handheld or other electronic device" (Executive Order No. 13,513, 2009, p. 247).

As noted, FMCSA created rules and regulations in an effort to increase safety on the Nation's roadways. In October of 2009, FMCSA created a rule that prohibits CMV drivers from texting while partaking in interstate commerce; it also prohibits motor carriers from requiring or allowing their employees to text while driving (Limiting the use of wireless communication devices, 2010). The Drivers of CMVs: Restricting the Use of Cellular Phones rule (2010) prohibits a CMV driver from reaching for, dialing, or holding a cell phone in order to make a phone call while driving. The rule still allows drivers to talk on a hands-free device, since talking and listening do not require drivers to take their eyes off of the road and may be beneficial while driving (Drivers of CMVs: Restricting the use of cellular phones, 2010).

The rule noted above does not include all subtasks related to cell phone use because of unanticipated benefits that have been found in past research. The results of the studies found in this paragraph indicate not all types of secondary and tertiary task, defined in The Driving Task subsection, engagement are detrimental. Kantowitz, Hanowski, and Tijerina (1996) described how complex secondary and tertiary tasks affect driver workload and performance on various tasks in a truck driving simulator. The researchers found that the commercial drivers detected pedestrians approximately a second quicker when talking on a cell phone than when they were not talking on a cell phone in a driving simulator; driver underload was cited as the reason for this result (Kantowitz et al., 1996). Williamson, Feyer, Friswell, and Finlay-Brown (2001) asked drivers about strategies they use to manage fatigue in a survey; 65% of drivers reported that they used their Citizen's Band (CB) radio as a strategy. Baker, Bowman, Nakata, and Hanowski (2008) also inquired about countermeasures to driver drowsiness through focus groups with various types of CMV drivers. Researchers found that approximately half of the drivers reported talking on their CB radio to help them stay awake when drowsy. In a naturalistic driving study, talking/listening on a hands-free cell phone has been associated with a decreased SCE risk (Olson et al., 2009; Hickman, Hanowski, & Bocanegra, 2010). In an empirical, test-track study, it was also found that measures of alertness increase after the first phone call during a driving period (Jellentrup, Metz, & Rothe, 2011). These results point to the fact that not all secondary or tertiary task engagement is detrimental.

Other issues contribute to roadway safety, in addition to distraction. In 2001, the Advocates for Highway and Auto Safety noted that, according to FMCSA, each year approximately 750 deaths and 20,000 injuries are directly related to a CMV driver who is fatigued (Advocates for Highway and Auto Safety, 2001). Fatigue is a more elusive problem than other issues, such as speeding, because it is a construct that is hard to understand and impossible to measure directly (Williamson, 2009). This may be the reason that statistics on fatigue in CMV crashes have not been published in recent years. In 1994, the National Highway Traffic Safety Administration (NHTSA) published a report that addressed fatigue and drowsiness related crashes between the years of 1989 and 1993 (Knipling & Wang, 1994). The report indicated that although the total number of crashes related to fatigue or drowsiness decreased by almost 30,000, the number of fatalities (1,544) and fatal crashes (1,357) involving fatigue or drowsiness remained nearly the same.

Hours of Service of Drivers (2011) bans CMV drivers from driving if they have not taken a break for at least 30 min or been off duty in the last 8 hr. In addition the hours a driver is allowed to work in a week were reduced from 82 to 70 hr. The rule also restricts hours off and the periods of the day during which the off-duty time should occur. This rule will allow drivers to sleep more and avoid driver fatigue.

The rules noted in this section, and other government regulations, are based on findings from driving research, such as Olson et al. (2009). There are many studies that focus on driver distraction in light vehicles, such as passenger cars, but the body of research related to CMV driver distraction is not as large (Drivers of CMVs: Restricting the use of cellular phones, 2010). There is even less research that examines the relationship between fatigue, drowsiness, and distraction, so their relations to each other and their effects are unknown (Williamson, 2009).

The current research is a secondary data analysis of naturalistic data that focuses on analyzing the relationship between fatigue, drowsiness, distraction, and vigilance, illustrated by arrows in Figure 1. This conceptual model is grounded in the literature. A more detailed description of these terms will be given in the Literature Review section.

Briefly, naturalistic driving data captures participants, or drivers, in their normal, everyday operation. Vigilance is the driver's ability to pay attention to the roadway; it encompasses the primary driving task. There have been findings that indicate some tasks help maintain vigilance but others cause performance decrements (Atchley & Chan, 2011; Olson et al., 2009); more research will help clarify these findings. Fatigue is a loss of attention that increases as a task is performed and drowsiness is the inclination to sleep. The terms drowsiness and sleepiness may be used interchangeably; however, fatigue and drowsiness are distinct concepts. There are questions regarding the interaction between fatigue and distraction and drowsiness and distraction (Williamson, 2009). However, their effects on the driving task are fairly well known. The causes of fatigue and drowsiness were examined as the factors related to each concept in relation to SCE risk and mobile device use of CMV drivers. Driving time and time on duty are associated with fatigue and time of day and amount of sleep are associated with drowsiness.

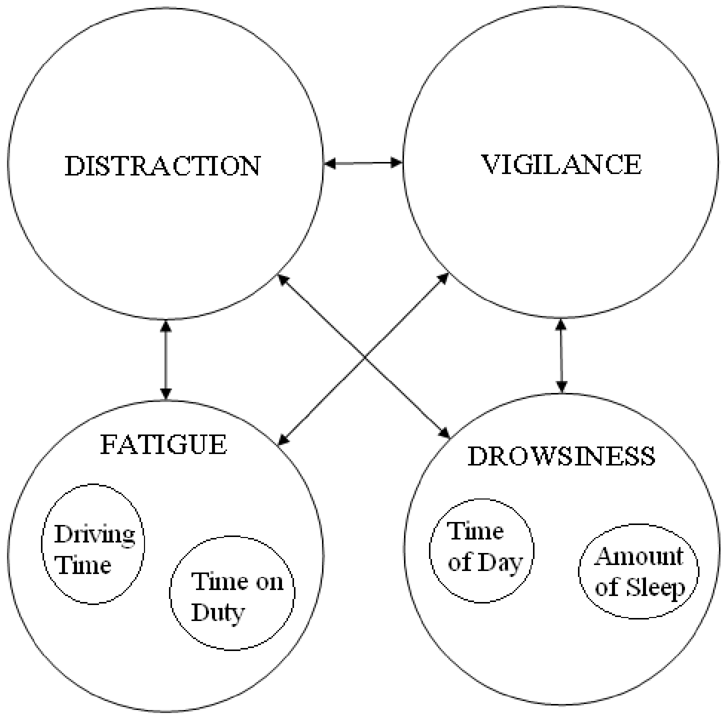


Figure 1. Relationships of interest in the current research (denoted by arrows).

Although the body of research relating to the topics of distraction and fatigue is somewhat small, exploratory studies have been performed, which the current research honed in on. The results from this study were used to create a suggested update of an education and training tool, evaluate existing policy and technology, clarified results of past studies, and may support other countermeasures, such as in-vehicle technologies. The following sections define driver distraction and fatigue, as well as summarize past research that has been conducted in these areas.

Review of the Literature

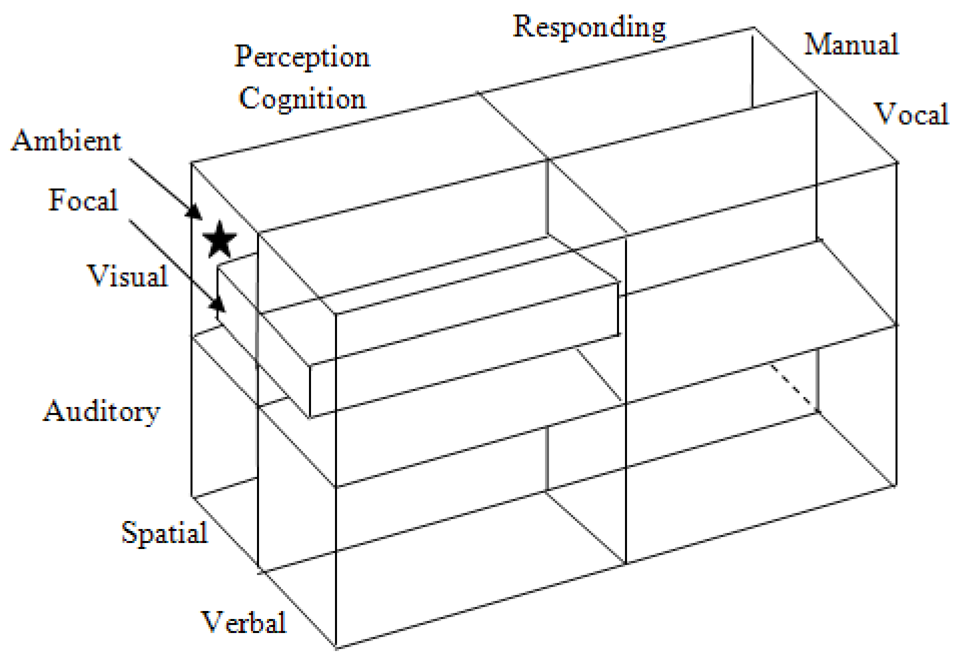
This section will provide a foundation for the present research. The task of driving will be explained more thoroughly, as well as driver distraction, fatigue, drowsiness, and mobile device use. In addition past research about each of the factors and mobile device use will be presented.

Attention

Attention has been defined as applying oneself to a task or activity, which could be seen as having an amount or intensity (Kahneman, 1973). Depending on how many tasks or items an individual is focusing on, attention is either selective or divided. Selective attention occurs when one task is favored through effort distribution and divided attention occurs when an individual is attending to multiple tasks or activities (Kahneman, 1973). In his book *Attention and Effort*, Kahneman (1973) explains that attention is limited and it may not be possible to allocate attention to multiple tasks, or mental activities, depending on the amount of attention required by the tasks.

Humans typically perform multiple tasks simultaneously, which causes our attentional resources to be more limited and our attention to be divided. Dividing attention forces individuals to select which task they will allocate more resources to, or manage which stimuli will influence their behavior (Kahneman, 1973). However, it is possible to improve the ability to attend to multiple stimuli by focusing on stimuli that require different attentional resources. For example, it will be easier to perform a visual and an auditory task than it would be to perform two visual tasks (Wickens & Hollands, 2000).

Wickens (2002) reviews the four dimensional multiple resources model; it states time-sharing performance can be accounted for by four clear-cut and dichotomous dimensions: stages, perceptual modalities, visual channels, and processing codes. The stages dimension indicates that there are different cognitive resources that are required for perceptual activities than for selecting and carrying-out a response. The two perceptual modalities are visual and auditory. Within the visual modality, there is a focal visual channel, which is required for recognizing fine detail and pattern, and an ambient visual channel, which is required for perceiving orientation and ego motion. In terms of processing code, a task will either necessitate spatial or verbal processes. If two tasks, being performed simultaneously, are in the same dimension they will be harder to process and perform than if they were in different dimensions.



Note. The star indicates where driving falls in the model.

Figure 2. Representation of the multiple resource theory (Wickens, 2002, p. 163) Used under fair use, 2012.

Performing one or more tasks requires effort; the effort it takes to attend to a task or event can be measured using indicators of arousal (Kahneman, 1973). Yerkes and Dodson (1908) established there is a relationship between difficulty of visual discrimination and the rate of learning. In other words, the performance and the amount of effort needed to perform a task, measured by arousal, are related. Figure 3 depicts the Yerkes-Dodson inverted-u curve with the best performance occurring at medium levels of arousal. In the current research, the continuum of arousal will span from drowsiness or fatigue on the low end to overload on the high end.

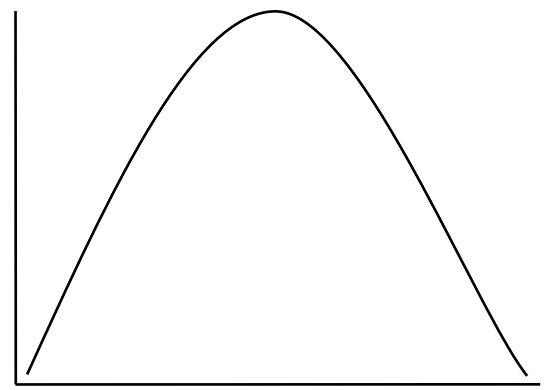


Figure 3. *Representation of the Yerkes-Dodson inverted-u curve (Hebb, 1955, p. 250) Used under fair use, 2012.*

Driver Distraction

This chapter highlights various components of the driving task and driver distraction. These topics are important to understand in order to fully appreciate what is being analyzed in the current research. The explanations will also allow for easier interpretation of the results of the reports discussed throughout the literature review.

The driving task. An understanding of the task of driving is the basis for comprehension of driver distraction. As noted in the Attention subsection, there are multiple dimensions of attention (Wickens, 2002). Driving falls primarily on the left side of the cube in the dimension of perception cognition, unless the driver needs to react to something in the roadway or change lanes. In addition, driving primarily requires spatial processing. More visual resources will be allocated to the task than auditory; although auditory cues, such as screeching breaks, provide the driver important information. More specifically, ambient vision is needed to determine speed and movement around the driver (Wickens, 2002).

Given the dimensions of driving, it is not alerting that studies have indicated that driving is a task that requires vigilance (Atchley & Chan, 2011; Hancock & Verwey, 1997; Larue, Rakotonirainy, & Pettitt, 2011); vigilance has been defined as a preparedness to identify and react to slight, irregular changes in the environment (study by Mackworth [as cited in Mackworth, 1968]). Examples of a change in the driving environment are a pedestrian entering the street or a merging vehicle. However, the understimulation and monotony of the task can cause drivers to experience a vigilance decrement (Atchley & Chan, 2011; Hancock & Verwey, 1997; Larue et al., 2011). A vigilance decrement has been defined as a decrease in correct detections or in sensitivity to change throughout a period of time (Mackworth, 1968) or a steady deterioration of performance in constant watch-keeping (Kahneman, 1973). The monotony of the driving task can be attributed to improvements in vehicle and roadway infrastructure, which can take away from the attention required (e.g., cruise control), and/or very predictable and uneventful environments, such as rural roads or highways that do not have a lot of curves (Larue et al., 2011). As noted, when low effort is required, performance typically decreases (Yerkes & Dodson, 1908).

Ablassmeier, Poitschke, Wallhoff, Bengler, & Rigoll (2007) described the classification of the types of tasks that can be performed while driving. Tasks associated with direct control of the vehicle's direction are considered to be primary tasks, which are further categorized into navigation, steering, and stabilization. Secondary tasks are connected to driving, but they are not fundamental to keeping the vehicle on course. Turning on the windshield wipers and honking are examples of secondary tasks. Tasks not related to driving are considered to be tertiary. This includes actions such as tuning the radio or eating, but this classification does not generalize to all situations. For instance, a driver may need to turn the radio down in order to aurally locate an ambulance siren. The radio task, in that situation, becomes a secondary rather than a tertiary task. Secondary and tertiary tasks are not necessarily harmful to the driver or driving task.

Because of secondary and tertiary tasks, driving is a combination of both selective attention and divided attention. Selective attention is being paid to the task of driving until there is a something taking the driver's attention away from the forward roadway. For example, an individual is driving down the highway with both hands on the wheel and eyes on the forward roadway. When he/she has to exit the highway to get to his/her destination, the driver has to look at road signs or a navigation system, which will cause them to divide their attention between the driving task (i.e., looking at the forward roadway) and road signs or an in-vehicle device (Wickens & Hollands, 2000). The current research focuses on the driver interacting with a mobile device, so divided attention will be the focus. The next section will discuss when these secondary and tertiary tasks, as well as divided attention, become detrimental.

Defining driver distraction. There have been many definitions of driver distraction in the past two decades. A review of the definitions reveals three common themes.

1. Driver distraction caused an individual to take away attention or causes a shift in or diversion of attention (research by Ranney, Mazzae, Garrott, & Goodman; Horberry, Anderson, Regan, Triggs, & Brown; Treat [as cited in Lee, Young, & Regan, 2009]; Williamson, A., 2009; Smiley, 2005).
2. Driver distraction caused the driver to remove their attention from the task of driving *safely* (research by McAllister, Dowsett, & Rice and Manser, Ward, Kuge, & Boer [as cited in Lee, Young, & Regan, 2009]; Streff & Spradlin, 2000; Patten, Kircher, Ostlund, & Nilsson, 2004).
3. Driver distraction caused a decrease in performance (research by Laberge, Scialfa, White, & Caird and Hedlund, Simpson, & Mayhew [as cited in Lee, Young, & Regan, 2009]; Stutts, Reinfurt, Staplin, & Rodgman, 2001; Drews, F. & Strayer, D., 2009; Pettitt, Burnett, & Stevens, 2005).

The first two themes are similar in the sense that an individual acting in any of these ways would be dividing their attention between two tasks. The first theme includes more general definitions that deal with distraction as a concept. For example, Smiley (2005) noted driver distraction was “misallocated attention” (p. 1). Whereas the second theme is more specific; it focuses on when the driver is distracted and not paying as much attention to driving safely. Streff and Spradlin (2005) noted distraction was a shift from “stimuli that [are] critical for safe driving toward stimuli that are not related to safe driving” (p. 3). Distraction tasks, according to the second theme, would include all tertiary tasks and potentially some secondary tasks, as noted above. Patten and colleagues (2004) state that a driver’s attention required for safe driving is disturbed when he/she engages in activities that are not germane to driving safely.

One of the more comprehensive definitions, accounting for each of the three themes, is by Pettitt et al. (2005). After assessing crash databases from the United Kingdom, the authors developed a definition, which included the following components: (i) the difference between distraction and inattention; (ii) the recognition that distraction can be internal or external to the vehicle; (iii) that distraction can be categorized into four types (visual, cognitive, biomechanical, and auditory); and (iv) the effect of distraction on the driving task.

The Pettitt et al. (2005) definition is as follows:

> Delay by the driver in the recognition of information necessary to safely maintain the lateral and longitudinal control of the vehicle (the driving task) (**Impact**) [d]ue to some event, activity, object or person, within or outside the vehicle (**Agent**) [t]hat compels or tends to induce the driver's shifting attention away from fundamental driving tasks (**Mechanism**) [b]y compromising the driver's auditory, biomechanical, cognitive or visual faculties, or combinations thereof (**Type**). (p.11)

Hanowski, Perez, and Dingus (2005a) used this definition in regards to the analysis and description of naturalistic driving data. The inattentive behaviors prior to a SCE (or an impact as described above) are considered to be the agents and underlying mechanisms that can distract drivers. Three main conclusions were established from Hanowski et al. (2005a). First, a distracting agent that occurs frequently, even if it does not demand a lot of time or vision, has an associated risk. Second, some distracting agents can occur infrequently and for shorter amounts of time, but they are still demanding tasks. Third, some distracting agents that require a moderate amount of time, vision, and frequency were associated with the occurrence of SCEs.

A more recent definition of driver distraction was composed by a focus group of 6 experts from the United States and Europe for the US-EU Bilateral TIS Technical Force. The definition developed was "the diversion of attention from activities critical for safe driving to a competing activity" (US-EU Technical Task Force, 2010, p. 3). The focus group indicated that activities for safe driving are those that "allow the driver to avoid or not cause a crash" (p. 3). It is difficult, if not impossible, to create a set list of these activities because they are situation dependent. A competing activity was defined as any task that distracts the driver; most importantly, the task is not crucial for driving safely. Again, these tasks are situation dependent and depend upon what the definition of "critical" is. There were many issues, such as creating a "distraction threshold", which the focus group discussed, but did not achieve consensus.

Although this definition of driver distraction is recent, the unresolved issues associated with it are too numerous to use, at this point, as a model for the current research. The Pettitt et al. (2005) definition, noted previously in this section, is one of the most comprehensive and pragmatic definitions in the literature. This definition, in combination with the explanation by Hanowski et al. (2005a), was used in the current research. A distinction between driver distraction and inattention must be made, which follows in the next section.

Driver distraction versus driver inattention. Driver inattention and driver distraction may seem similar and can be confused. Driver distraction is a sub-component of driver inattention, so it is important to distinguish between the two phenomena. Authors may use these terms interchangeably; therefore, it is essential to determine what concept they are discussing in order to compare results from multiple studies.

Lee, Young, and Regan (2009) state that driver inattention encompasses many situations in which the driver does not to attend to the driving task. They define driver inattention as a "decrease in attention to activities critical for safe driving in the absence of a competing activity" (p. 32). To the authors, inattention is a mental state that causes the driver to have less attentional resources to allocate to the roadway. This is different from driver distraction because distraction is an interaction, whether it is physical or visual, with an actual item that causes a diversion of attention away from the roadway. The current research focuses on driver distraction and not driver inattention. The next section will discuss the various types of driver distraction and specify which is being examined presently.

Internal versus external driver distraction. There are two key types of driver distraction: internal and external. According to the information-processing model, attention must be paid to stimuli in order for them to be perceived (Wickens & Hollands, 2000). Therefore, there is conscious processing involved in any sort of interaction, whether it is an internal or external distraction. It is important to recognize what is classified as internal distraction versus external distraction in order to understand what is being examined in the current research.

As defined by Regan et al. (2009), internal driver distraction sources are those within the vehicle. This includes passengers, food, and in-vehicle systems. External distraction sources are anything outside of the vehicle. Examples of external distracters include billboards, a crash, or a driver in another vehicle. Since using a mobile device, such as a cell phone, involves interacting with an object that is inside the vehicle, it is considered a type of internal distraction. As mentioned, other concepts can also effect distraction, internal or external. These concepts will be defined in the following sections.

Driver Fatigue and Drowsiness

Definition of fatigue. It is important to have an understanding of what driver fatigue is, since the current research examines factors related to fatigue. Desai and Haque (2006) defined driver fatigue as both a psychological and a physical unwillingness to continue the task an individual is performing or to begin a new task. They determined that this opposition to continue is caused by "prolonged physical and emotional engagement" and it is dependent on the "nature of the work and work environment, and the frequency of the engagement" (p. 141). Brown (1994) defined fatigue as an unwillingness to perform a task, as well. However, he also included in his definition that attention would be progressively withdrawn from the driving task. Williamson (2009) indicates that fatigue causes a loss of attention to a task, which is always unintentional.

In the current research, the term fatigue refers to an involuntary state in which there is a loss of attention or physical unwillingness that escalates as the task continues to be carried out and impairs performance. As noted, the factors associated with fatigue in the current research are driving time and time on duty. As outlined in the next section, a distinction in the current research is made between fatigue and drowsiness.

Fatigue versus drowsiness. The terms "fatigue" and "drowsiness" are often used interchangeably despite the fact that they are different concepts. Stutts, Wilkins, and Vaughn (1999) defined sleepiness, or drowsiness, as "the inclination to sleep" (p. 7), and as a physiological state that occurs when an individual has had limited or interrupted sleep (Stutts et al., 1999). Johns (2000) defined sleepiness in the same way Stutts et al. (1999) did and added that sleepiness was the likelihood of an individual falling asleep at a certain moment. When comparing the definitions of fatigue stated in the previous section to the definitions of drowsiness from Stutts et al. (1999) and Johns (2000), it is clear that drowsiness is a feeling (of sleepiness) or inclination, whereas fatigue is an involuntary mental state. The difference between fatigue and drowsiness is that fatigue results from physical or mental labor; it is possible for a driver to feel fatigued without feeling drowsy (Stutts et al., 1999).

In the current research, the term drowsiness refers to a desire to sleep. As noted, the factors associated with drowsiness, in the current research, are time of day and amount of sleep. It is not only important to understand the definition of these concepts, but also the causes.

Possible causes of fatigue and drowsiness. Beyond the simple definitions, it is critical to the current research to understand what leads to fatigue and drowsiness; this will help explain the factors being examined. As mentioned, Desai and Haque (2006) indicated fatigue stems from the amount of time a driver had been working and driving and the amount of time since his/her last break. Hancock and Verwey (1997) and Brown (1994) also noted fatigue stems from the number of hours a driver had been working. In addition, Brown (1994) suggested daily duty periods also cause fatigue. These findings supported driving time and time on duty as the factors being examined for fatigue.

The circadian rhythm, or time of day, was cited as a cause of drowsiness in Stutts et al. (1999), Johns (2000), and Desai and Haque (2006). In addition, Stutts et al. (1999) noted that sleep restriction would cause drowsiness. The period of wakefulness was also suggested as a cause of drowsiness in Johns (2000); this can relate to amount of sleep in that if an individual slept for a shorter amount of time he/she would have a longer period of wakefulness. These results supported time of day and amount of sleep as the factors being examined for drowsiness.

The next section will give a more in-depth explanation of how cognitive processing and attention are affected by fatigue and drowsiness.

Fatigue and drowsiness in attention allocation. According to Dinges (1995), the strongest effect of fatigue or sleepiness is a vigilance decrement. Kahneman (1973) noted when an individual is sleepy or fatigued he/she has a more difficult time performing a continuous task; however, an increase in effort will compensate for this difficulty. The increase in effort requires attentional resources, so the individual has fewer resources to allocate to the task(s) he/she is performing. More automatic regulation by fatigued individuals (i.e., decrease in planning, less action towards a goal, and maintenance of action even if feedback indicates a change in behavior is needed) could also indicate fewer attentional resources are allocated to the task at hand (van der Linden, Frese, & Meijman, 2003). However, if the individual is made more alert he/she will be able to allocate more resources to both primary and secondary tasks (Kahneman, 1973).

Desmond and Matthews (1997) performed a simulator study with light-vehicle drivers to examine fatigue and task demand. Fatigue was induced by participants reacting to information on road signs while driving. Drivers had to attend to the numbers presented in a message on the sign, which contained numbers and letters (e.g., CU4KPIA), and react based on information from a cue. In a later report, Matthews and Desmond (2002), the two studies conducted were described in more detail, but only the first study will be discussed. The participant performed the driving task alone, drove while performing the fatigue inducing task (experimental session only), performed the driving task alone, then drove while performing a pedestrian detection task on both curved and straight segments of roadway.

The comparison of results from the control to the fatigued condition indicated that fatigued participants seem disinclined to use effort to maintain task performance (Matthews & Desmond, 2002). Instead, the effort may be used to manage effects of fatigue. In addition, when drivers were fatigued they could manage increased demands when the driving task was difficult (i.e., curved road), but their performance was worse when the task was easy (i.e., straight road) (Desmond & Matthews, 1997; Matthews & Desmond, 2002). This study supports an effect similar to that of the Yerkes-Dodson inverted u-curve (Yerkes & Dodson, 1908), noted previously, in that if driver arousal is too low (from low task demand) there is a performance decrement.

Gugerty and Brooks (2002) examined the effects of sleep deprivation, which would cause drowsiness, on attention allocation using a driving simulator. Three measures captured attentional capacity and situation awareness; "percent hazards detected" and "blocking-car detection" measured aspects of the participants' driving performance and "percent cars recalled" measured the participants' ability to recall information from scenes. Results indicated participants had a decrease in performance in all measures, suggesting that as a driver becomes drowsier their attentional capacity for a task decreases and situation awareness becomes worse.

The effects of fatigue or drowsiness on attention allocation can be seen in Figure 4. The solid rectangles represent a limited attentional capacity and the dashed lines within the rectangles indicate the resources allocated to the task or mental state can fluctuate. Attention allocation when an individual is alert is represented on the left. It can be seen that there are more resources allocated to the driving task. However, when the individual becomes fatigued (represented on the right), there are less resources allocated, as noted by Gugerty and Brooks (2002). The arrow between the two indicates the driver can be alerted and fatigue can decrease.

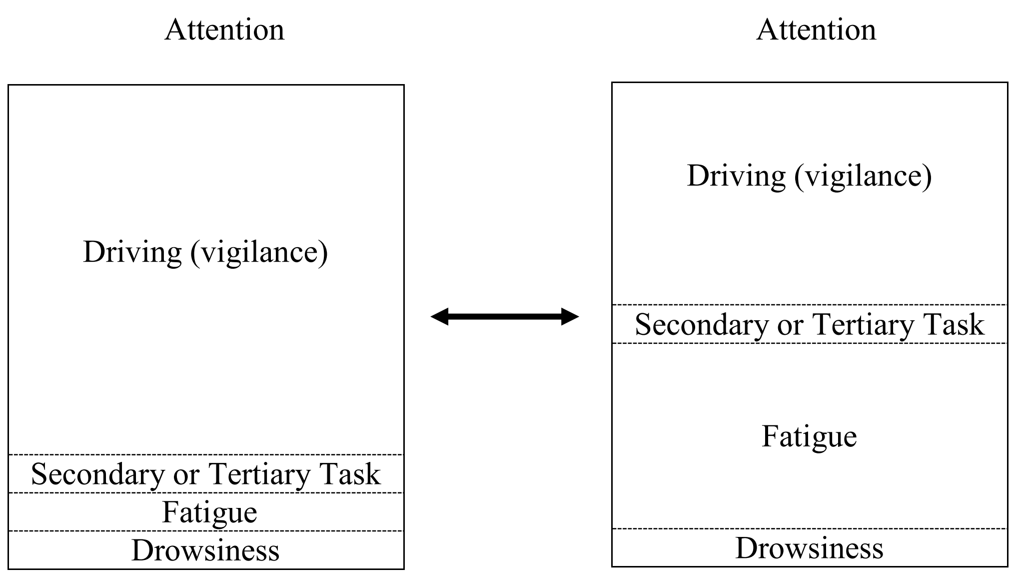


Figure 4. Attention allocation when alert (left) and when fatigued (right).

With an understanding of concepts in the current research and the specific elements being studied, insight into how the research will be conducted can be gained. The various types of driving research will be outlined in the following section.

Types of Driving Research

The decision about the method of research that will be used should take into account the data that is accessible and the questions being answered. There are three key types of driving research; each has its own benefits and limitations. Through epidemiological research, researchers examine crash databases or police accident reports (PAR). The information on a PAR is not necessarily correct or comprehensive, with respect to driver behavior, because it is difficult to determine exactly what drivers were doing or, more precisely, where drivers were looking prior to a crash. Because of this, it can be hard to assess the "human-factor", or driver factor, of a crash using this method. Examples of a human-factor include distraction and drowsiness. Therefore, it is not possible to ascertain a cause-and-effect relationship from epidemiological analyses. Epidemiological research is a good way to analyze the non-behavioral component of a crash, such as the weather, lighting, road condition, and other external factors (Hanowski et al., 2005a).

Empirical research is another method typically used in driving research. These types of studies are typically conducted in laboratories or on driving simulators or test tracks. This method provides a high level of control and can show cause-and-effect relationships. Key measures used in the analysis of distracted driving, such as eyes-off-road-time, can be calculated accurately with in-vehicle instrumentation, including video cameras. A potential limitation of this method is that drivers participating in an experiment may not act like they would in the real world, especially if the study involves using unfamiliar equipment. Further, empirical studies may lack the risk related to real-world driving (Drivers of CMVs: Restricting the use of cellular phones, 2010). Since these studies typically involve participant testing a product for a short duration (e.g., minutes or hours), it can be difficult to determine if a driver would have a long term change in behavior while using the technology or system being evaluated (Hanowski et al., 2005a).

Naturalistic driving research combines components of the empirical and epidemiological methods. Large naturalistic driving studies, such as the Naturalistic Truck Driving Study (NTDS) (Blanco et al., in press), bridge the two methods by providing a large amount of data, similar to epidemiological analyses, with detailed information on the driver, the vehicle, and the environment, similar to empirical analyses (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). CMV naturalistic driving studies collect data while drivers perform their normal revenue-producing runs. Since the data contains information about drivers in real-world conditions for extended amounts of time (e.g., weeks or months), this method has high external validity (Hanowski et al., 2005a).

The current research examined internal driver distraction, so of the three methods naturalistic research provided the most external and ecological validity. Bronfenbrenner (1977) defined ecological validity as the extent to which the environment of an experiment, or investigation, has the characteristics the experimenter expects it to have or that it should have. In other words, was the environment of the study representative of what the environment should be? Since naturalistic research involves analyzing participants in their typical work environment, it is not only representative, but generalizable to the larger population of CMV drivers. Due to the timeframe of the current research, a secondary data analysis of previously collected naturalistic data was conducted. A more detailed description of secondary data analysis can be found in the Secondary Data Analysis subsection.

Definition of a SCE

The term "safety-critical event" has been used previously in this report and will appear more in the following sections. A grasp of what the term refers to is important to understand the literature being discussed and the analyses of the current research. A SCE can be classified as a crash, near-crash, crash-relevant conflict, or unintentional lane deviation (Olson et al., 2009). The definition of these classifications can be found in Table 1.

Table 1

SCE Classifications (Olson et al., 2009, p. 25) Used under fair use, 2012.

Classification	Description
Crash	Contact with a moving or fixed object (e.g., roadside barrier, pedestrian, animals) at any speed
Near-Crash	A situation that required a quick, evasive maneuver (e.g., steering) to avoid a crash by the participant or another vehicle, pedestrian, or animal
Crash-Relevant Conflict	A situation that required a crash-avoidance maneuver (e.g., breaking, accelerating, steering) by the participant or any other vehicle or pedestrian. However, it was less severe than that required for a near-crash, but more severe than a normal movement
Unintentional Lane Deviation	A situation where the participant's vehicle crossed a solid lane line, but there was no hazard (e.g., ditch, vehicle, guardrail, etc.)

The term "crash" will be used to refer to a situation similar to a SCE, but that was not classified in the same way by the authors

Past Research on Factors

As noted, there has been minimal research done on CMV driver distraction and even less on CMV driver distraction and its relation to fatigue and drowsiness. The following review describes what research has been conducted in the areas of driving time, time on duty, time of day, and amount of sleep, which are the four factors in this thesis, for CMV drivers. As noted, driving time and time on duty are associated with fatigue and time of day and amount of sleep are associated with drowsiness. In the summaries of reports in the Driving Time and Time on Duty subsections the term “fatigue” will be used even if the term "drowsiness" was used in the original study. Although the original reports in the Time of Day and Amount of Sleep subsections may have used the term “fatigue”, “drowsiness” will be used in the summaries.

Driving time. The reports summarized below discuss driving time and how it is related to arousal and SCE or crash risk.

A study by Harris and Mackie (1972) measured the effects of prolonged driving on driver alertness and vigilance, for regular schedule drivers. The researchers analyzed driver interviews from three types of CMV drivers who were engaged in interstate transport. Based on the survey results, drivers indicated they had been driving for approximately 1 to 3 hr when the majority of their crashes occurred. In addition, 23% of drivers said they had been involved in a crash or near-crash after they had been driving for a long period or when they were tired. Of the 23%, 5% indicated the crash or near-crash occurred because a car pulled out in front of them. This is an example of the driving task relating to vigilance (i.e., detecting the car about to pull out) and a vigilance decrement resulting from fatigue.

In addition to the survey, Harris and Mackie (1972) conducted a field study. Two types of truck drivers were involved in this study; (i) sleeper berth drivers were typically on the road for 40 hr to 100 hr or more, and (ii) relay drivers made more than four runs in a driving cycle and did not have extended time off. Measures of driver performance (i.e., lateral position, fine steering adjustments, and reaction time) and physiological measures (i.e., alpha rate in electroencephalogram [EEG], heart rate, and blink frequency) were used to reflect a driver’s level of fatigue and vigilance. Results from the field study indicated that relay drivers had a decrease in arousal after 5 hr and sleeper drivers had even earlier declines.

Mackie and Miller (1978) continued the Harris and Mackie (1972) study in its second phase; Phase 2 aimed to determine a relationship between fatigue and driver safety for drivers who do not work regularly scheduled shifts and spend more time performing non-driving tasks. To do this, researchers reviewed previous literature, conducted a nationwide survey, analyzed crash data, and performed three field experiments. During the field experiments, driver performance and physiological measures, similar to those used in Harris and Mackie (1972), were collected to assess fatigue. Results from the study indicated that sleeper berth drivers showed decreased arousal after approximately 4.50 hr and relay drivers showed similar decreases between 5 hr and 8 hr of driving.

Hanowski, Olson, Bocanegra, and Hickman (2008) analyzed sensor and video data from the Drowsy Driver Warning System Field Operation Test (DDWS FOT) (Hanowski et al., 2008). They performed analyses, including calculating odds ratios to determine how time of day, hours driven, and driving shift affected SCEs (Hanowski et al., 2008). An odds ratio, in driving research, is used to determine the odds of an event (i.e., SCE) occurring when a certain factor is present, such as talking/listening on a hand-held cell phone. The odds ratio is the quotient of the probability of a SCE occurring over the probability of a SCE not occurring. Using this number, an upper confidence limit (UCL) and lower confidence limit (LCL) are also calculated. If the confidence interval does not include 1.0, the odds ratio is considered significant. If the odds ratio is above 1.0, there is an increase in risk and if it is less than 1.0 there is a decrease in risk. In this section, only the results from the analysis concerning hours driven will be discussed.

An odds ratio analysis was conducted in Hanowski et al. (2008) to examine all of the data in which the participant driver was judged to be at fault. Results indicated the first hour of driving had a significantly higher SCE risk than all other hours of driving. A second odds ratio analysis was conducted to examine SCE risk for each hour of driving for participants who drove in the 11^{th} hr and were judged to be at fault. The results for this analysis also indicated a significantly higher SCE risk in the first driving hour than all other driving hours. The researchers hypothesized that the spike in the first driving hour could be attributed to sleep inertia, when drivers were not as alert after waking up, the local roads at the beginning of a trip having higher traffic densities, or to time of day. These alternative explanations somewhat diminish the result that SCE risk was significantly higher in the first driving hour.

Time on duty. The reports summarized below discuss time on duty, work activities, and how they relate to fatigue.

Through a field study detailed in the previous section, Harris and Mackie (1972) found that the performance and physiological results indicated participants experienced an increase in arousal and a decrease in fatigue when they took a break after 3 hr of driving. There were less beneficial effects after taking a break when participants had been driving for 6 hr. After 9 hr of driving, participants showed no increase in arousal or decrease in fatigue after taking a break.

The performance and physiological results from the field experiment conducted by Mackie and Miller (1978), also detailed in the previous section, indicated that driver fatigue was more extreme when a relay driver engaged in moderately heavy cargo loading versus light cargo loading. For sleeper berth drivers, subjective feelings of fatigue did not change between light and moderately heavy loading; however, some physiological measures (i.e., heart rate variability) and type of steering (i.e., fine versus course) showed a benefit of moderately heavy loading.

Williamson et al. (2001) conducted a survey of long distance truck drivers to gain information about driver fatigue throughout Australia. Approximately one fourth of drivers noted they performed some loading or unloading during their trips. The results indicated that loading and unloading and the waiting associated with the task increased driver fatigue; participants noted companies should better the process. Half of participants felt drivers should not be allowed to perform these tasks.

Time of day. The reports summarized below discuss time of day, drowsiness, and SCE risk.

One of the first studies to record video of drivers on their revenue producing runs was by Wylie, Shultz, Miller, Mitler, and Mackie (1996). The primary goal of this study was to investigate the effects of driving time, number of consecutive days of driving, time of day, and schedule regularity on safety-related driving performance. These factors were thought to lead to driver drowsiness, loss of alertness, and degraded driving performance. Through on-road data collection, the researchers aimed to determine a quantitative relationship between driver drowsiness and a potential decrease in the ability to perform driving-related tasks. Measures of driving performance (i.e., lane position, steering wheel movement, speed, and distance) and physiological measures (i.e., body temperature, polysomnography [PSG] during sleep and driving, and quantitative EEG during driving) were collected during the on-road data collection, as well as logbook data and self-assessment of drowsiness. Researchers found that night driving, as opposed to day driving, was associated with a higher level of drowsiness, especially the hours between late evening and dawn. The higher level of drowsiness was related to a decrease in driver performance. This is especially relevant to the current research since two of the time of day bins are in the daytime and two are in the nighttime; it will be possible to compare those bins results.

Hanowski, Wierwille, Garness, and Dingus (2000) studied local/short-haul (L/SH) operations to determine if drowsiness was an issue for these types of drivers. In the first phase of the study, 11 focus groups were conducted with a total of 82 drivers in order to obtain their perspectives on fatigue and safety. The second phase was an on-road study in which trucks from two companies were instrumented. In addition, questionnaires and wrist activity data from 42 drivers were analyzed. The results indicated that there were the most SCEs of an at-fault driver between 12:00 p.m. and 1:00 p.m.

Barr, Yang, Hanowski, and Olson (2005) used the data from Hanowski et al. (2000) to examine specific factors associated with drowsy driving. The study was comprised of four main tasks: search the video data for episodes of driver drowsiness, characterize drowsiness, and relate driver drowsiness to driver performance and driver distraction. When data analysts found videos where the driver was drowsy they gauged how drowsy he/she was by looking for signs, such as yawning, bobbing head, or rubbing eyes. The analyst assigned a number to the video based on the Observer Rating of Drowsiness (ORD) 5-point scale; an ORD 1 indicated the driver was not drowsy and an ORD 5 indicated the driver was extremely drowsy. There was a statistically significant increase in the amount of driver drowsiness between 3:00 a.m. and 9:00 a.m. and again between 3:00 p.m. and 6:00 p.m. For the highest two levels of ORD, drowsiness was a cause of 64% of events between the hours of 6:00 a.m. and 9:00 a.m. and more than a third of all drowsy events occur between those hours.

Mitler, Miller, Lipsitz, Walsh, and Wylie (1997) examined 80 long-haul truck drivers by comparing 4 highly demanding driving schedules, 2 in the United States and 2 in Canada. The American schedules took place on a route between St. Louis and Kansas City, Missouri; both consisted of five 10 hr shifts. The first was a “steady day schedule”, which began at 9:00 a.m. every morning, and the second was an “advancing night schedule”, which began at 9:30 a.m. the first morning and 2 to 3 hr earlier on the following days. The Canadian schedules took place on a route between Toronto and Montreal; both consisted of four 13-hr trips. The first was a "steady night schedule", which began at 11:00 p.m. each night and the second was a "delaying evening schedule", which began at 11:30 a.m. the first morning and 1 hr later on the following days. Although 83% of instances with drowsiness were between 7:00 p.m. and 7:00 a.m., the majority of the drivers' crashes were attributable to worked either the evening or night shift, so the result is somewhat skewed.

No strong conclusions can be made from these results because it is unclear at what time of day most drivers drove during these studies. However, it is interesting to note that high drowsiness or SCE rates occurs at low or moderate (neither high nor low) periods in the circadian rhythm and low SCE periods occur during high or moderate periods.

Amount of Sleep. The reports summarized below discuss amount of sleep and its relation to drowsiness.

Mitler, Miller, Lipsitz, Walsh, and Wylie (1997) collected data with polysomnography during drivers' longest sleep periods in 24 hr, electrophysiological recording while they drove, and video. Drivers who worked the steady day shift slept the longest and those who worked the steady night shift had the least amount of sleep. Over half of the videos that showed instances of drowsy driving were from only 8 participants, 5 of whom were on the steady night shift. These results indicated that the drivers who received the least amount of sleep accounted for the most data involving drowsy driving.

The focus groups from Hanowski et al. (2000) indicated that drowsiness was the fifth highest critical issue and causal factor for SCEs. When participants were asked what caused them to be drowsy on the job, the most frequent answer across all groups was a lack of sleep. Researchers analyzed a dataset that compared SCEs when drivers were at-fault and drowsy versus at-fault and not drowsy. Drivers in the at-fault and drowsy group self-reported a mean amount of sleep that was approximately an hour less than the at-fault and not drowsy group; data from the wrist activity monitor showed a similar trend between groups. The amount of sleep drivers were getting in both groups was less than the recommended 7 to 8 hr of sleep for adults (Bonnet & Arand, n.d.).

The National Sleep Foundation (NSF) conducted a nationwide survey of transportation professionals', including pilots, truck drivers (short haul and long haul), train drivers, and bus/taxi/limo drivers, sleep habits and compared their answers to a control group comprised of employees not in the transportation field (NSF, 2012). Participants were asked how much sleep they needed to perform their best the following day; 31% of truck drivers indicated 6 to 7 hr, 26% indicated 7 to 8 hr, 23% indicated less than 6 hr, and 19% indicated 8 hr or more. In the 24 hr before work days, three fourths of drivers slept for at least 8 hr, which reveals drivers are actually sleeping for the amount that they need.

Aside from these factors, distraction is the other key component in the current research. An explanation of restrictions regarding distraction can be found in the next section, as well as the specific tertiary tasks of interest.

Mobile Device Use

There is disagreement in the United States, at this time, regarding what types or subtasks of mobile device use should be allowed while driving and what should be banned. As noted previously, FMCSA has enacted two rules related to mobile device use, which prevent texting and reaching for, holding, or dialing a cell phone, respectively. In December of 2011, the National Traffic Safety Board (NTSB) made a recommendation that there should be a nationwide ban of the use of portable electronic devices, except in an emergency or ones that are designed to aid the driving task, while operating a vehicle (National Transportation Safety Board [NTSB], 2011). The proposed NTSB ban would be more restrictive than any rule or regulation thus far.

The current research examined internal driver distraction and focused on mobile device use, which included cell phones, CB radios, and dispatching devices. It is important to divide the use of these devices into subtasks, such as “dialing”, because making conclusions about use as a whole can cloud what is really happening. In order to prevent this confusion, a task analysis was used to assess the mobile device use subtasks and their risk. A task analysis involves examining what actions and cognitive processes an individual has to do to meet a goal (Hollnagel, 2006). The specific subtasks that were examined in this research, and their definitions, can be found in Table 2.

Table 2

Definitions of Subtasks Used in Current Research (Olson et al., 2009, p. 205-206) Used under fair use, 2012.

Subtask	Definition
Dial Cell Phone	The driver dials a cell phone, which may also include answering or hanging up the phone. It is assumed the driver is looking at and may reach for the object.
Text Message on Cell Phone	The driver appears to be text messaging on the cell phone, which includes the driver focusing on the cell phone for an extended period of time and continuously pressing keys. It is assumed the driver is looking at and may reach for the object.
Talk/Listen to Hand-Held Phone	The driver holds a hand-held phone to his/her ear and appears to be talking and/or listening.
Talk/Listen to Hands-Free Phone	The driver has an earpiece in his/her ear and appears to be talking and/or listening.
Talk/Listen to CB Radio	The driver talks and/or listens to a CB radio. It is assumed the driver is looking at and may reach for the object.
Interact With/Look at Dispatching Device	The driver interacts with or looks at the dispatching device, which includes holding the device on his/her lap or steering wheel while in use. The device is usually kept on the passenger seat or on the floor between the two seats. It is assumed the driver is looking at and may reach for the object.

Results from past research regarding these subtasks informed the analyses performed in the current research and can be found in the subsequent section.

Past Research on Mobile Device Use

This section will summarize past studies that examine the effects of mobile device use on SCE or crash risk.

Between 1985 and 1995, mobile phone subscriptions increased from 340,213 to more than 33.8 million (“History of”, 2011). At that time, NHTSA was concerned with how this substantial increase was affecting safety on the Nation’s roadways. Goodman, Tijerina, Bents, and Wierwille (1999) performed an analysis on data and information gathered from crash statistics, statistical analyses, a literature review, user characteristics, and design issues. There was not enough information to characterize cell phone related crashes. However, they were able to conclude that a decrease in the amount of attention a driver paid to the roadway, because of a cell phone, caused degradation in vehicle control, object and event perception, or situational awareness.

A very recent study examined the ability of cell phone conversations to keep drivers awake and alert (Jellentrup et al., 2011). Two truck drivers and 1 light-vehicle driver participated in each session, in which they had to drive on a test track for 6 hr in a convoy. While they were driving, participants wore EEG, electrooculograph (EOG), electrocardiogram (ECG), and electrodes to measure alertness and other psychophysiological measures. Participants also wore two metal coils, one on the upper lid and one on the lower lid of the same eye, to obtain a measure of eye-closure. As participants in the "communication" sub-study drove in the convoy, they received a total of six phone calls within two experimental blocks. These calls occurred 1 hr, 2 hr, and 2.5 hr into each 3 hr block and lasted no more than 5 min.

Results from subjective measures used in Jellentrup et al. (2011) indicated that participants thought the phone calls were reviving and over 80% of participants thought they were important during driving. In the analysis of EEG data, an increase in alpha spindle rate indicates that participants are more fatigued and they have a decrease in attention. In a comparison of the alpha spindle rate 20 min before a phone call and 20 min after, results indicated that there was a significant main effect between the period before and after the call. The alpha spindle rate decreased during and after the call compared to before the call. Since the rate decreased, the participants most likely experienced an increase in attention and a decrease in fatigue.

Eye-lid opening analyses were performed separately for morning and afternoon blocks, as well as for each phone call (Jellentrup et al., 2011). When analyzing blink duration, a decrease indicates that the driver is more alert. Results indicated that the first phone call was associated with a significant decrease in blink duration during the phone call and 10 min after versus the 20 min before in the morning and afternoon. The second call was also associated with a significant decrease in blink durations when comparing the phone call and 10 min after to the 20 min before in the morning. The third phone call was not associated with a significant decrease in blink duration in either the morning or afternoon. It can be seen from the morning block that the longer the participants drove the less likely their blink duration was to decrease after a phone call. A decrease in blink duration after only the first phone call in the afternoon may indicate an influence of time of day.

As noted, Olson et al. (2009) examined CMV driver distraction, defined using the Pettitt et al. (2005) definition noted previously. The objective was to categorize tasks that drivers performed prior to an event as secondary, tertiary, or other. Researchers also calculated the frequency and percentage of each task, as well as SCE risk associated with each task. Data from the DDWS FOT (Hanowski et al., 2008) and the NTDS (Blanco et al., in press) were used in the analysis. From the two datasets, there was a total of 4,452 SCEs which were broken down into crashes (21 SCEs), near-crashes (197 SCEs), crash-relevant conflicts (3,019 SCEs), and unintentional lane deviations (1,215 SCEs). They also randomly selected 19,888 BLs.

Olson and colleagues (2009) calculated odds ratios to assess the SCE risk of tasks drivers performed prior to a SCE/BL of interest. The results indicated that the secondary and tertiary tasks that posed the most risk were those with high visual and/or visual-manual demand, such as text messaging on a cell phone, reaching for an electronic device, looking at a side-view window, or other visually demanding tasks. SCE risk for drivers was 23.2 times higher than normal driving if they were text messaging and 5.9 times higher than normal driving if they were dialing a cell phone. Talking/listening on a hand-held cell phone was not found to significantly increase or decrease a driver's SCE risk. However, talking/listening on a hands-free cell phone or CB radio significantly decreased drivers' SCE risk and the tasks were found to be beneficial.

Hickman et al. (2010) performed a study to identify the prevalence of distracting tasks while driving. Driver distraction was defined using the Pettitt el al. (2005) definition, noted previously. Researchers used kinematic and categorical data from DriveCam®, a company that provides onboard safety monitoring devices to professional fleets. For one of the datasets used, DriveCam® documented distractions that were present in each SCE. This dataset contained a total of 40,121 SCEs, including crashes, near-crashes, and crash-relevant conflicts, and 211,171 BLs. Documenting distractions allowed researchers to categorize the data by device use subtasks, such as reaching for a cell phone or dialing a cell phone, before analyzing the data. A descriptive analyses, calculation of odds ratios for tertiary tasks, calculation of population attributable risk, and calculation of odds ratios of fleet cell phone policy and state cell phone law were conducted. For the purpose of this thesis, only the odds ratios for tertiary tasks will be discussed.

Table 3

Significant Odds Ratios for Tertiary Tasks (Hickman et al., 2010, p. 41) Used under fair use, 2012.

Tertiary Task	Odds Ratio	95% CI	
		LL	*UL*
Any Cell Phone Use	1.14	1.06	1.23
Dialing Cell Phone	3.51	2.89	4.27
Reaching for Headset/Earpiece	3.38	2.64	4.31
Reaching for Cell Phone	3.74	2.97	4.71
Texting/E-mailing/Accessing the Internet	163.59	51.77	516.73
Talking/Listening Hands-Free Cell Phone	0.65	0.56	0.76

Note. CI = confidence interval; *LL* = lower limit, *UL* = upper limit.

Table 3 contains the significant odds ratios, including lower and upper confidence limits, of the tertiary tasks. The calculation of odds ratios for tertiary tasks indicated that texting/e-mailing/accessing the internet posed the second highest SCE risk (Hickman et al., 2010). However, since the confidence interval was so large, the authors were only able to conclude that there was a very strong relationship between texting/e-mailing/accessing the internet and involvement in SCEs. The researchers found that a driver's risk of being involved in a SCE was significantly reduced while talking/listening on a hands-free phone. However, there was not a significant increase or decrease in SCE risk compared to BLs when talking/listening on a hand-held cell phone. These findings were very similar to the results of Olson et al. (2009). The difference in these finding relate directly to Wickens' multiple resource model, noted previously. The tasks that require more visual resources are in the same dimension as the driving task, so resources are limited and performance will decrease. However, talking or listening while being able to keep both hands on the wheel and eyes on the road is in a different dimension than the visual aspect of the driving task, so there is less performance decrement when performed simultaneously (Wickens, 2002).

A recent study by Fitch and Hanowski (2011) examined driver risk while using a mobile device under various levels of driving task demand in two preexisting datasets. Data from the 100-Car Study (Klauer et al., 2006) focused on light vehicle drivers and data from the CVO study (Olson et al., 2009) focused on CMV drivers. These datasets were not combined in the analyses. In order to divide the data into levels of driving task demand, researchers established criteria using external factors (seen in Table 4), such as weather, light condition, and surface condition, based on a literature review. One of the factors was Level of Service (LOS), which is a way to characterize traffic density. There are 6 levels (A-F), LOS A being the lowest and LOS F being the highest traffic density.

Table 4

Criteria Used to Define Each Level of Driving Task Demand (Fitch & Hanowski, 2011, p. 5) Used under fair use, 2012.

Demand Level	Criteria for the SCE\BL of interest
Low	• Daylight conditions • No adverse weather • Road must be straight, level and dry • Not junction-related • LOS A
Moderate	• Did not fall under the “high” or “low” category
High	• At intersection or intersection related • On an exit/entrance ramp • On a driveway • On a bridge • In a parking lot • At a rail crossing • LOS C or greater

Researchers first identified the external factors, in the data (Fitch & Hanowski, 2011). After, they coded the thresholds for the low and high categories base on the criteria set. Subsets were created in each database by using the Structured Query Language (SQL) procedure in Statistical Analysis Software (SAS). The SCEs and BLs that did not fall into the low or high driving task demands subsets made up the moderate driving task demand subset in each database. After the driving task demand subsets were formed, any video that included a driver performing a mobile device use subtask was marked for the specific subtask. If the task involved a cell phone, it was also marked for cell phone use (including all subtasks). The CMV data were also marked for talking/listening on a CB radio. This procedure was used as a model for creating subsets in the current research.

Odds ratios were calculated for each level of driving task demand in both databases and for the various subtasks, such as talking/listening on a hand-held cell phone (Fitch & Hanowski, 2011). The results indicated that in the low task demand subset, dialing a cell phone increased the light vehicle drivers' SCE risk and no tasks affected CMV drivers' SCE risk. In the moderate task demand subset, cell phone use (including all subtasks) increased the CMV drivers' risk of a SCE, but talking/listening on a hands-free cell phone or CB radio decreased their risk. Cell phone use (including all subtasks) also increased the light vehicle drivers' risk in the moderate task demand subset. Complex subtasks, such as text messaging or dialing, increased SCE risk the most in the moderate subset. Cell phone use (including all subtasks) decreased drivers' SCE risk from both datasets in the high task demand categories; however, talking/listening was represented the most in this workload category and was found to decrease SCE risk individually.

Summary

The above literature explains the effects of driving time, time on duty, time of day, and amount of sleep on mobile device use and SCE risk. There is a clear need for more research regarding these factors and their relation to driver distraction because, as noted, the amount of knowledge regarding the effect of fatigue or drowsiness on distraction is insufficient (Williamson, 2009). Although there was a decrease in the number of large trucks involved in fatal crashes between 2007 and 2009, 3,619 individuals were killed in crashes involving a bus or large truck ("Commercial motor", 2011). The current research will help increase the body of knowledge related to fatigue, drowsiness, and distraction and will support training and education about the subject.

It has been established that attention is a limited resource; performing multiple tasks is difficult and may not be possible depending on the amount of attention each requires (Kahneman, 1973). Wickens (2002) describes the various dimensions of attention and indicates, as Kahneman did, that performing more than one task in the same dimension causes a decrease in performance. The driving task is primarily visual, so secondary or tertiary tasks that also involve visual resources are more likely to cause a decrease in performance. Fatigue and drowsiness make performing a task it more difficult, so more attentional resources are required (Kahneman, 1973). Having fewer attentional resources available increases the likelihood of performance decrement, which could lead to a SCE (Gugerty & Brooks, 2000; van der Linden et al., 2003).

Attention encompasses the key terms that have been defined in the literature review (e.g., vigilance and fatigue) related to the factors being studied in the current research and driver distraction. The task of driving requires vigilance (Atchley & Chan, 2011; Larue et al., 2011), or the capacity to hold continuous attention on the roadway while driving (Kahneman, 1973). When the driver becomes fatigued or drowsy he/she will experience a vigilance decrement. Monotony and understimulation from the task of driving will also intensify a vigilance decrement (Atchley & Chan, 2011; Larue et al., 2011) because task demand is too low (Yerkes & Dodson, 1908). When task demand is too low, performance has been found to worsen (Yerkes & Dodson, 1908). In order to cope with a decrease in alertness, drivers have indicated they self-regulate and perform secondary or tertiary tasks to increase arousal (Baker et al., 2008; Williamson et al., 2001). However, these tasks become distracters when they are the underlying mechanism that diverts attention from the task of driving and lead to a SCE (Pettitt et al., 2005; Hanowski et al., 2005).

The tertiary tasks that are being examined in the current research include dialing a cell phone, text messaging on cell phone, talking/listening to hand-held phone, talking/listening to hands-free phone, talking/listening to CB radio, and interacting with/looking at a dispatching device. Olson et al. (2009) and Hickman et al. (2010) found similar results that indicated visual and/or visual-manual subtasks were associated with high SCE risk. These types of tasks included text messaging or dialing a cell phone. Talking/listening on a hand-held or hands-free phone or CB radio did not increase SCE risk, but rather decreased it or had no effect. Jellentrup et al. (2011) found an increase in arousal after a phone call as compared to before for most calls in the driving period. Overall, these studies found that not all tertiary tasks related to mobile device use are distracters.

As noted, fatigue and drowsiness influence the amount of attentional resources available for other tasks. Driving time and time on duty can be seen as the causes of fatigue and time of day and amount of sleep can be seen as the causes of drowsiness. These potential causes were the factors examined in the current research. Relay drivers began to show a decrease in arousal after approximately 5 hr of driving and sleeper berth drivers show decreases earlier (Harris & Mackie, 1972; Mackie & Miller, 1978). Breaks are not as effective at decreasing vigilance decrements as they occur later in the shift, which is a sign that fatigue becomes too intense to overcome (Harris & Mackie, 1972).

Night driving has been found to have an increase in driver drowsiness, which leads to decreased performance and an increase in SCEs (Wylie et al., 1996; Mitler et al., 1997). CMV drivers have been found to sleep less than the recommended 7 to 8 hr of sleep for adults (Hanowski et al., 2000; Bonnet & Arand, n.d.). Mitler and colleagues (1997) found that the drivers who received the least amount of sleep throughout the study accounted for the most data involving drowsy driving.

With a thorough understanding of the concepts examined in the current research and the results of past studies regarding these concepts, specific decisions about the analyses could be made. These decisions and more specific information about the current research can be found in the Method section.

Method

Goal of Current Research

The goal of the current research was to explore how SCE risk associated with mobile device use differs as a function of driving time, time on duty, and time of day. The research also examined the relationship between mobile device use, fatigue, and drowsiness. It is important to understand exactly what each of these factors is through the operational definitions found in the next section.

Operational Definitions

The following operational definitions were adapted from the reports cited in the Source column, which defined each of these concepts.

Table 5

Operational Definitions of Variables for Current Research

Factor	Operational Definition	Source	Data
Driving Time	Estimated amount of time, from the beginning of the shift, including only driving time, until the SCE/BL of interest.	Blanco et al., in press	Logbook
Time on Duty	Estimated amount of time, from the beginning of the shift, including driving and non-driving time and breaks, until the SCE/BL of interest. The driver is allowed to be on duty for a maximum of 14 hr and he/she is allowed to drive for 11 of those 14 hr.	Blanco et al., in press; Barr et al., 2011; FMCSA, 2011	Logbook
Time of Day	Time of day that the SCE/BL of interest occurred (based on the 24-hr clock)	Hanowski et al., 2000; Barr et al., 2011	Logbook and video
Circadian Rhythm	An endogenous physiological clock, which causes self-sustained oscillations in body characteristics (e.g., temperature)	Aschoff, 1965	N/A
Amount of Sleep	The time the driver spent sleeping in the 24 hr preceding the SCE/BL of interest.	Blanco et al., in press	Actigraphy

Research Questions

This section contains the research questions (RQ), hypotheses (H), and rationale for the current research. As noted, the current research aimed to build upon the results of past studies, so hypotheses were directional.

RQ 1: To what extent does the *risk* of a SCE associated with mobile device use differ as a function of *driving time*?

H 1.1: Conversing on a hands-free mobile device will be associated with a decreased SCE risk compared normal driving.

H 1.1: Performing all other mobile device subtasks will be associated with an increased SCE risk compared normal driving.

Rationale: Olson et al. (2009) and Hickman et al. (2010) found that talking/listening on a hands-free cell phone significantly decreased drivers' SCE risk and may be beneficial. In both studies, subtasks that were visually demanding, such as text messaging, were associated with a much higher SCE risk (Hickman et al., 2010; Olson et al., 2009). Performing two tasks that are in the same dimension (visual, auditory, etc.) will limit attentional resources allocated to the tasks and decrease performance (Wickens, 2002). This rationale will stand, in terms of the effects of subtasks, for all SCE risk related RQ in the current research.

Results from Larue et al. (2011) indicated that the participants no longer paid attention to specific driving tasks when they drove on a monotonous road. Harris and Mackie (1972) reported that 23% of drivers indicated that they had been involved in a crash or near-crash after driving for a long period of time. Similarly, Williamson and colleagues (2001) found that 21% of drivers reported experiencing at least one crash that was related to fatigue; these included crossing lane lines (11%), having a near miss (5%), and over or under steering (5%). The drivers in the Williamson et al. (2001) study reported their reaction time slowed and their gear changing and steering worsened when they were fatigued, which influences SCE risk. However, Atchley and Chan (2011) found that when participants performed a verbal task in the last period of their drive they were better able to maintain lane position, had less road infractions, and showed a decrease in steering variability.

RQ 2: What is the relationship between *mobile device use* and *driving time*?

H 2: If used as a countermeasure to fatigue, drivers that used their mobile device will have been driving longer per driving shift before a SCE/BL of interest with use compared to drivers that did not use their mobile device.

Rationale: As noted, Harris and Mackie (1972) found that relay drivers showed a decrease in arousal after 5 hr of driving; Mackie and Miller (1978) found similar results. Baker et al. (2008) inquired about countermeasures to driver drowsiness through focus groups with various types of CMV drivers and found drivers use CB radios to stay alert. Williamson and colleagues (2001) studied long distance road transport drivers across Australia to examine the effects of fatigue. Through a survey, the researchers found that 48% of drivers reported long driving hours as a contributor to their fatigue. Researchers also asked drivers about strategies they use to manage fatigue; 65% of drivers reported that they used their CB radio as a strategy (Williamson et al., 2001). Jellentrup et al. (2011) found participants who received a cell phone call 1 hr, 2 hr, and 2.5 hr into a 3 hr, monotonous drive had a significant decrease in alpha spindle rate and blink duration during and after a phone call as compared to before the call. A decrease in alpha spindle rate and blink duration are both signs of increased alertness.

RQ 3: To what extent does the *risk* of a safety-critical event associated with mobile device use differ as a function of *time on duty*?

H 3.1: Conversing on a hands-free mobile device will be associated with a decreased SCE risk compared to normal driving.

H 3.2: Performing all other mobile device subtasks will be associated with an increased SCE risk compared to normal driving.

Rationale: A study by van der Linden and colleagues (2003) found that fatigued drivers had more automatic regulation, which included a decrease in planning and a decrease in task maintenance even when feedback indicated the driver needed to make a change. This could affect a driver's response to situations in which they need to change a behavior to avoid a SCE. Also, it has been found that fatigue-inducing tasks intrinsic to driving work and the safety practices surrounding the field account for variability in close calls (Morrow & Crum, 2004). One such task for relay drivers is moderately heavy lifting (Mackie & Miller, 1978). Talking/listening on a hands-free device will have an alerting effect; however, other subtasks will increase SCE risk (Olson et al., 2009; Hickman et al., 2010). Performing two tasks that are in the same dimension (visual, auditory, etc.) limits attentional resources allocated to the tasks and decreases performance (Wickens, 2002).

RQ 4: What is the relationship between *mobile device use* and *time on duty*?
H 4: If used as a countermeasure to fatigue, drivers that used their mobile device will have been on duty for longer per work shift before a SCE/BL of interest with use compared to drivers that did not use their mobile device.
Rationale: Caldwell, Caldwell, and Schmidt (2008) suggest breaks are important in keeping sustained attention, but their beneficial effects may be short-lived. Harris and Mackie (1972) found that when participants took a break after 3 hr of driving the drivers experienced an increase in arousal, after 6 hr of driving there was a decrease in benefit, and a break after 9 hr of driving had no benefit. However, the drivers who participated in Baker et al. (2008) indicated that the breaks they took were typically a maximum of 30 min when necessary. Although breaks have been found to give some benefit, loading and unloading has been found to increase fatigue (Mackie & Miller, 1978). Williamson et al. (2001) found that 36% of drivers reported that loading or unloading was a contributing factor to driver fatigue. Drivers will still use their phones, or another mobile device, as an alerting mechanism as suggested in Jellentrup et al. (2011); however, use might be later in their shift if breaks have alerted them.

RQ 5: To what extent does the *risk* of a safety-critical event associated with mobile device use differ as a function of *time of day*?
H 5.1: Conversing on a hands-free mobile device will be associated with a decreased SCE risk compared to normal driving.
H 5.2: Performing all other mobile device subtasks will be associated with an increased SCE risk compared to normal driving.
Rationale: According to Wylie and colleagues (1996), time of day was consistently related to driver alertness and performance. This could be used to explain the results from the study by Dingus et al. (2001), which found that hour of day was a significant predictor of SCE rate. Although time of day could be used to predict crash rate, the results from Takayama and Nass (2008) indicate that drivers could still be alerted with the correct level of interaction. For example, talking/listening on a hands-free device will have an alerting effect; however, other

subtasks will increase a driver's SCE risk (Olson et al., 2009; Hickman et al., 2010). Performing two tasks that are in the same dimension (visual, auditory, etc.) will limit attentional resources allocated to the tasks and decrease performance (Wickens, 2002).

RQ 6: What is the relationship between *mobile device use* and *time of day*?
H 6: If used as a countermeasure to drowsiness, drivers that used their mobile device will have been driving during a circadian low period as compared to drivers that did not use their mobile device.
Rationale: It has been noted that individuals feel drowsier during circadian low periods than other times of the day (National Sleep Foundation [NSF], n.d.). According to Barr et al. (2011), the high rate of driver drowsiness in the afternoon (approximately 2:00 p.m. – 4:00 p.m.) could be related to the circadian rhythm. Also, Caldwell et al. (2008) indicate the circadian rhythm causes individuals to be less alert and capable during low periods. As noted, Takayama and Nass (2008) found that drowsy participants' driving performance was better with interactive media.

RQ 7: How is amount of sleep related to the proportion of SCEs associated with mobile device use versus SCEs not associated with mobile device use?
H 7: If used as a countermeasure to fatigue, drivers that used a mobile device will have received less sleep the night before a shift than drivers that did not use a mobile device.
Rationale: Mitler and colleagues (1997) found that 8 drivers who were assigned to the schedule that caused them to have the least amount of sleep accounted for over half of the drowsy driving videos. Along the same lines, Hanowski and colleagues (2000) found, through focus groups, that not getting enough sleep was in the top five reasons for drowsy driving. Not only does getting less sleep increase driver drowsiness, but it also affects alertness and performance. In an article by Ferrara and De Gennaro (2001), the authors stated that alertness and performance levels were made worse when sleep was moderately restricted. In addition, Gugerty and Brooks (2000) found that when drivers were drowsy they had a decrease in attentional capacity and situational awareness. Taub and Berger (1973) found that participants who received 3 hr less sleep the night before performing a vigilance task had a significant decrease in accuracy and speed in their response. However, Takayama and Nass (2008) found that drowsy drivers who were engaged in more interactive media (i.e., language learning that required listening and responding) drove

more safely than those who were engaged in media that did not require a response (i.e., language learning that only required listening).

As noted, these research questions were answered through a re-analysis of preexisting data. A description of secondary data analysis can be found in the subsequent section.

Secondary Data Analysis

Secondary data have been made attainable for individuals aside from the original investigator to use (Pienta, O'Rourke, & Franks, 2011). Secondary data analysis uses these data to answer different or new research questions (Windel, 2010; Clarke & Cossette, 2000). This method of research limits the need to observe more participants by maximizing the use of the available data (Sandelowski, 1997; Heaton, 1998; Szabo & Strange, 1997; Smith, 2008). In addition, it is cost effective and typically requires fewer resources, since no data collection is required (Windel, 2010; Clarke & Cossette, 2000; Castle, 2003). Existing databases are often larger and contain higher quality data than could be collected by an individual or in a short amount of time (Windel, 2010; Pienta et al., 2011). These benefits make this method appealing to undergraduate and graduate students (Windel, 2010; Pienta, et al., 2011; Clarke & Cossette, 2000). Although no data collection is required, understanding what data are available, what state they are in, the methods used to collect them, and preparing the data for use will take time, so it is not necessarily a quicker or easier method (Clarke & Cossette, 2000; Pienta et al., 2011; Windel, 2010). The data used in the current research is summarized in the following two sections.

Summary of the NTDS

This section summarizes the NTDS, the study from which the data used in the current research originates. The details in the following sections were obtained from the NTDS final report (Blanco et al., in press).

Project overview. The primary purpose of the NTDS was to investigate the interactions between light vehicles and heavy vehicles, as well as other related safety issues, through a naturalistic driving study. Researchers used data from the perspective of the heavy vehicle driver to fulfill their primary goal of investigating SCEs (e.g., crashes, near-crashes, and crash-relevant conflicts) to establish countermeasures that would drive technology, policy, and training.

Research design. The research design included an on-road driving study and required no experimental manipulation, since it was naturalistic. Researchers recruited participants from seven terminals, which were owned by one of four truck fleets. Each of the 100 participants, who held a Class-A CDL, was observed for 4 work weeks while driving the same truck. Once a participant completed his/her 4 weeks another participant would begin in the same truck.

Participants and setting. Of the 100 participants, 95 were male and 5 were female. The mean age of participants was 44.50 (*SD* = 12.20) and ranged from 21 to 73 years. The participants had between 0.1 to 54 years of driving experience with a mean of 9.10 years (*SD* = 10.46). Participants were selected from for-hire companies that included both line-haul and long-haul operations. Line-haul is when a driver departs from a location, drives to another location to drop off or pick up, and then returns to the original location in less than 24 hr. Long-haul is when a driver leaves a location to make deliveries and returns to the original location after more than 24 hr. These terms are synonymous with "sleeper berth" (i.e., long-haul) and "relay" (i.e., line-haul) drivers or schedules, which were used in Mitler et al. (1997).

Data collection. The data collected in the NTDS included driver input/performance measures, video, actigraphy data, daily log books, which had a record of the drivers’ work/rest schedule, and pre- and post-test questionnaires.

The system that collected the data was called the Data Acquisition System (DAS), which included a Pentium-based computer and had four major components, all of which would start upon the initiation of the ignition. The first component was an array of sensors, which included an accelerometer to collect data on the longitudinal and lateral acceleration of the truck and a global positioning system (GPS). The first component also collected information on the distance to the lead vehicle. A computer collected the data from the second component, a vehicle network. The vehicle network was a from-the-factory, on-board data collection system installed by the manufacturer of the truck. It collected measures such as vehicle speed, ignition signal, and break pressure. The format of the messages displayed and the data collected were defined by the standard SAE J1587 and the Virginia Tech Transportation Institute (VTTI) developed an interface to access the data and bring it into the DAS dataset. The third component was comprised of video cameras that collected views of the driver's face, forward roadway, steering/dash, and left- and right-side of the tractor trailer. A view of the face camera can be seen in Figure 5 and images captured from these camera views can be seen in Figure 6. These videos were used to validate the information collected by the sensors and the lane tracker.

Figure 5. Face camera located in truck cab (Blanco et al., in press, p. 13). Used with permission of Dr. Blanco.

Note. The individual pictured is an employee of VTTI.

Figure 6. Five camera views (Blanco et al., in press, p. 15). Used with permission of Dr. Blanco.

Data were also collected with a video based lane tracker, Road Scout, which was developed by VTTI. The system included an analog black and white camera, a personal computer (PC) with a frame grabber card, and an interface-to-vehicle network, which was used to obtain the ground speed. Road Scout obtained information about six variables: distance from the center of the truck to the left and right lane markings, angular offset between the truck centerline and the road centerline, approximate road curvature, confidence in reported values for each marking found, and marking characteristics (i.e., in-lane or solid line). The estimated maximum error for the distance of truck to lane markings was less than 6 in and the mean error was less than 2 in. The estimated maximum error for the angular offset was less than 1 degree.

Through these systems, the researchers of the NTDS collected 6.20 terabits of video and performance data (Blanco et al., in press). This included more than 14,500 driving-hours and 26,000 on-duty hours from log books. There was also 65,000 hr of actigraphy data collected.

Data reduction. Data Analysis and Reduction Tool (DART) was the software program the researchers and trained data reductionists from the NTDS used to examine the data. First, DART identified and flagged incidents of interest by scanning for hard breaking and other such happenings based on the threshold, or trigger, values found in Table 5. Then the trained reductionists examined these incidents and identified if they were valid or invalid. A valid incident was one in which the trigger value was met and could be verified through video or other sensor data. An invalid incident was one in which the sensor reading gave a false positive due to an event, such as braking at a stop light, or a transient spike. All of the valid incidents are classified as one of the six different types of SCEs noted previously. Finally, the reductionists answered questions about the valid SCEs.

Table 6

Trigger Values Used in the NTDS (Blanco et al., in press, p. 43) Used under fair use, 2012.

Trigger Type	Definition	Description
Longitudinal Acceleration	Firm braking or rapid acceleration.	"Acceleration or deceleration greater than or equal to | 0.20 g |. Speed greater than or equal to 1 mph (1.6 km/h)." (p. 43)
Time-to-Collision (TTC)	The number of seconds in which two vehicles would collide if one did not carry out an evasive maneuver.	"A forward TTC value of less than or equal to 2 s, coupled with a range of less than or equal to 250 ft, a target speed of greater than or equal to 5 mph (8 km/h), a yaw rate of less than or equal to | 6°/s |, and an azimuth of less than or equal to | 0.12° |." (p. 43)
Swerve	An abrupt "yank" of the steering wheel in order to restore the truck to its initial location in the lane.	"Swerve value of greater than or equal to 2 rad/s^2. Speed greater than or equal to 5 mph (8.05 km/h)." (p. 43)
Lane Deviations	Any instance when the truck leaves the lane and returns to the same one without changing lanes.	"Lane tracker status = abort. Distance from center of lane to outside of lane line < 44 in." (p. 43)
Critical Incident Button	A self-reported incident.	Initiated by the driver when the button, positioned by the driver's visor, was pressed after an incident occurred, which he/she considered critical.
Analyst Identified	A SCE identified by the reductionist but has not been recognized by a trigger.	SCE that was discovered by a data analyst examining video footage that was not recognized by any trigger listed above.

After data reduction was complete, there were a total of 2,889 SCEs, which included 13 crashes, 61 near-crashes, 1,594 crash-relevant conflicts, 1,215 unintentional lane deviations, and

16 illegal maneuvers. An example of an illegal maneuver is crossing the center double yellow line to pass another vehicle. There was also a total of 456 BLs, which were randomly selected at a rate of one BL for every week a driver participated.

Actigraphy data were available for 97 of the 100 participating drivers and were analyzed to determine sleep quantity. Five steps were taken to obtain sleep measures. The first was to discriminate between when the driver was wearing their actigraphy monitor and when he/she was not; periods of time when the actigraphy data indicated the driver was not wearing his/her monitor were marked as "bad" data. Next, instances of sleep and wake were noted. The data were then converted into minute-by-minute files with the various periods coded, which were imported into an actigraphy database. Finally, an algorithm was applied to the data files to determine sleep periods.

The data collected in the NTDS has been used in many studies in addition to the current research (e.g., Olson et al., 2009; Fitch and Hanowski, 2011). A description of the Olson et al. (2009) study is presented in the next section with more focus on its use in the current research.

Summary of the CVO Study

The purpose of the CVO study was to investigate driver distraction in relation to CMV crashes (Olson et al., 2009). To do this, researchers identified if a driver was performing another task during the 6 s video clip of the SCE/BL of interest. If he/she was, the task was categorized as secondary or tertiary. These included the mobile device use subtasks discussed in the Mobile Device Use subsection. There were instances in which multiple types of distraction occurred for one SCE/BL of interest, in which case the SCE/BL would be included in both categories. For example, the driver could have been talking/listening on a hands-free phone and biting his/her nails and the SCE/BL would be counted in both subtasks.

Since data from the NTDS was included in the CVO study, the number of SCEs was the same and, therefore, the type of distraction(s) for each SCE has been identified. However, BLs were sampled differently in the CVO study; the percent of the total driving time of the DDWS FOT (Hanowski et al., 2008) and the NTDS that each participant's driving time equaled determined how many BLs were included for him/her. In addition, the truck had to be moving at a minimum of 15 mi/hr for the BL to be included. This change in selection method increased the number of BLs included in the CVO study as compared to the NTDS. A more detailed description of the data used in the current research and analyses performed can be found in the next section.

Analyses

The types of data needed for analyses of the SCE\BLs of interest in the current research were:

- The amount of time a driver had been driving before the SCE/BL of interest,
- The amount of time a driver had been on duty before the SCE/BL of interest,
- The time of day the SCE/BL of interest occurred,
- The amount of sleep a driver received 24 hr before the SCE/BL of interest, and
- Whether or not the driver was distracted during the SCE/BL of interest and the type of distraction(s) present.

Table 7 indicates what data existed for the NTDS and CVO study before any additional reduction was done for the current research. The decision about further calculations was based on what SCE/BLs of interest had information about distraction. Driving time and time on duty were calculated for the BLs for the CVO study, as well as the SCEs, since they had information about the type of distraction and the BLs from the NTDS did not. These calculations were made using updated logbook information, which was created for a study on hours-of-service (Blanco et al., 2011), and the time of day the SCE/BL of interest occurred. The SCEs from both studies and CVO BLs were used in analyses for driving time, time on duty, and time of day. However, there is no data regarding amount of sleep for the CVO BLs, so for the sleep analyses only SCEs were included.

Table 7

Information That Existed for SCEs and BLs for Each Study

Data	NTDS		CVO	
	SCE	BL	SCE	BL
Time of Day	Yes	Yes	Yes	Yes
Amount of Sleep	Yes	Yes	Yes	No
Type of Distraction	Yes	No	Yes	Yes

The data consisted of 2,152 SCEs and 3,958 BLs for driving time, time on duty, and time of day; there were 747 SCEs and 804 BLs that were included in the CVO study, but not included in the current study because they occurred after 11 hr of driving or 14 hr on duty. In addition, 1,836 SCEs were used for amount of sleep analyses; again, the decrease in the number of SCEs resulted from approximately 500 SCE that occurred after 11 hr of driving or 14 hr on duty. As noted, the method of dividing data into smaller subsets used in Fitch and Hanowski (2011) was used in the current research, particularly for SCE risk calculations. Before any analyses were performed, a normality test was conducted and a distribution of SCE/BLs of interest was plotted for each factor. All statistical tests and analyses were conducted using SAS.

Bins. Bins were determined based on previous studies that examined how the factors affected fatigue or drowsiness. For amount of sleep, literature about how many hours of sleep individuals actually needed was also used. Each table below lists the source and findings that the bins were based on for each factor. Table 12 shows the bins that were used in the current research.

Table 8

References and Findings to Support Driving Time Bins

Reference	Finding
Mackie & Miller, 1978	Drivers showed a decrease in arousal after 4.5 hr (sleeper) and 5 to 8 hr (relay).
Harris & Mackie, 1972	Drivers showed a decrease in arousal after 5 hr or less.
Jellentrup et al., 2011	A call after 2.5 hr did not decrease blink duration.
Barr et al., 2011	Drivers who drove more than 3 hr were more likely to be in the "high fatigue" group (OR = 3.75). Driving time was an important factor when the "high fatigue" and "low fatigue" groups were compared, but was not significant (p = .052).

Table 9

References and Findings to Support Time on Duty Bins

Reference	Finding
Harris & Mackie, 1972	When drivers took a break after 3 hr there was an increase in arousal. When they took a break after 6 hr there was less of an increase. When drivers took a break after 9 hr there was no increase in arousal.
Jellentrup et al., 2011	A call after 5.75 hr and 6.25 hr of "on-duty" time (including the 45 min break between 3 hr blocks) did not decrease blink duration.
Powell, Spencer, Holland, Broadbent, & Petrie, 2007	A 7-point Sanm-Perelli fatigue scale was used to measure short-haul pilot fatigue. If this scale was divided into low, moderate, and high levels there were no duty hours in the low level, hours 1-6 were in the moderate level, and 7-10 in the high level.

Table 10

References and Findings to Support Time of Day Bins

Reference	Finding
Jellentrup et al., 2011	In the morning, only the third phone call did not decrease blink duration. However, in the afternoon both the second and third calls did not decrease blink duration, which would have to most likely be between 1:45 p.m. - 3:15 p.m.
Wylie et al., 1996	The highest level of drowsiness occurred between late evening and dawn (approximately 8:30 p.m. – 4:30 a.m.). During this time 60 trips were starting and 80 trips were ending (140 trips total out of 360 trips overall).
Lenné, Triggs, & Redman, 1997	Drivers had the poorest driving performance at sessions that occurred at 2:00 p.m. (versus those that occurred at 2:00 a.m., 6:00 a.m., 10:00 a.m., 6:00 p.m., and 10:00 p.m.) for both straight and curved roadways. Performance was also better at sessions at 10:00 a.m. than sessions at 6:00 a.m., 2:00 p.m., and 2:00 a.m.
Moller, Kayumov, & Shapiro, 2003	Drivers reaction time to a wind gust in a simulator was significantly faster at 10:00 a.m. than at 12:00 p.m., 2:00 p.m., or 4:00 p.m.
NSF, n.d	The low arousal periods in the circadian rhythm occur between 2:00 a.m. - 4:00 a.m. and 1:00 p.m. - 3:00 p.m. in the average adults.
Figure 7	The high arousal periods in the circadian rhythm occur between 9:00 a.m. - 11:00 a.m. and 7:00 p.m. - 9:00 p.m. in the average adult.

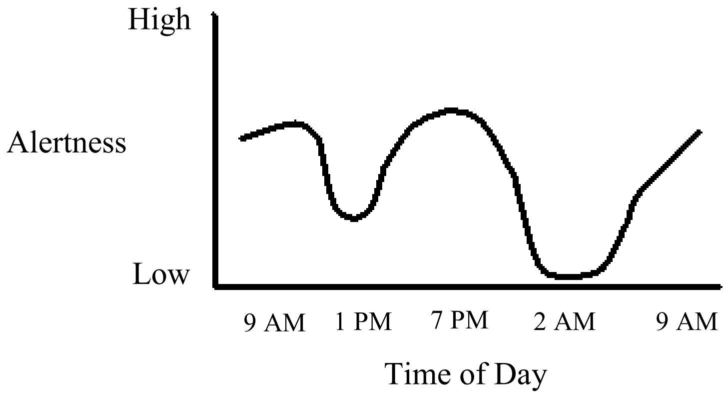


Figure 7. *Circadian rhythm for alertness by time of day.*

Table 11

References and Findings to Support Amount of Sleep Bins

Reference	Finding
Hanowski et al., 2000	Drivers received 5 to 6 hr of sleep the night before a SCE.
Taub & Berger, 1973	Participants showed a decrease in performance after sleeping for 3 hr less than normal (8 hr).
NSF, 2012	When asked how much sleep they need 31% of drivers indicated they need 6 to 7 hr of sleep, 26% need 7 to 8 hr of sleep, and 23% need less than 6 hr of sleep. When asked how many hours they actually sleep for on work nights 58% of drivers indicated they slept for 6 to 8 hr and 17% slept less than 6 hr.
Hanowski et al. 2005b	Drivers had an average of 5.28 hr (*SD* = 2.03) of sleep before a SCE, but an overall average sleep quantity of 6.63 hr (*SD* = 1.47).
Luckhaupt, Tak, & Calvert (2010)	Between 2004 and 2007, 37% of employees in the transportation field slept for less than or equal to 6 hr.

Table 12

Bins of Hours That Were Used in Current Research

Factor	Low	Moderate	High
Driving Time	1 - 4.99 hr	5 - 7.99 hr	8 – 11 hr
Time on Duty	1 - 4.99 hr	5 – 7.99 hr	8 – 14 hr
Time of Day	2:00 a.m. - 3:59 a.m. 1:00 p.m. – 2:59 p.m.		9:00 a.m. – 10:59 a.m. 7:00 p.m. – 8:59 p.m.
Amount of Sleep	1 - 5.99 hr	6 - 9.99 hr	10 – 15 hr

The subsequent sections describe how these bins were used in the analyses of SCE risk and mobile device use.

SCE Risk. As noted, the data for amount of sleep only included SCEs, so risk could not be calculated (i.e., no corresponding BLs). As noted, the SCEs and BLs were separated into low, moderate, and high bins for driving time, time on duty, and time of day. The data in the bins was then separated into subsets based on the presence or absence of mobile device use, so the frequency of SCEs and BLs with and without mobile device use could be input into a 2 x 2 contingency table for odds ratio analyses, Table 13. When odds ratios for subtasks were being performed, SCEs with and without each subtask were compared to BLs with and without that subtask.

Table 13

2 X 2 Contingency Table for Odds Ratios

	SCE	BL
Mobile Device Use	A	B
No Mobile Device Use	C	D

Odds ratios, lower confidence levels, and upper confidence levels were then calculated using the following equations. The exponents for "*e*" are based on the Z-table and vary depending on the alpha level. They are +/-1.645 for 90% confidence intervals and +/-1.96 for 95% confidence intervals.

$$\textit{Odds Ratio} = (A \text{ x } D)/(B \text{ x } C) \qquad \text{(Equation 1)}$$

$$\text{LCL} = \textit{Odds Ratio} \text{ x } e^{-1.96\sqrt{(1/a) + (1/b) + (1/c) + (1/d)}} \qquad \text{(Equation 2)}$$

$$\text{UCL} = \textit{Odds Ratio} \text{ x } e^{1.96\sqrt{(1/a) + (1/b) + (1/c) + (1/d)}} \qquad \text{(Equation 3)}$$

There were very few instances in which at least one cell in the contingency table had less than five data points. For these cases, a Fisher's exact test was used to calculate risk (Regan, Braude, & Trembath, 1989; Kaplan et al., 1998; Singh et al., 2007) in addition to an odds ratio.

When comparing SCEs and BLs, there has to be a ratio between the number of BLs and SCEs that is large enough. Maclure and Mittleman (2000) indicated that a ratio of 4:1 has a sufficient amount of power. The ratio of the data for the current study was 1.83:1when all classifications of SCEs (defined in the Mobile Device Use subsection) were included, which has little power and creates a weak comparison to subtask results from Olson et al. (2009) and Hickman et al. (2010) that have ratios of 4.46:1 and 5.26:1, respectively. Since there is a fixed number of BLs for the present data, the number of SCEs included had to be adjusted to increase the ratio. First, only the most severe SCE classifications (i.e., crash, near-crash, and crash-relevant conflict) were included and led to a ratio of 3.21:1. In order to determine if the SCE classifications included impacted the results, analyses were also conducted with only crash, near-crash, and unintentional lane deviation SCEs, which had a ratio of 4.08:1. It was possible to combine various SCE classifications since they are identified by the data collection system reflecting driver error.

The analyses that included the more severe types of SCEs contained a total of 1,232 SCEs, 181of which contained mobile device use. There were 970 SCEs in the analyses with crashes, near-crashes, and unintentional lane deviations and 188 contained mobile device use. With these decreases in SCE count, the number of data points in the contingency tables for analysis of mobile device use subtasks in each bin of the factors was reduced. Therefore, analyses of the subtasks were performed for all of the data and of mobile device use (including all subtasks) for each bin. In addition, all subtasks that require visual-manual resources (i.e., dialing cell phone, text messaging on cell phone, and interacting with/looking at a dispatching device) we combined in analyses for all data and each bin of the factors.

Analyses were conducted with an alpha level of .05 and .10. For all but one bin the significance of the results did not change between the two alpha levels. The difference will be discussed in the results section for that factor. The results of analyses with $\alpha = .05$ were used to compare the results of the current research to past studies, which had 95% confidence intervals. The results reported have an alpha level of .05, unless otherwise noted.

Mobile Device Use. First, the mean driving times, times on duty, and times of day for SCEs and BLs with and without mobile device use were found for each driver. The difference between these means was calculated and the mean difference was found for all drivers combined.

Before use analyses were conducted, it was important to ensure BLs were not oversampled in bins after the subsets were created. To do this, the proportions of the total number of BLs in each bin and the proportions of driving opportunities, seen in Figure 8, in each bin were calculated and compared for driving time. A driving opportunity for driving time is any instance in which a participant was driving in a single hour, whether or not there was a SCE or BL. For example, if a participant completed 1 hr of driving for 11 of his/her shifts there would be 11 driving opportunities in driving hour one. Table 14 shows the frequency of BLs and driving opportunities for each bin, as well as the proportions. It can be seen that the proportion of BLs and driving opportunities are very similar. This indicates the data are normalized, which allows comparisons of BLs across bins.

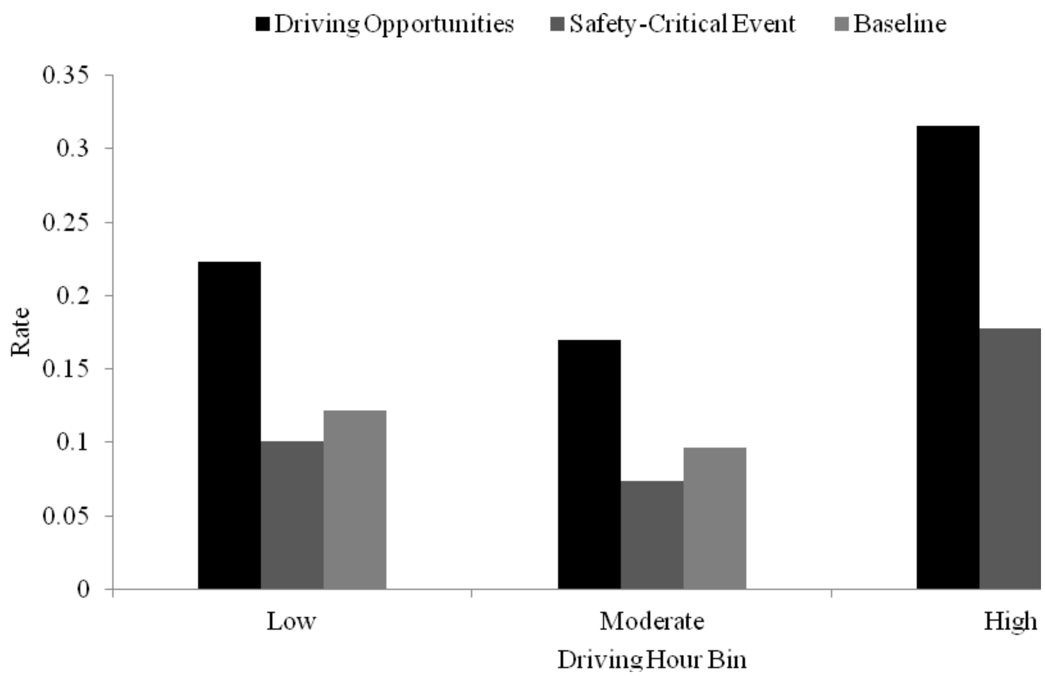


Figure 8. *Rate of SCEs and BLs with mobile device use to driving opportunities by hour of driving time.*

Table 14

Frequency of BLs and Driving Opportunities and Proportions for Each Bin of Driving Time

Bins	Frequency BLs	%	Frequency of Driving Opportunities	%
Low	1,968.00	49	6,692.91	50
Moderate	1,178.00	30	4,032.04	31
High	812.00	20	2,419.39	18
	Total = 3,958		Total = 13,144.35	

A generalized linear mixed model (GLMM) was used to model the probability of SCE/BLs of interest with or without mobile device use as a function of driving time, time on duty, and time of day. The model included a term for driver that controlled for differences across participants and an intercept that accounted for random error and captured driver behavior.

In addition to a GLMM, a chi-square test was also conducted to determine if the proportion of mobile device use changed across bins for each factor. If the result was significant, additional chi-square tests were conducted to compare the bins against each other to establish which bins were different. It is important to realize that although the contingency table for the test contains counts of SCE/BLs of interest, a chi-square actually analyzes the proportion of SCEs and BLs.

Performing these analyses with either SCEs or BLs is acceptable. However, if a difference in the amount of mobile device use between SCEs and BLs is found, it is unfair, and may cause bias, if the two are combined. In that case, only BLs or only SCEs would be included.

As with the risk calculations, mobile device use results were analyzed with an alpha level of .05 and .10. The significance of the results remained the same for all but three bins, which will be discussed in the results section. The results noted in the report are for an alpha level of .05 unless otherwise noted.

Amount of sleep. First, the mean amounts of sleep for SCEs with and without mobile device use were calculated for each driver. The difference between these means was calculated and the mean difference was determined for all drivers combined.

As noted previously, the data for the factor amount of sleep only included SCEs, which limited the types of analyses that could be performed. It was not possible to calculate risk using odds ratios, so a GLMM was chosen to assess the probability of SCEs with or without mobile device use as a function of amount of sleep. As with the other factors, a chi-square test was also used to determine if the proportion of mobile device use changed across bins.

An alpha level of .05 and .10 were used to analyze results; however, there was no difference between them. The results noted in the report have an alpha level of .05.

Results

As noted previously, the data used for the analyses of driving time, time on duty, and time of day was different than that used for the analyses of amount of sleep. The sleep data came from the NTDS and the mobile device use data came from the CVO study. However, the BLs were selected using different criteria, so there is no sleep data for the CVO BLs. Table 15 and Table 17 contain counts of SCEs and BLs in different categories used in the analyses. As noted, it was possible for a single SCE/BL of interest to have multiple mobile device use subtasks, so simply adding the number of SCEs or BLs with each subtask will not return the correct number of SCEs or BLs with mobile device use. Table 16 and Table 18 include the frequency of the various SCE classifications, defined previously, in each data subset. In both data subsets crash-relevant conflicts and unintentional lane deviations are the most frequent types of SCEs.

Table 15

Frequency of SCEs and BLs for All Driving Time, Time on Duty, and Time of Day

Category/Subtask	SCE	BL
No Mobile Device Use	1787	3543
With Mobile Device Use	365	413
Dial Cell Phone	89	30
Text Message on Cell Phone	16	3
Talk/Listen to Hand-Held Cell Phone	108	169
Talk/Listen to Hands-Free Cell Phone	43	157
Talk/Listen to CB Radio	22	40
Interact with/Look at Dispatching Device	108	26

Table 16

SCE Classification Frequency and Percent for All Driving Time, Time on Duty, and Time of Day Data

SCE Classification	Frequency	Percent
Crash	4	0.19
Near-Crash	46	2.14
Crash-Relevant Conflict	1182	54.93
Unintentional Lane Deviation	920	42.75

Table 17

Frequency of SCEs for All Amount of Sleep Data

Category/Subtask	SCE
No Mobile Device Use	1494
With Mobile Device Use	342
Dial Cell Phone	81
Text Message on Cell Phone	16
Talk/Listen to Hand-Held	101
Talk/Listen to Hands-Free	39
Talk/Listen to CB Radio	21
Interact with/Look at Dispatching Device	105

Table 18

SCE Classification Frequency and Percent for All Amount of Sleep Data

SCE Classification	Frequency	Percent
Crash	4	0.22
Near-Crash	34	1.91
Crash-Relevant Conflict	980	53.38
Unintentional Lane Deviation	817	44.50

Mobile Device Subtask Results

As noted, the SCE risk of all of the mobile device use subtasks was calculated using crashes, near-crashes, and crash-relevant conflicts and crashes, near-crashes and unintentional lane deviations that were not divided into bins. The results, seen in Table 19, indicate that texting messaging on a cell phone, interacting with/looking a dispatch device, and dialing a cell phone have the highest SCE risk. When these subtasks were combined in a "visual-manual" subset, SCE risk also increased. However, talking/listening on a hands-free cell phone significantly decreased SCE risk. These analyses reveal particular subtasks increase risk while others do not. Therefore, considering all mobile device use subtasks as equivalent, with "mobile device use (including all subtasks)", fails to acknowledge these subtasks SCE risk differences.

Table 19

Odds Ratio Results for Each Subtask

				95% CI					95% CI	
Task	SCE	BL	OR	*LL*	*UL*	SCE	BL	OR	*LL*	*UL*
	C, NC, CRC					C, NC, ULD				
Dial Cell Phone	41	30	4.50*	2.80	7.25	49	30	6.96*	4.40	11.03
Text Message on Cell Phone	10	3	10.78*	2.96	39.26	6	3	8.20*	2.04	32.86
Interact with/Look at Dispatch Device	39	26	4.94*	2.99	8.15	69	26	11.58*	7.33	18.28
Talk/Listen to Hands-Free Phone	26	157	0.52*	0.34	0.79	17	157	0.43*	0.26	0.72
Mobile Device Use	181	413	1.47*	1.22	1.78	188	413	2.06*	1.70	2.49
Visual-Manual	90	59	5.20*	3.72	7.28	124	59	9.68*	7.04	13.32
Talk/listen to CB Radio	13	40	1.04	0.56	1.95	10	40	1.02	0.50	2.05
Talk/Listen to Hand-Held Phone	61	169	1.17	0.86	1.58	49	169	1.19	0.86	1.65

Note. CI = Confidence interval; *LL* = lower limit, *UL* = upper limit; OR = odds ratio; C = crash, NC = near-crash, CRC = crash-relevant conflict, and ULD = unintentional lane deviation.
Note. Results do not change with 90% confidence intervals.
*Refers to statistically significant results.

A Fisher's exact test was also conducted to examine the significance of the relationship between SCEs and BLs when text messaging on a cell phone was present. Results were significant when both crash-relevant conflicts and unintentional lane deviations were included ($p < .001$ and $p < .001$, respectively), which indicated text messaging was associated with an increase in the number of SCEs. These results were consistent with the odds ratios.

A comparison of the odds ratio results of Hickman et al. (2010) when only tractor trailer/tanker data were included and Olson et al. (2009) to the odds ratio results of the current research can be found in Table 20. This table is an adaptation of Table 8 from Hanowski (2011). It can be seen that the results are similar, which supports the inclusion of only certain SCE classifications in the current research, to increase the BL/SCE ratio.

Table 20

Comparison of Past Odds Ratio Results to Odds Ratio Results of the Current Research

	Hickman et al. (2010)[a]	Olson et al. (2009)	Toole	Toole
Types of SCEs Included	C, NC, CRC	C, NC, CRC, ULD	C, NC, CRC	C, NC, ULD
Any Use (cell phone or mobile device)	1.08	1.04	1.47*	2.06*
Dialing Cell Phone	5.44*	5.93*	4.50*	6.96*
Talking/Listening Hands-Free	0.58*	0.44*	0.52*	0.43*
Talking/Listening Hand Held	1.01	1.04	1.17	1.19

Note. 95% confidence intervals.
Note. C = crash, NC = near-crash, CRC = crash-relevant conflict, and ULD = unintentional lane deviation.
*Refers to statistically significant results. [a] Only tractor trailer/tanker data were included.

Driving Time

General. In order to determine whether or not a parametric or nonparametric analysis should be used, a normality test was conducted. The results from the Kolmogrov-Smirnov test of all SCE/BLs of interest indicated the data were not normal ($D = 0.06$, $p < .01$). The distribution of the frequency of all SCE/BLs of interest by driving hour was skewed left, as can be seen in Figure 9. This is further supported by a mean of 4.44 hr ($SD = 2.78$) of driving time. This result indicates drivers drove for 4.44 hr, on average, before a SCE/BL of interest occurred throughout the study; if the data was distributed more normally the mean would be expected to fall at approximately 5.50 hr of driving.

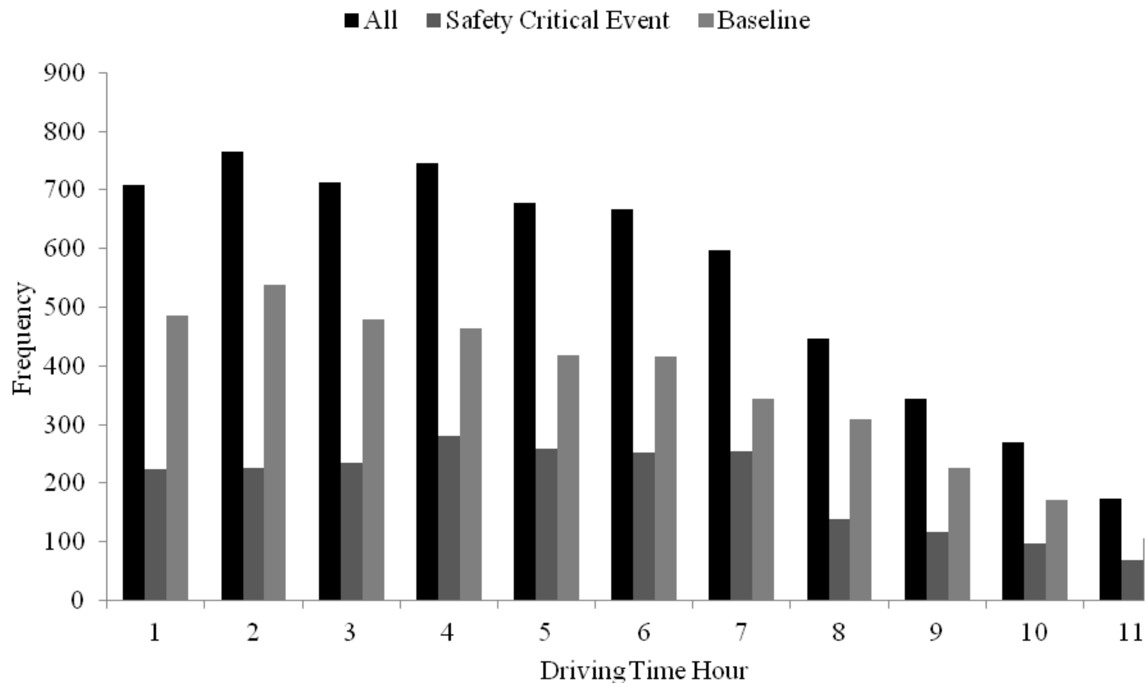


Figure 9. *Frequency of SCEs, BLs, and all data by hour of driving time.*

RQ 1: To what extent does the risk of a SCE associated with mobile device use differ as a function of driving time? Before the odds ratios, the number of each SCE classification was calculated for each bin. Table 21 contains the frequency and percent of SCE classifications present in each bin of driving time for all SCE classifications. Again, crash-relevant conflicts and unintentional lane deviations have the highest frequency and there are no crashes in the moderate bin.

Table 21

SCE Classification Frequency and Percent for Each Driving Time Bin

SCE Classification		Low	Moderate	High
Crash	Frequency	3	-	1
	Percent	0.31	-	0.24
Near-Crash	Frequency	21	16	9
	Percent	2.18	2.09	2.13
Crash-Relevant	Frequency	555	407	220
Conflict	Percent	57.57	53.20	52.01
Unintentional	Frequency	385	342	193
Lane Deviation	Percent	39.94	44.71	45.63

An odds ratio was used to compute the SCE risk associated with mobile device use for visual-manual subtasks and mobile device use (including all subtasks). The results, in Table 22, indicate drivers who were performing a visual-manual subtask had an increased SCE risk, compared to normal driving, in all bins. Mobile device use (including all subtasks) was also found to increase SCE risk. As expected, the odds ratio value is reduced when all subtasks are included (including talking/listening) as compared to visual-manual only. This was expected because the talking/listening subtasks did not increase risk.

Table 22

Odds Ratio Results for Each Bin of Driving Time

Bin	Subtask	SCE	BL	OR	95% CI *LL*	95% CI *UL*	SCE	BL	OR	95% CI *LL*	95% CI *UL*
		C, NC, CRC					C, NC, ULD				
Low	Visual-Manual	48	27	6.49*	4.01	10.51	63	27	13.09*	8.22	20.84
	Mobile Device Use	88	204	1.55*	1.18	2.03	82	204	2.16*	1.63	2.87
Moderate	Visual-Manual	27	22	3.58*	2.01	6.36	25	22	3.94*	2.19	7.08
	Mobile Device Use	88	129	1.96*	1.45	2.64	40	129	1.67*	1.15	2.43
High	Visual-Manual	15	10	5.59*	2.48	12.63	36	10	17.28*	8.41	35.52
	Mobile Device Use	35	80	1.64*	1.07	2.51	66	80	4.40*	3.03	6.40

Note. CI = Confidence interval; *LL* = lower limit, *UL* = upper limit; OR = odds ratio; C = crash, NC = near-crash, CRC = crash-relevant conflict, and ULD = unintentional lane deviation.
Note. Results do not change with 90% confidence intervals.
*Refers to statistically significant results.

RQ 2: What is the relationship between mobile device use and driving time? As noted, the difference between each driver's means driving time with and without mobile device use was calculated before the GLMM or the chi-square test were conducted. Figure 10 presents the difference between the mean hour of driving time for SCE\BLs of interest with and without mobile device use for each driver. It can be seen that SCE\BLs with mobile device use occurred at approximately the same time as SCE\BLs without mobile device use given that these differences are distributed closely to zero. The mean difference for all drivers was 0.13 hr (*SD* = 1.72), which indicates SCE\BLs of interest with mobile device use occurred when drivers had been driving approximately 7 min more than drivers during SCE\BLs of interest with no mobile device use.

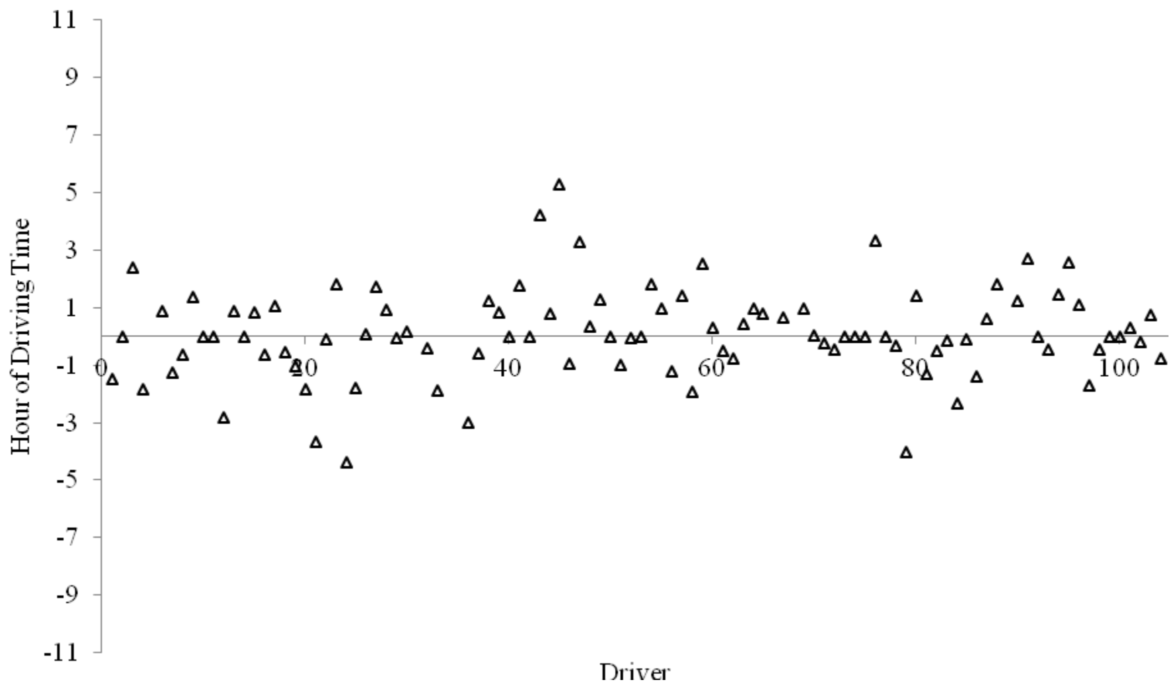


Figure 10. Difference between mean hour of driving time for SCE/BLs with and without mobile device use for each driver.

Since a difference in the amount of mobile device use between SCEs and BLs was found in the risk analyses, only BLs were used in the GLMM and chi-square test. The fact that SCE risk was significant indicates there was more mobile device use during SCEs and it is, therefore, not appropriate to combine SCEs and BLs. The results of the GLMM, listed in Table 23, indicated that driving time was not a good predictor of the probability that a BL will have mobile device use for any period. A significant intercept indicates that this probability differs across drivers. The distribution of driving time for BLs, seen in Figure 11, makes it clear that there is not a trend between BLs with and without mobile device use.

Table 23

GLMM Results for Driving Time (p value)

Bins	Driving Time	Intercept
All	.10	< .001*
Low	.71	< .001*
Moderate	.89	< .001*
High	.78	< .001*

Note. No change in significance with α = .05 or α = .10.
*Refers to statistically significant results.

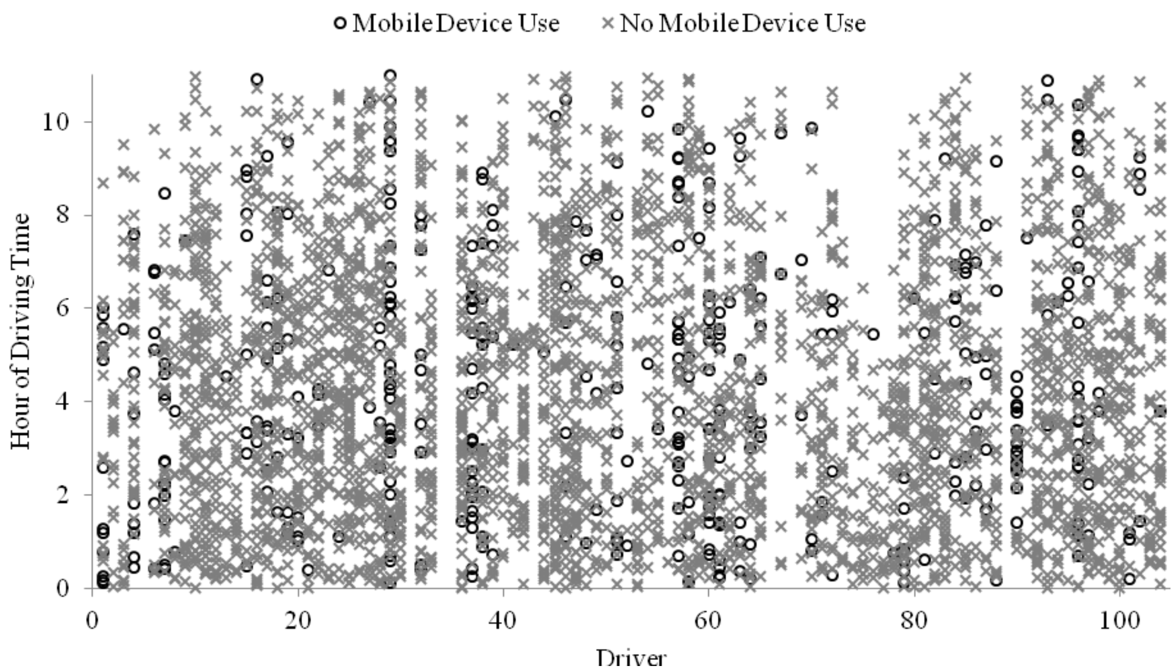


Figure 11. Distribution of driving time for BLs with and without mobile device use by driver.

The results of the chi-square test indicated there was no difference in the proportion of BLs with mobile device use for each bin, $\chi^2(2, N = 3{,}958) = 0.64$, $p = .72$. Table 24 is the contingency table used for the test.

Table 24

Chi-Square Contingency Table and Percentage for Driving Time

Bin	No Mobile Device Use	Mobile Device Use	Total	% With Mobile Device Use
Low	1764	204	1968	10.37
Moderate	1049	129	1178	10.95
High	732	80	812	9.85

Summary of driving time results. The odds ratios indicated drivers who were performing a visual-manual subtask had an increase in SCE risk, compared to normal driving, for each bin. Drivers who were using a mobile device had been driving for 7 min longer than drivers who were not using a mobile device. The GLMM results pointed to the fact that driving time was not a good predictor of mobile device use and the chi-square test results indicated the proportion of mobile device use did not differ significantly across bins.

Time on Duty

General. Non-parametric analyses were chosen because the results from the Kolmogrov-Smirnov test of all SCE/BLs of interest indicated the data was not normally distributed (D = 0.07, $p < .01$). The distribution of the frequency of SCEs, BLs, and all data by time on duty hour can be seen in Figure 12. The mean of the data was 6.01 hr (SD = 3.53) on duty, which is an indication the data were skewed left. In other words, drivers drove for an average of 6.01 hr before a SCE/BL of interest.

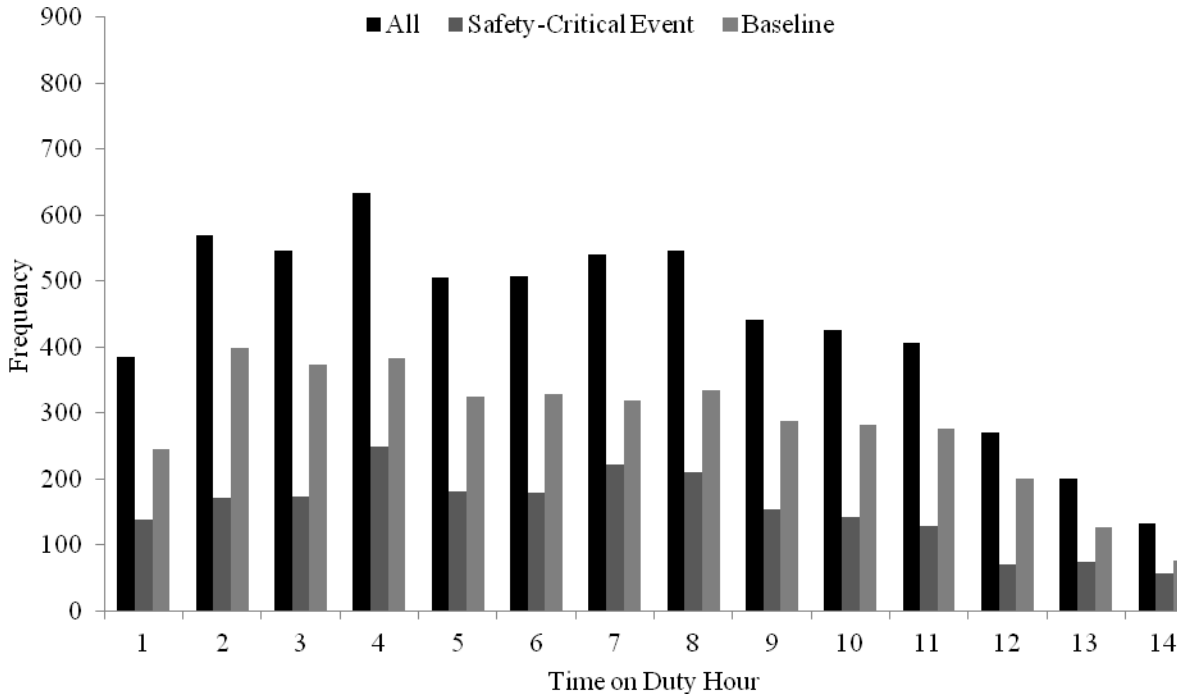


Figure 12. *Frequency of SCEs, BLs, and all data by hour of time on duty.*

RQ 3: To what extent does the risk of a SCE associated with mobile device use differ as a function of time on duty? Table 25 contains the frequency and percent of the SCE classifications associated with each time on duty bin. Crash-relevant conflicts and unintentional lane deviations have the highest frequency and there are no crashes in the moderate bin.

Table 25

SCE Classification Frequency and Percent for Each Time on Duty Bin

SCE Classification		Low	Moderate	High
Crash	Frequency	2	-	2
	Percent	0.27	-	0.24
Near-Crash	Frequency	15	9	22
	Percent	2.05	1.55	2.63
Crash-Relevant	Frequency	414	314	454
Conflict	Percent	56.48	53.95	54.24
Unintentional	Frequency	302	259	259
Lane Deviation	Percent	41.20	44.50	42.89

As with driving time, odds ratios were used to compute risk for visual-manual subtasks and mobile device use (including all subtasks) for time on duty. The results, in Table 26, indicate performing a visual-manual subtask increase SCE risk for all bins. Mobile device use (including all subtasks) increased SCE risk in the first 4.99 hr and the last 6 hr of being on duty. As expected, the odds ratio values and significance was less when including talking/listening subtasks, as compared to when these subtasks were not included in the visual-manual collapse, as talking/listening were not found to increase risk.

Table 26

Odds Ratio Results for Each Bin of Time on Duty

Bin	Subtask	SCE	BL	OR	95% CI *LL*	95% CI *UL*	SCE	BL	OR	95% CI *LL*	95% CI *UL*
		C, NC, CRC					C, NC, ULD				
Low	Visual-Manual	34	19	6.22*	3.51	11.04	42	19	11.02*	6.31	19.25
	Mobile Device Use	68	130	1.83*	1.34	2.51	60	130	2.26*	1.62	3.16
Moderate	Visual-Manual	21	17	3.90*	2.03	7.49	32	17	7.60*	4.15	13.93
	Mobile Device Use	33	121	0.79	0.53	1.20	37	121	1.12	0.75	1.67
High	Visual-Manual	35	23	5.36*	3.14	9.18	50	23	10.20*	6.14	16.95
	Mobile Device Use	80	162	1.77*	1.32	2.36	91	162	2.73*	2.05	3.64

Note. CI = Confidence interval; *LL* = lower limit, *UL* = upper limit; OR = odds ratio; C = crash, NC = near-crash, CRC = crash-relevant conflict, and ULD = unintentional lane deviation.
Note. Results do not change with 90% confidence intervals.
*Refers to statistically significant results.

RQ 4: What is the relationship between mobile device use and time on duty?

Multiple analyses of the data were conducted to determine if there was a relationship between time on duty and mobile device use. Figure 13 presents the difference between the mean hour of time on duty for SCE\BLs of interest with and without mobile device use for each driver. It can be seen that SCE\BLs with mobile device use occurred at approximately the same time as SCE\BLs without mobile device use based on the fact that the data are centered near zero. The mean difference for all drivers was 0.25 hr (*SD* = 2.06), which indicates SCE\BLs of interest with mobile device use occurred when drivers had been on duty approximately 15 min longer than drivers during SCE\BLs of interest with no mobile device use.

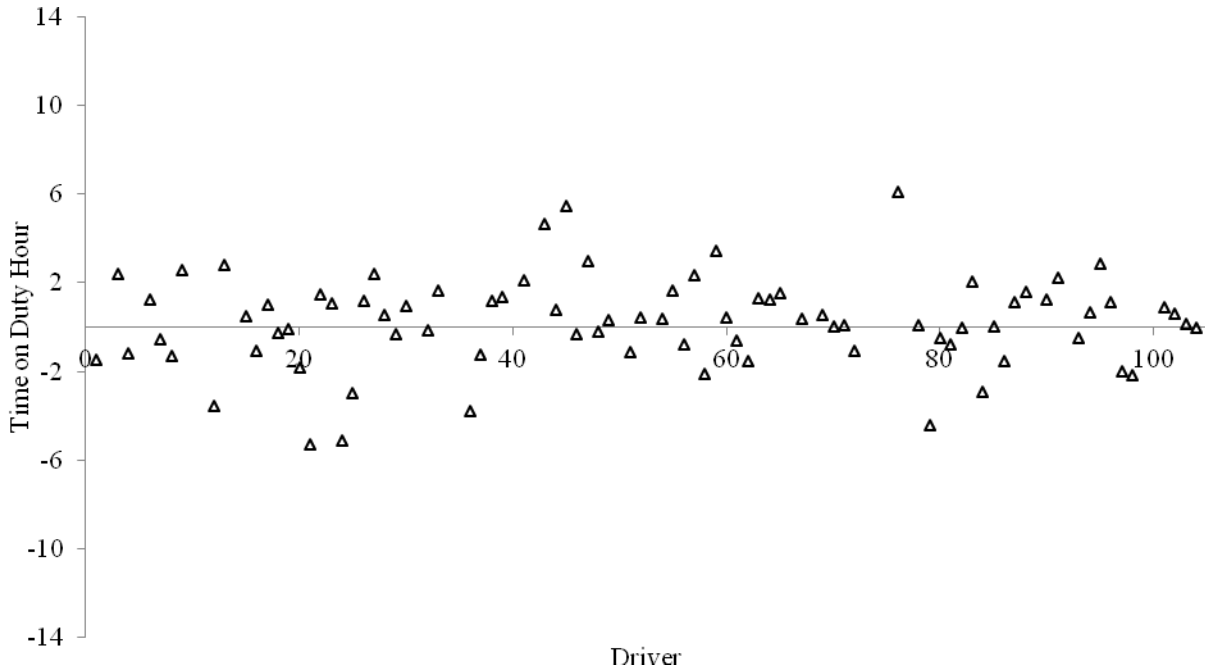


Figure 13. Difference between mean hour of time on duty for SCE/BLs with and without mobile device use for each driver.

Since there was a difference in the amount of mobile device use between SCEs and BLs found in the risk analyses, only BLs were used in the GLMM and chi-square test. The results of the GLMM indicated that time on duty was not a good predictor of the probability that a BL will have mobile device use at any time, Table 27. A significant intercept indicates that this probability differs across drivers. The distribution of time on duty for BLs with mobile device use and without, Figure 14, shows no clear trend for either BL type.

Table 27

GLMM Results for Time on Duty (p value)

Bin	Time on Duty	Intercept
All	.75	< .001*
Low	.39	< .001*
Moderate	.84	.002*
High	.20	< .001*

Note. Results do not change with α = .05 or α = .01.
*Refers to statistically significant results.

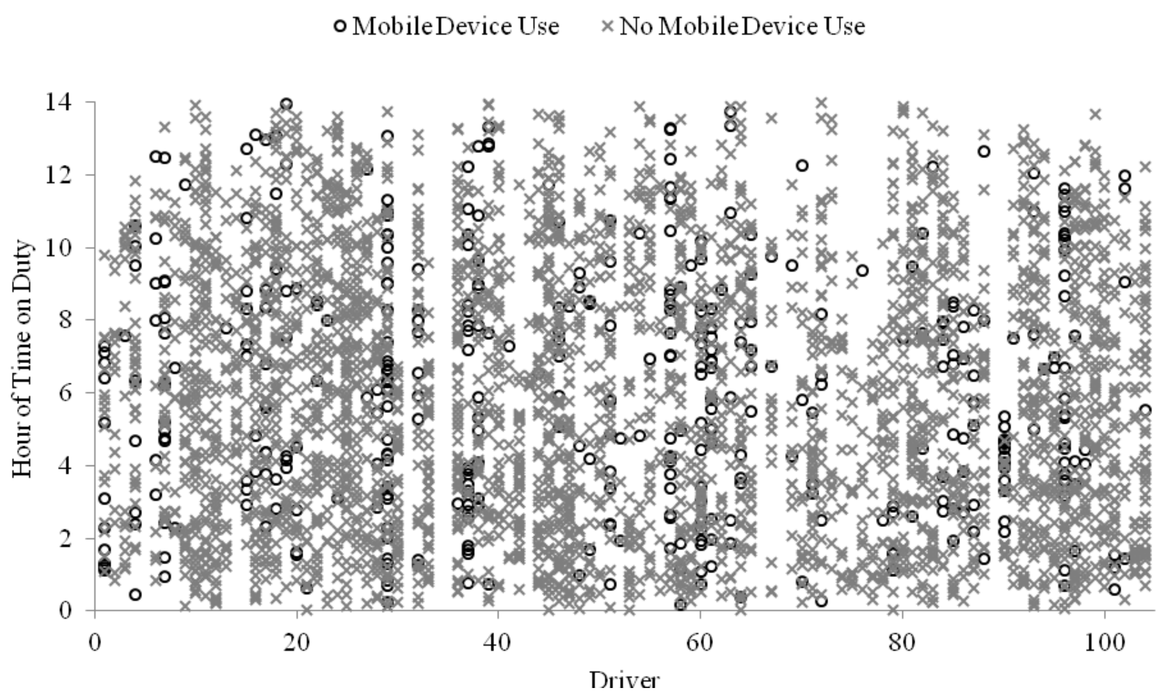


Figure 14. Distribution on time of duty for BLs with and without mobile device use by driver.

Interestingly, the results of the chi-square test indicated the proportion of BLs with mobile device use does differ across bins, $\chi^2(2, N = 3{,}958) = 6.35$, $p = .04$. To determine what bins were significantly different from each other chi-square tests were conducted for each pair of bins ($df = 1$ for all). It can be seen from Table 28 that there was approximately a 3% difference between the low and moderate bins, which were significantly different. At an alpha level of .10, there was also a significant difference between the moderate and high bins, Table 29.

Table 28

Chi-Square Contingency Table and Percentage for Time on Duty

Bin	No Mobile Device Use	Mobile Device Use	Total	% With Mobile Device Use
Low	1271	130	1401	9.28
Moderate	850	121	971	12.46
High	1424	162	1586	10.21

Table 29

Chi-Square Test Results of Bin Comparisons for Time on Duty

Bin Combinations	*N*	X^2	*p* value
Low and Moderate	2,372	6.13	.01*
Low and High	2,987	0.74	.39
Moderate and High	2,557	3.09	.08**

*Refers to statistically significant results with α = .05.
**Refers to statistically significant results with α = .10.

The difference in the results between the two analysis methods is most likely due to an influence of extreme values on the sample as a whole. It can be seen from Figure 15 that there are six data points above 0.6; these would be considered “extreme values” considering most of the data falls no higher than 0.2.

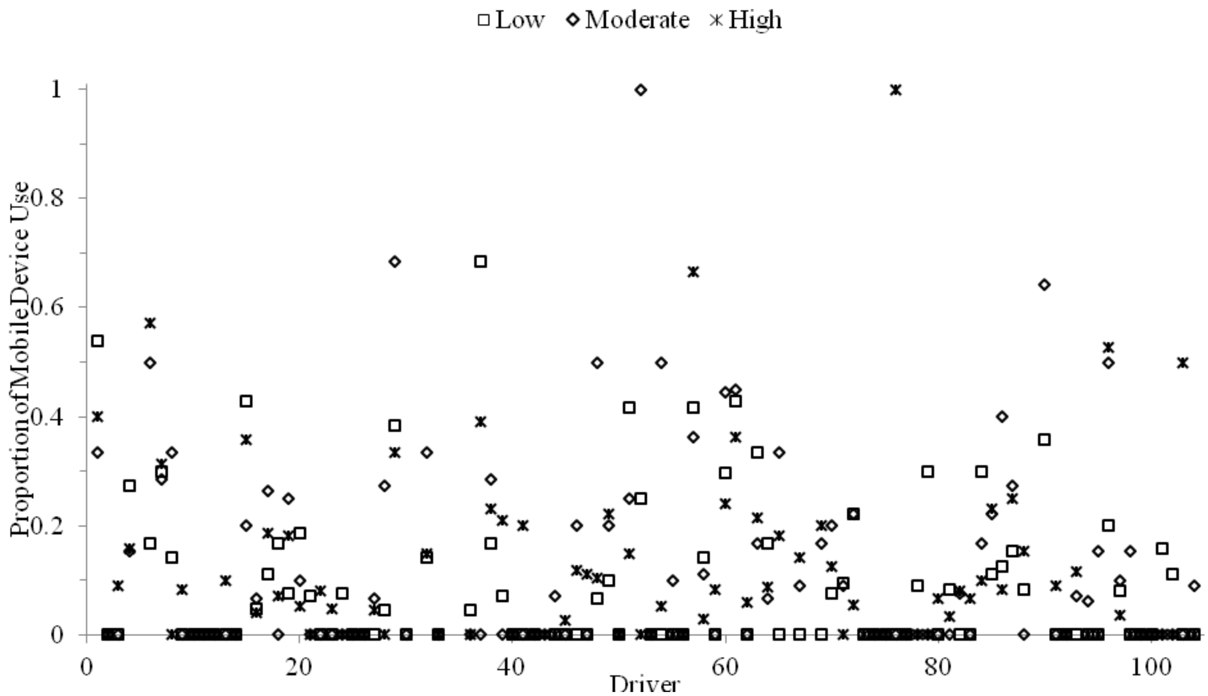


Figure 15. *Proportion of mobile device use for each driver for each bin of time on duty.*

Summary of time on duty results. There was significant SCE risk for drivers performing visual-manual subtasks for all bins. In addition, an increase in SCE risk for drivers who were using a mobile device for the first 4.99 hr and last 6 hr. There was a difference in time on duty of 15 min between SCE/BLs of interest with mobile device use and those without mobile device use. Results from the GLMM indicated time on duty was not a good predictor of mobile device use. However, the chi-square test revealed there was a higher proportion of BLs with mobile device use in the moderate bin than the low bin ($\alpha = .05$) and the high bin ($\alpha = .10$).

Time of Day

General. General analyses were conducted on the time of day data before answering the research questions. A Kolmogrov-Smirnov test of SCE/BLs of interest indicated the data were not normal ($D = 0.12$, $p < .01$). The distribution of the frequency of SCEs, BLs, and all data by hour of day can be seen in Figure 16. The mean time of day was 2:26 p.m. ($SD = 0.27$). This indicates that SCE/BLs of interest occurred, on average, at 2:26 p.m.; this supports the fact that the data are skewed.

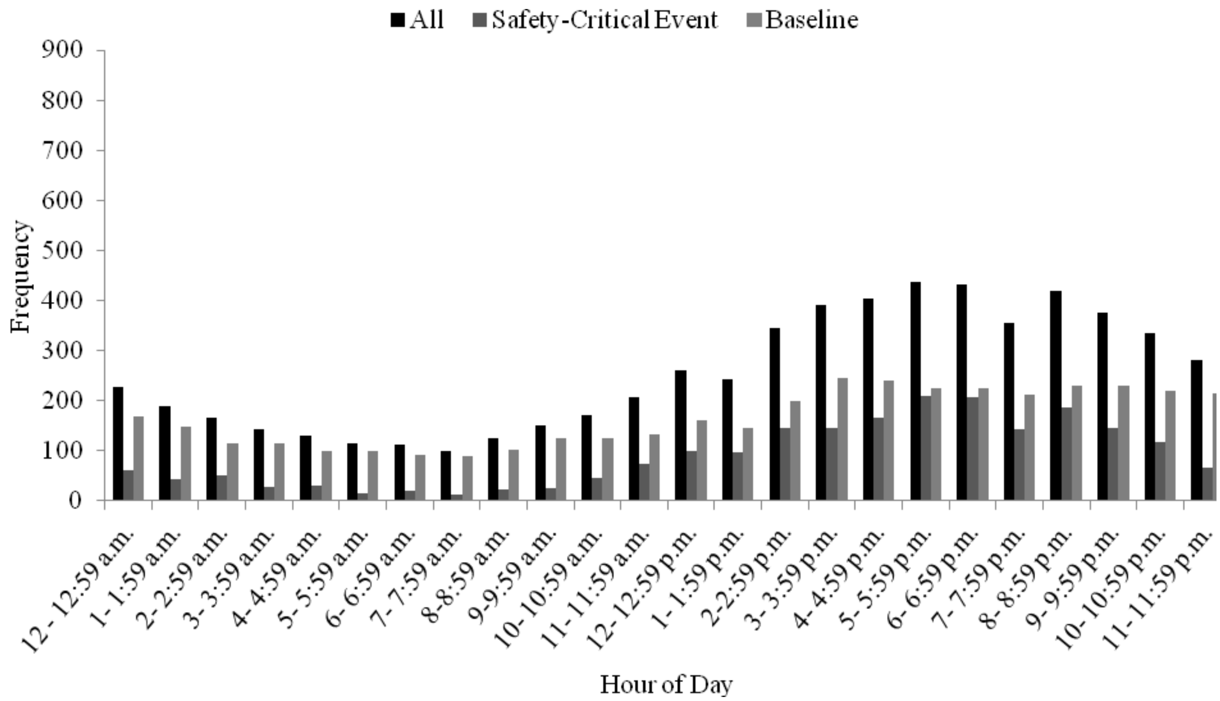


Figure 16. *Frequency of SCEs, BLs, and all data by time of day.*

RQ 5: To what extent does the risk of a SCE associated with mobile device use differ as a function of time of day? To determine the number of each SCE classification in each bin, a count was performed. Table 30 contains the frequency and percent of the SCE classifications present in each time of day bin. Again, crash-relevant conflicts and unintentional lane deviations have the highest frequency and there are no crashes in the high morning and low afternoon bins.

Table 30

SCE Classification Frequency and Percent for Each Time of Day Bin

SCE Classification		Low Morning	High Morning	Low Afternoon	High Evening
Crash	Frequency	1	-	-	2
	Percent	1.28	-	-	0.60
Near-Crash	Frequency	2	2	4	3
	Percent	2.56	2.82	1.66	0.91
Crash-Relevant	Frequency	50	29	131	192
Conflict	Percent	64.10	40.85	54.36	58.01
Unintentional	Frequency	25	40	106	134
Lane Deviation	Percent	32.05	56.34	43.98	40.48

Odds ratio were also used to calculate risk for visual-manual subtasks and mobile device use (including all subtasks) for time of day. As can be seen in Table 31, analyses of visual-manual subtasks were not possible for the high morning bin for both SCE classifications and the low morning bin when crashes, near-crashes, and crash-relevant conflicts were included. In bins where analyses were possible, performing a visual-manual subtask significantly increased a driver's SCE risk. Due to the small number of SCE/BLs of interest in the low morning bin, the confidence interval was extremely large and error related to the odds ratio was high. A Fisher's exact test supported the odds ratio and will be discussed later in this section.

When crashes, near-crashes, and crash-relevant conflicts were included in the mobile device use (including all subtasks) analyses, there was a significant risk of being involved in a SCE, than BL, for the low afternoon bin. When performing this calculation with a 90% confidence interval, a significant SCE risk existed for the high evening bin (OR = 1.57, LCL = 1.01, UCL = 2.45). Results indicated there was a decreased SCE risk in the low morning bin. When crashes, near-crashes, and unintentional lane deviations were included for mobile device use (including all subtasks), drivers were at a significant risk of being involved in a SCE than a BL for the high morning, low afternoon, and high evening bins.

Table 31

Odds Ratio Results for Each Bin of Time of Day

Bin	Subtask	SCE	BL	OR	95% CI *LL*	95% CI *UL*	SCE	BL	OR	95% CI *LL*	95% CI *UL*
		C, NC, CRC					C, NC, ULD				
Low Morning	Visual-Manual	-	-	-	-	-	8	2	45.60*	9.06	229.39
	Mobile Device Use	2	41	0.18*	0.04	0.77	13	41	3.99*	1.77	9.03
High Morning	Mobile Device Use	3	11	2.31	0.61	8.81	3	11	1.66	0.44	6.23
Low Afternoon	Visual-Manual	15	5	8.50*	3.02	23.88	13	5	9.11*	3.17	26.19
	Mobile Device Use	24	27	2.55*	1.41	4.60	21	27	2.77*	1.50	5.15
High Evening	Visual-Manual	19	5	9.35*	3.44	25.42	22	5	16.47*	6.11	44.42
	Mobile Device Use	26	39	1.57	0.92	2.66	31	39	2.97*	1.77	4.98

Note. CI = Confidence interval; *LL* = lower limit, *UL* = upper limit; OR = odds ratio; C = crash, NC = near-crash, CRC = crash-relevant conflict, and ULD = unintentional lane deviation.
Note. Changes with 90% confidence intervals are noted in body.
*Refers to statistically significant results.

A Fisher's exact test was also conducted for the low afternoon and high evening bins when both crash-relevant conflicts and unintentional lane deviations were included and the low morning bin when unintentional lane deviations were included for visual-manual subtasks. The results of all analyses were significant ($p < .001$) and indicated that visual-manual subtasks were better associated with an increase in the number of SCEs, which was consistent with the odds ratios.

A Fisher's exact test was also conducted for the low morning bin when crash-relevant conflicts were included and the high morning bin when both crash-relevant conflicts and unintentional lane deviations were included. The result for the low morning bin was significant ($p = .004$) and indicated that mobile device use (including all subtasks) was better associated with an increase in the number of BLs, which is consistent with the odds ratios. The results for the high morning bins with crash-relevant conflicts and unintentional lane deviations were not significant (p = .14 and p = .20, respectively).

RQ 6: What is the relationship between mobile device use and time of day? To begin answering this question, each driver's mean time of day was calculated for SCE/BLs of interest with and without mobile device use as well as the difference between these means. Figure 17 presents the difference between mean hour of the day for SCE\BLs of interest with and without mobile device use for each driver. It can be seen that SCE\BLs with mobile device use occurred at approximately the same time as SCE\BLs without mobile device use since the data are centered around zero. The mean difference for all drivers was 0.34 hr (*SD* = 4.12), which indicates SCE\BLs of interest with mobile device use occurred approximately 20 min after SCE\BLs of interest with no mobile device use.

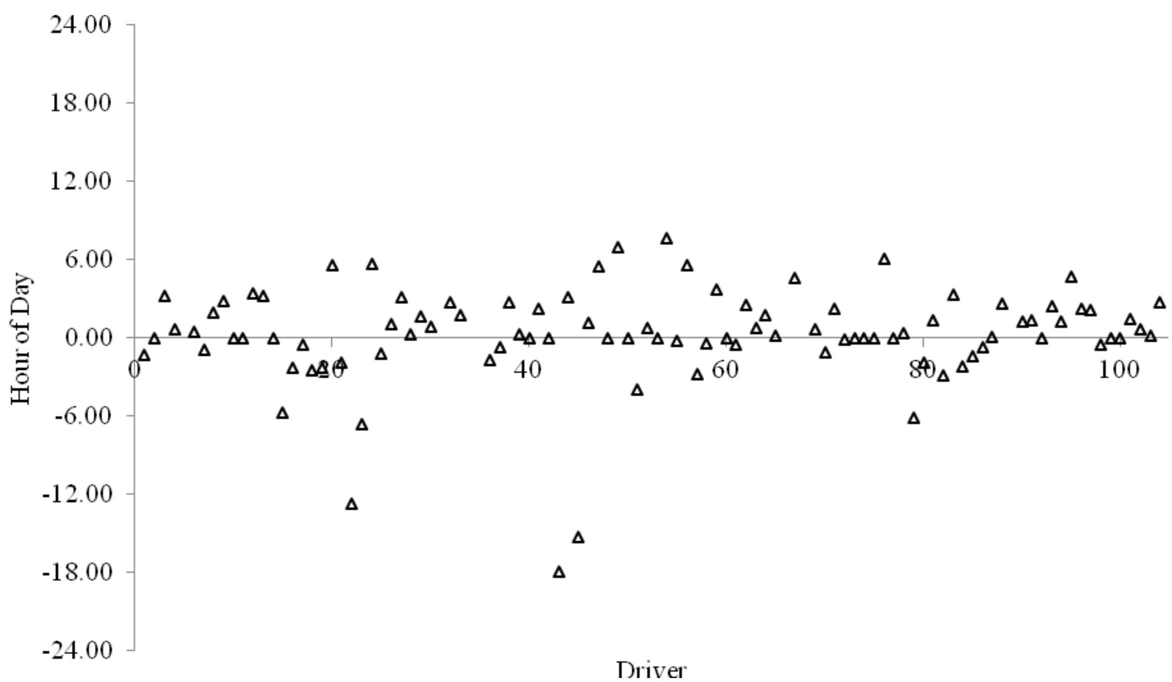


Figure 17. Difference between mean time of day for SCE\BLs with and without mobile device use for each driver.

As noted, there was a difference in the amount of mobile device use between SCEs and BLs found in the risk analyses; therefore, only BLs will be used in the GLMM and chi-square test. The results of the GLMM indicated that time of day was a good predictor of the probability that a BL will have mobile device use for all periods ($p < .001$). A significant intercept indicates that this probability differs across drivers ($p < .001$), except for in the high morning ($p = .16$) and high evening ($p = .07$) bins. The intercept for the high evening bin was also significant with an alpha level of .10. The distribution of time of day for BLs with mobile device use and without, Figure 18, does show a difference in the time of day the different types of BLs occurred.

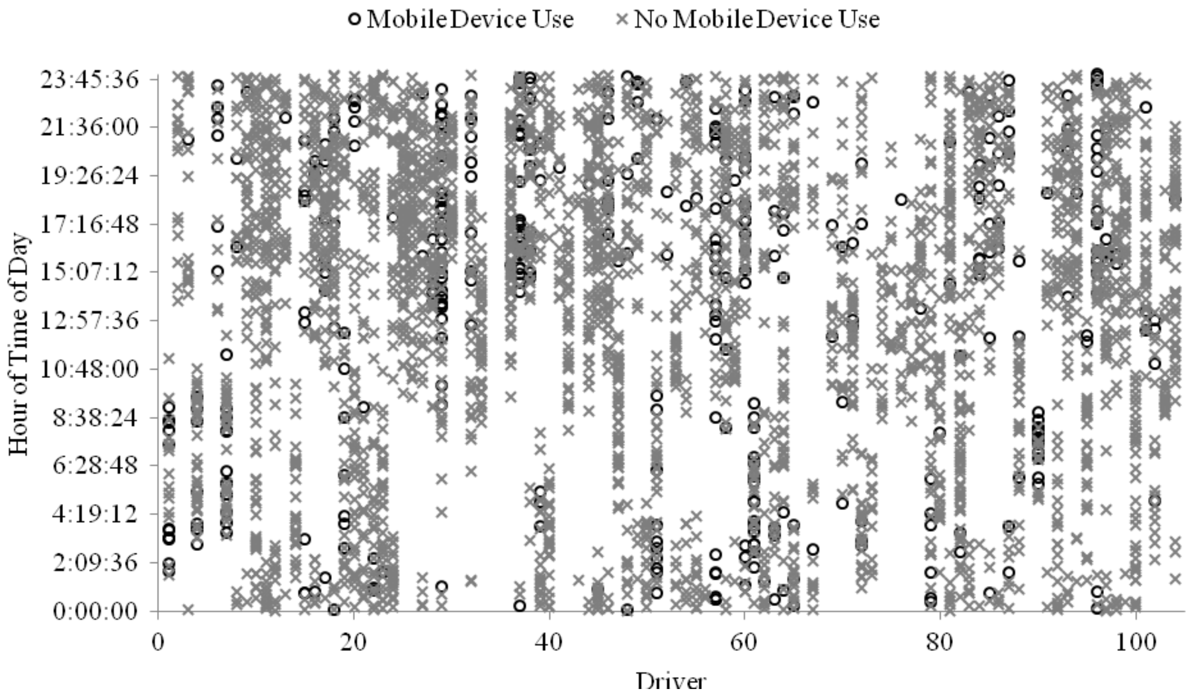


Figure 18. Distribution of time of day for BLs with and without mobile device use by driver.

The results of the chi-square test indicated there was a difference in the proportion of BLs with mobile device use across bins, $\chi^2(3, N = 1.267) = 27.84, p < .001$. To determine what bins were significantly different from each other, chi-square tests were conducted for each pair of bins ($df = 1$ for all). It can be seen from Table 32 that the low morning bin had a higher percentage than the rest. There are significant differences, presented in Table 33, of approximately 13%, 10%, and 9% between the low morning bin and high morning, low afternoon, and high evening, respectively. In addition, there was a significant difference of approximately 4% between the high evening and high morning bins. With an alpha level of .10, there was a significant difference between the low afternoon and high morning bins.

Table 32

Chi-Square Contingency Table and Percentage for Time of Day

Bin	No Mobile Device Use	Mobile Device Use	Total	% With Mobile Device Use
Low Morning	189	41	230	17.83
High Morning	238	11	249	4.42
Low Afternoon	318	27	345	4.83
High Evening	404	39	443	8.80

Table 33

Chi-Square Test Results for Bin Comparisons for Time on Duty

Bin Combinations	*N*	X^2	*p* value
Low Morning and High Morning	479	22.21	< .001*
Low Morning and Low Afternoon	575	13.23	< .001*
Low Morning and High Evening	673	11.76	< .001*
High Morning and Low Afternoon	594	2.81	.09**
High Morning and High Evening	692	4.57	.03*
Low Afternoon and High Evening	788	0.24	.62

*Refers to statistically significant results with α = .05.
**Refers to statistically significant results with α = .10.

Summary of time of day results. Results from odds ratios for visual-manual subtasks indicate SCE risk was increased in all bins for which analyses were possible. The odds ratio analysis for crashes, near-crashes, and crash-relevant conflicts indicated drivers who were using a mobile device had an increased SCE risk, compared to BLs, for the low afternoon bin. When performing this calculation with 90% confidence intervals, drivers who used a mobile device were at a significant risk of being involved in a SCE, than BL, for the high evening bin. This analysis also indicated mobile device use (including all subtasks) decreased SCE risk, compared to normal driving, for the low morning bin. The odds ratio analysis for crashes, near-crashes, and unintentional lane deviations indicated drivers who were using a mobile device had an increased SCE risk, compared to BLs, for the low morning, low afternoon, and high evening bins. Fisher's exact test results were similar to odds ratio results for both visual-manual subtasks and mobile device use (including all subtasks).

SCE/BLs of interest that included mobile device use occurred 20 min later in the day than SCEs/BLs without mobile device use. The GLMM results pointed to the fact that time of day was a good predictor of mobile device use. Through the chi-square tests, it was established that there was a higher proportion of BLs with mobile device use in the low morning bin than all other bins. Also, the high evening bin had a higher proportion of BLs with mobile device use than the high morning bin. The low afternoon had a higher proportion of BLs with mobile device use than the high morning bin ($\alpha = .10$).

Amount of Sleep

General. The results from the Shapiro-Wilk test of SCEs of interest indicated the data was not normal ($D = 0.97$, $p < .001$), which necessitated non-parametric analyses. The distribution of the frequency of SCEs, including those with and without mobile device use, by amount of sleep can be seen in Figure 19. The distribution may appear normal, but a mean of 6.67 hr of sleep ($SD = 1.90$) indicates the data were skewed slightly to the right. In other words, drivers received an average of 6.67 hr of sleep the 24 hr before a SCE of interest.

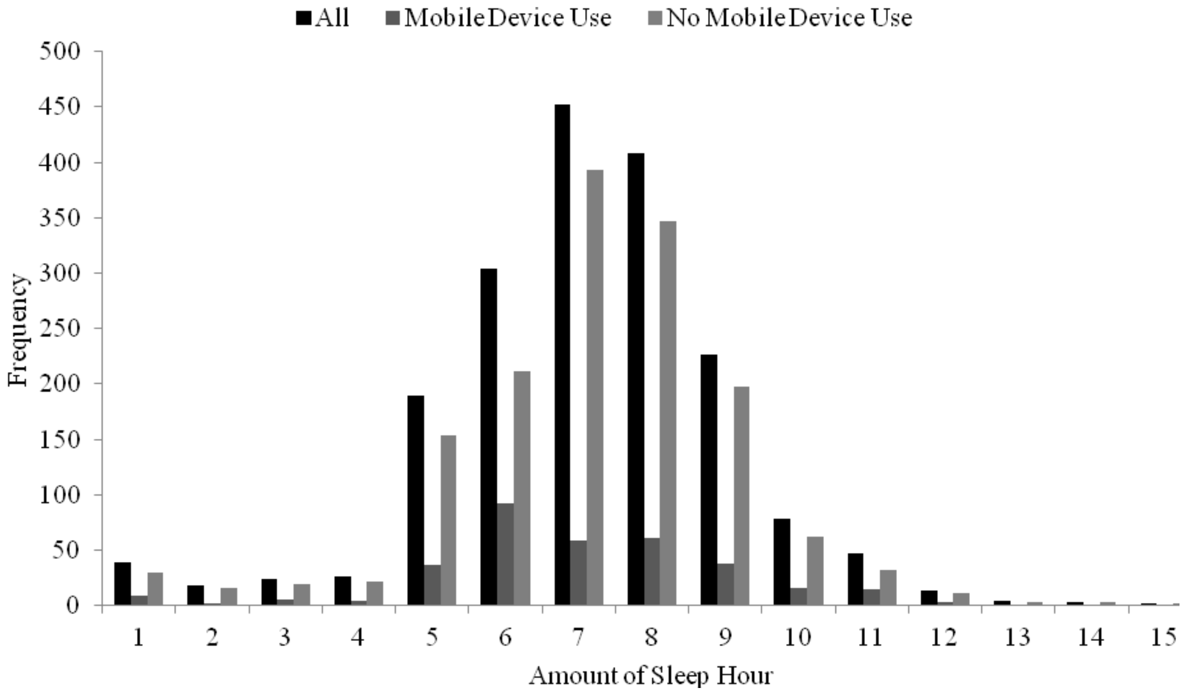


Figure 19. *Frequency of SCEs with and without mobile device use by amount of sleep hour.*

RQ 7: What is the relationship between mobile device use and the amount of sleep the night before a shift? As with the other factors, the difference between each driver's mean amount of sleep before SCEs with and without mobile device use was calculated. Figure 20 presents the difference between the mean hour of amount of sleep for SCEs with and without mobile device use for each driver. Differences close to zero are a sign that the SCEs with mobile device use occurred after approximately the same amount of sleep as SCEs without mobile device use. The mean difference for all drivers was -0.08 hr (*SD* = 1.71), which indicates SCEs with no mobile device use occurred after drivers had slept for approximately 5 min more than drivers did before SCEs with mobile device use.

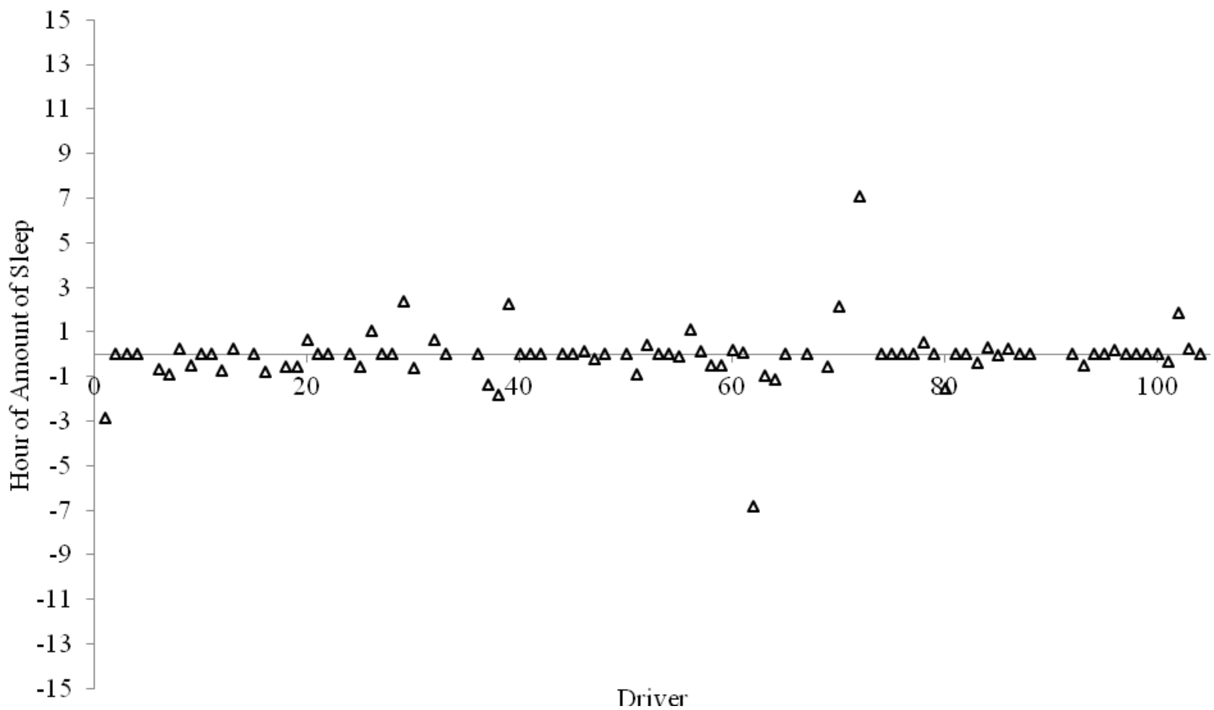


Figure 20. Difference between mean hour of amount of sleep for SCEs with and without mobile device use for each driver.

The results of the GLMM indicated that amount of sleep was not a good predictor of the probability that a SCE will have mobile device use for all periods, Table 34. A significant intercept indicates that this probability differs across drivers for all amounts of sleep and the low and moderate bins. The distribution of amount of sleep before SCEs with mobile device use and without, Figure 21, shows no difference.

Table 34

GLMM Results for Amount of Sleep (p value)

Bin	Amount of Sleep	Intercept
All	.43	< .001*
Low	.77	.001*
Moderate	.19	.04*
High	.72	.34

*Refers to statistically significant results.

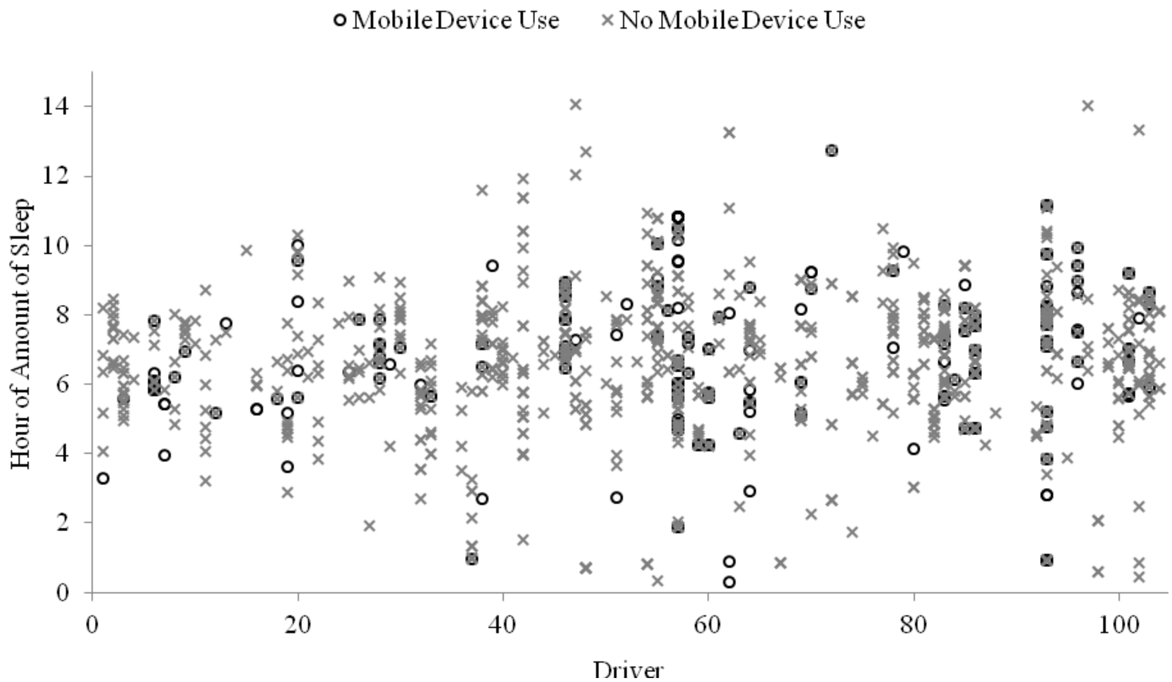


Figure 21. *Distribution of amount of sleep for SCEs with and without mobile device use by driver.*

The results of the chi-square test indicated that the proportion of SCEs with mobile device use does not differ across bins, $\chi^2(2, N = 1{,}836) = 2.92$, $p = .23$. The frequencies used in the contingency table can be seen in Table 35.

Table 35

Chi-Square Contingency Table and Percentage for Amount of Sleep

Bin	No Mobile Device Use	Mobile Device Use	Total	% With Mobile Device Use
Low	240	1141	113	19.19
Moderate	57	250	35	17.97
High	297	1391	148	23.65

Overall, drivers are not using a mobile device more after a certain amount of sleep.

Results Summary

Mobile device use subtasks that required a large amount of visual or manual-visual resources were found to increase SCE risk compared to normal driving. Talking/listening on a hands-free cell phone was found to decrease SCE risk. Visual-manual subtasks increased SCE risk for all bins in which analyses were possible. Using a mobile device (including all subtasks) increased SCE risk, compared to BLs, for all bins of driving time and the low and high bins of time on duty. When crashes, near-crashes, and crash-relevant conflicts were included mobile device use (including all subtasks) increases SCE risk, compared to BLs, in the low afternoon and high evening bins (with 90% confidence interval). SCE risk decreased for the low morning bin. When crashes, near-crashes, and unintentional lane deviations were included, SCE risk, compared to BL, was increased for the low morning, low afternoon, and high evening bins.

The GLMM found time of day to be significant for all bins. The chi-square test also found a difference in the proportion of mobile device use between the low morning bin and all other bins, the high evening and high morning bins, and the low afternoon and high morning bins ($\alpha = .10$). The chi-square test for time on duty found a small difference in percent of mobile device use between the low and moderate bins and moderate and high bins ($\alpha = .10$). Time on duty was not significant for any bin for the GLMM. There were no significant findings for driving time or amount of sleep.

Discussion and Conclusions

Driver distraction, fatigue, and drowsiness are important safety topics in CMV operations. However, there is a gap in the literature regarding how these topics relate, which a small number of exploratory studies have started to address. The aim of the current research was to delve deeper into the relationships between these concepts. More specifically, the purpose was to examine the relationship between CMV driver mobile device use and driving time, time on duty, time of day, and amount of sleep and the SCE risk as a function of driving time, time on duty, and time of day. Risk could not be calculated for amount of sleep due to the fact that sleep data were not available for BLs. Driving time and time on duty were associated with driver fatigue and time of day and amount of sleep were associated with driver drowsiness in the current research.

A secondary analysis of data from the NTDS and the CVO study was performed. SCE risk was calculated using odds ratios for visual-manual subtasks (i.e., dial cell phone, text message on cell phone, and interact with/look at dispatching device) and mobile device use (including all subtasks) for each bin of driving time, time on duty, and time of day. Since the ratio of BL to SCE was too low when all SCE classifications were included, analyses with only crashes, near-crashes, and crash-relevant conflicts and crashes, near-crashes, and unintentional lane deviations were conducted. Additionally, SCE risk was calculated for each mobile device use subtask when data was not divided into bins. Mobile device use was calculated using a GLMM and chi-square test for all of the factors in the current research.

Review of Results

Risk. In this section, the results of odds ratios for driving time, time on duty, and time of day will be discussed for visual-manual subtasks, mobile device use (including all subtasks), and each subtask.

SCE risk for each subtask. It was hypothesized that talking/listening on a hands-free cell phone would decrease a driver's SCE risk and all other subtasks would increase a driver's SCE risk. These hypotheses were supported by the current research when odds ratios were performed for each subtask without dividing the data. Talking/listening on a hands-free cell phone significantly decreased a driver's risk of being involved in a SCE, compared to normal driving, for all combinations of SCE classifications. Text messaging on a cell phone, interacting with/looking at a dispatching device, and dialing a cell phone were the riskiest subtasks. An analysis with these subtasks combined also indicated an increase in SCE risk.

These results are similar to those found in Olson et al. (2009) and Hickman et al. (2010). There are two subtasks that have different results: mobile device use (including all subtasks) and talking/listening to CB radio. The current research included CB radios and dispatching devices in the calculation with all subtasks combined, whereas the CVO study and Hickman et al. (2010) only included cell phones. In Olson et al. (2009), talking/listening to a CB radio was found to significantly decrease SCE risk, but the result was not significant in the current research. The likely reason for differences across analyses could be due the fact that the CVO study included data from the DDWS FOT (Hanowski et al., 2008), as well, so there were more BLs than in the current research.

The results from the current research align well with the information in *Attention and Effort* and the multiple resource theory (Kahneman 1973; Wickens, 2002). The driving task is primarily visual, so it is possible that performing another visual task caused attentional resources to be further limited and performance to decrease. The mobile device use subtasks that required a large amount of visual resources were more risky individually. When combined in an analysis together, visual-manual subtasks also increased SCE risk.

Visual-manual subtasks. For all research questions pertaining to risk, it was hypothesized that engaging in visual-manual subtasks would increase a driver's SCE risk, as noted. The results for driving time, time on duty, and time of day supported this hypothesis; they indicated drivers who performed visual-manual subtasks had an increased SCE risk for all bins in which analyses were possible. These results can be explained with the multiple resource theory, since performing a subtask that requires the same attentional resources may cause a performance decrement (Wickens, 2002), which leads to a SCE. As noted, these results also support the findings from past studies that also indicate visual-manual subtasks increase SCE risk (Olson et al., 2009; Hickman et al., 2010).

In addition to the analyses noted above, odds ratios were conducted for driving time to determine if a low bin of 3 hr, instead of 4 hr, would result in different findings, since Jellentrup et al. (2011) used 3 hr periods of driving. When these analyses were conducted with visual-manual subtasks, results did not differ. In addition, the results did not differ when the odds ratios were conducted with mobile device use (including all subtasks).

Mobile device use (including all subtasks). For time on duty, mobile device use (including all subtasks) was associated with an increase in SCE risk, versus normal driving, when time on duty was low and high. These results could be influenced by certain subtasks that may occur more at the beginning and end of the shift. In addition, Mackie and Miller (1978) found that moderately heavy cargo loading, versus light cargo loading, increased fatigue for relay drivers. An increase in fatigue necessitates more effort to perform a task, which requires more attentional resources (Kahneman, 1973). Fewer resources allocated to a task leads to a performance decrement (Kahneman, 1973; Wickens, 2002) and there is a greater chance of a SCE.

For time of day, there were some instances in which the odds ratio results differed between the inclusion of crashes, near-crashes, and crash-relevant conflicts and crashes, near-crashes, and unintentional lane deviations. In these cases, the results from analyses when all SCE classifications were included were also examined, even though the BL to SCE ratio was small. The results for all three of the SCE classification combinations indicate a circadian rhythm low period had the highest SCE risk. Two of the three SCE classification combinations (crashes, near-crashes, and crash-relevant conflicts and all classifications) indicated the circadian rhythm low period in the afternoon had the highest risk.

The result that the afternoon circadian low period had the highest risk is similar to that found in Lenné et al. (1997), in which driving performance was worst at 2:00 p.m. This result also supports the trend that high drowsiness, SCE rate, or crash rate occur during circadian rhythm low periods as found in Wylie et al. (1996), Hanowski et al. (2000), and Barr et al. (2005). In addition, the SCE risk results may support the finding that time of day is related to driver performance (Wylie et al., 1996). The increase in risk may be explained by the fact that a drowsy driver is using more attentional resources to perform a task because more effort is required; having fewer resources to allocate causes a decrease in performance (Kahneman, 1978; Wickens, 2002). When a driver attempts to perform multiple visual-manual tasks simultaneously, performance is impacted and error is more likely to occur.

Mobile device use. This section will describe the results for mobile device use for all factors.

Driving time. It was hypothesized that BLs of interest with mobile device use would occur after more driving than BLs with no mobile device use, if used as a countermeasure to fatigue. This hypothesis was not supported by the results from the current research. The GLMM indicated driving time was not a good predictor of mobile device use. The proportions of events with mobile device use for the three bins, resulting from a chi-square test, were not significantly different given that they were within approximately 1% of each other.

Analyses were also conducted to determine if a low bin of 3 hr, as in Jellentrup et al. (2011), instead of 4 hr would impact the mobile device use results; the difference in the number of hours included did not change the results. One reason why the same amount of driving time could have had more of a fatiguing effect for the participants of Jellentrup et al. (2011) is that the drivers made a total of seven trips (one trip during training and three trips during each 3 hr block) around the test track they were driving. This is most likely more monotonous than the roads driven by participants from the data used in the current research.

Time on duty. It was hypothesized that drivers with mobile device use BLs would have been on duty for longer than those that did not if used as a countermeasure to fatigue. The results from the chi-square test indicated the moderate time on duty bin had a significantly higher proportion of mobile device use than the low ($\alpha = .05$) and high ($\alpha = .10$) bins; however, the differences were approximately 3% or less, so the safety impact is unclear. As mentioned, Morrow and Crum (2004) found that fatigue-inducing tasks associated with driving work and safety practices account for variability in close calls. In addition, drivers have been found to perform non-driving work, such as loading or unloading in the first hours of their shift (Williamson et al., 2001).

Although the results of the chi-square test indicated there was a difference in the proportion of mobile device use, the GLMM results revealed time on duty was not a good predictor of mobile device use. The difference in significance between the two analyses is most likely due to the fact that the GLMM accounted for driver variability, or extremes, by comparing drivers to themselves. Therefore, values that were very different from the rest did not influence the sample as much as in the chi-square test. The results of the chi-square test may support the hypothesis; however, the results of the GLMM do not.

Time of day. It was hypothesized that drivers mobile device use may be associated with circadian low periods, whereby drivers may use mobile devices as an alerting mechanism. The result that the circadian low morning bin had a significantly higher proportion of mobile device use than all other bins supports the hypothesis. Figure 22 shows the circadian rhythm curve with the percentage of mobile device use in each bin overlaid; see the time of day results subsection for specific percentages. In addition, analysis indicated that the low afternoon bin had more mobile device use than the high morning bin. The combination of these results supports the finding from Wylie et al. (1996) that indicated the hours between late evening and dawn had the highest level of drowsiness.

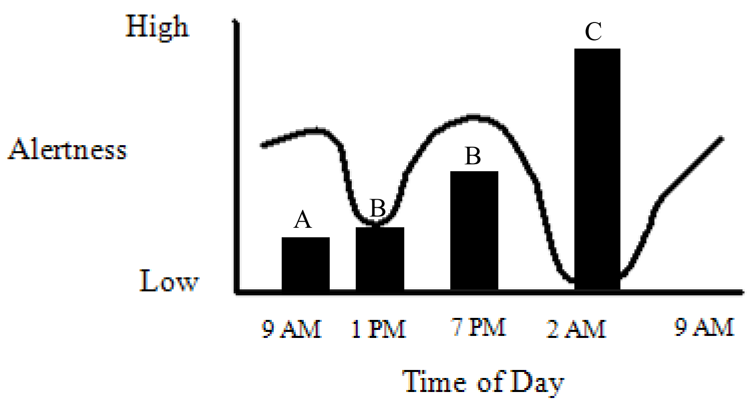


Figure 22. Circadian rhythm curve with mobile device use percentage bars overlaid.

It is important to realize that the factors, such as time on duty, may have some influence on each other. Drivers had more mobile device use during the middle of their shifts than at the beginning or end. If a large number of drivers started their shift at the same time of day, the mobile device use results of time on duty and time of day might influence each other.

Amount of sleep. It was hypothesized that a higher proportion of SCEs with mobile device use would occur after fewer hours of sleep than SCEs without mobile device use, if used as a countermeasure to drowsiness. This hypothesis was not supported by the GLMM or the chi-square test. It is interesting to note that the National Sleep Foundation (2012) survey found the highest percentage of drivers indicated they need between six and seven hours of sleep and they actually sleep that much in the 24 hr before a work day. The average amount of sleep drivers received before a SCE in the current study was 6.67 hr of sleep (*SD* = 1.90), which falls in the same range. The similarity in results shows the drivers in the current study are a good representation of what is actually happening in the larger population of CMV drivers.

Percent of Mobile Device Use

The results from the National Occupant Protection Use Survey (NOPUS) for 2010 provided an estimation of the number of drivers using a hand-held or hands-free cell phone at a given instant throughout the country (NHTSA, 2011). These estimations were calculated using the total number of vehicles on the road in 2010, percent of drivers using a hand-held cell phone from the data collected in 2010, and proportion of hand-held to hands-free cell phone use. The total number of vehicles on the road in 2012 was based on how many vehicles were on the road in 2009 and the number of vehicle miles traveled (VMT) in 2010. The results indicate that 5% of drivers use hand-held cell phones and 4% use hands-free; in total, 9% of drivers were using a cell phone at any given daylight moment. These results do not include heavy trucks.

Fitch and Hanowski (2011) estimated cell phone use for heavy truck drivers, while the vehicle was in motion, using data from Olson et al. (2009) that was collected in 2004 and 2005. The results indicated that approximately 4% of the time the drivers talked/listened on a hand-held cell phone and they talked/listened on a hands-free cell phone approximately 4% of the time. In total, drivers communicated on a cell phone approximately 8% of the time. If dialing a cell phone, which was found to occur 1% of the time, was included, the results would be almost exactly the same as the NOPUS results.

In the current research, the drivers in the data used for driving time, time on duty, and time of day used a hand-held cell phone approximately 4% of the time and a hands-free cell phone approximately 3% of the time, for a total of approximately 7%. As with Fitch and Hanowski (2011), including dialing, which occurred for approximately 2% of the time, brings the total to just over 9%. This result can be most closely compared to the results from NOPUS and Fitch and Hanowski (2011) and it is nearly identical.

Since there were devices other than a cell phone included in the current research, the total percentage of time the drivers spent using a mobile device for all the data was approximately 13%. More mobile device use has been found in SCEs, so the same calculation was performed with only BLs; results indicated drivers used a mobile device for approximately 10% of the time.

Limitations and Future Research

The main limitation of the current research is that there was no BLs for the amount of sleep data. This prevented any risk calculations from being performed, since there was no representation of normal driving to compare to SCEs. In addition, general conclusions about occurrences, such as SCEs, after drivers sleep for a certain number of hours could not be made. Having these data would provide more information about the extent to which SCE risk differs as a function of the amount of sleep the night before a SCE/BL of interest. Depending on the results of the odds ratios, the analyses for mobile device use could also change (i.e., only BLs would be included if SCEs were found to have more mobile device use than BLs). This change could provide a more unbiased picture of general mobile device use.

The second limitation is that the amount of data available for the current research restricted the risk analyses for mobile device use subtasks. No analysis could be conducted for approximately 20% of the bin subtasks since there was at least one cell in the odds ratio contingency table with no data points. Other studies, such as Olson et al. (2009) and Fitch and Hanowski (2011), have used the NTDS (Blanco et al., in press) *and* DDWS FOT (Hanowski et al., 2008) data in order to utilize a larger dataset. However, the DDWS FOT did not include logbook information and, therefore, driving time and time on duty could not be calculated.

Having more data, either from one dataset or a combination of datasets, would allow more analyses to be conducted; particularly regarding the mobile device use subtasks. Conducting analyses on the subtasks for each bin of each factor could potentially provide information about what types of tasks drivers are performing during specific hours, which could give additional insight into strategies to address drowsy or fatigued driving.

Drowsiness and fatigue are impossible to measure directly (Williamson, 2009); only measures that are related to alertness and arousal can be collected. In the current research, those measures are the number of SCEs and the amount of mobile device use that occurred during different bins for each factor. Having additional physiological measures, such as EEG as used in

Jellentrup et al. (2011), or driver self-report, may help support the findings related to drowsiness and fatigue more strongly. The driver self-report could include follow-up interviews with CMV drivers that contain questions regarding their willingness to engage in mobile device use subtasks in various situations (i.e., ones with different levels of workload) and levels of fatigue and drowsiness.

Design Implications

As noted, a recommended training tool and policy and technology evaluations were conducted in addition to the analyses discussed above. This section provides more detail about the training tool and the results of the policy and technology evaluations.

Recommended training. When creating the recommended training, three of the six steps from the modified Research-to-Practice (mr2p) were used to convert the results from the current research into practical use (i.e., the training tool). Detailed information about the mr2p steps was obtained from Nakata, Smith-Jackson, & Kleiner (2011). The first step is "prioritize"; this step involves determining what critical issues are present in the research and how the results can be applied. For the current research, the relationship between driving, distraction, drowsiness, and fatigue was critical. It was decided that the results from the research could be applied to training based on FMCSA's web-based training tool called "CMV Driving Tips".

In using this training tool as a guide, the second step (i.e., Target) was established, since the tool was designed for fleet managers to educate drivers and raise drivers' awareness about different areas of driver behavior and performance errors (FMCSA, n.d.b). The web-based training tool can allow drivers or fleet managers to access the information when they have time and may give them the ability to control the amount of content reviewed (Goldstein & Ford, 2002); this is potentially useful for CMV drivers if they have limited amounts of time to use this tool during breaks. Although it was not possible to work and partner with (i.e., the third stage in mr2p) fleet managers or CMV drivers in the recommended design, this was previously accomplished during the initial tips development.

Step four is to translate results into the useful product. Nakata et al. (2011) recommend following the Function for Innovation Translation model; the ideas from this model were used in creating the recommended training page. As noted, FMCSA's web-based training tool was used as the basis for the recommended design. The current pages were examined in order to determine the levels (i.e., the actual tips and the "Did you know" facts) and type of information presented. The results were used to inform the general tips. In addition, more specific information from the results was used in the "Did you know" facts as well as information from reports and articles found in the Literature Review subsection and rationale for hypotheses. Although employees of CMV fleets were not included in the design, a researcher who was involved in the creation of the current tips was asked to review the tips and provide feedback on the content and its possible acceptance by CMV fleet employees.

In addition to the review of the content, the readability of the recommended training was calculated using the Flesch Reading Ease Test (Flesch, 1948) and the Flesch-Kincaid Readability Test (Kincaid, Fishburne, Rogers, & Chissom, 1975). These tests were chosen because they were used to determine the readability of the current FMCSA driving tips (Morgan, Medina, Blanco, & Hanowski, in press). The Flesch Reading Ease score for the recommended training document was 64.1. According to Flesch (1948), the style of the document, based on the score, is standard and would be similar to a piece found in a digest versus a quality, academic, or scientific magazine. The grade level given by the Flesch-Kincaid Readability Test was a 9.0. This is most likely appropriate considering the largest percentage of CMV drivers have graduated high school or had some college education. The second largest percentage of CMV drivers has some high school experience and CMV drivers that did not finish high school comprise the smallest percentage (Blanco et al., 2009; Blanco et al., in press).

The final two steps- disseminate and evaluate- were not possible in the current research; this could be the focus of a follow-on study. The recommended training page that contains information about distraction, fatigue, and drowsiness while driving can be found in Appendix B.

These tips or similar safety information can not only be shared with CMV fleet managers and drivers, but also individuals (i.e., light-vehicle drivers) who share the road with heavy trucks. Baker, Schaudt, Freed, and Toole (2012) examined the extent to which driver education for light-vehicle drivers across the nation included characteristics of and how to drive safely around heavy trucks. Instructional safety information based on the recommended training could also be included in light-vehicle driver education.

Policy evaluation. In addition to the recommended training, an evaluation of current FMCSA policies and the NTSB recommended policy was performed based on the findings from the current research. As noted in the Motivation subsection, FMCSA has enacted a new rule pertaining to hours of service. One provision (i.e., 49 CFR 395.3) specifies that property-carrying CMV drivers must be off duty for at least 34 hr after 7 or 8 work days. Beginning June 30, 2013 the 34 hr period must include time off duty from 1:00 a.m. to 5:00 a.m. two days in a row. The finding from the current research that driver mobile device use was significantly higher from 2:00 a.m. – 3:59 a.m. than any other time of day examined could be an indication that drivers are drowsier during that time. If so, the result supports FMCSA's effort to prevent drivers, especially those that work night shifts, from working during the early morning; this will afford them the opportunity to sleep during that time and reduce their sleep deprivation (Hours of Service of Drivers, 2011, December 27).

In addition, FMCSA enacted a regulation, which was effective in October of 2010, that prohibits CMV drivers from text messaging while driving on the job and prohibits CMV companies from requiring and/or allowing drivers to perform this task (Limiting the use of wireless communication devices, 2010). The findings of the current research most likely provide support for this regulation, since it was found that text messaging on a cell phone significantly increased a driver's SCE risk compared to normal driving. FMCSA also enacted a regulation, effective at the beginning of 2012, which banned CMV drivers from reaching for a cell phone, holding a cell phone while on a call, and dialing a cell phone (Drivers of CMVs: Restricting the use of cellular phones, 2010). Again, this regulation prohibited CMV companies from allowing or requiring their drivers to perform such tasks. The findings of the current research could provide some support for the regulation. The results of the odds ratio indicated dialing a cell phone increased a driver's SCE risk compared to normal driving. The definition of dialing that was used assumes the driver may reach for the phone, so no results were specific to the subtask.

The NTSB policy recommendation notes, "[…] the 50 states and the District of Columbia [should] ban the nonemergency use of portable electronic devices (other than those designed to support the driving task) for all drivers" (NTSB, 2011, p. 1). The findings of the current research may support this recommendation only for visual-manual subtasks; the odds ratio indicated there was an increase in SCE risk when drivers were performing such subtasks. Considering all mobile device use subtasks as equivalent was shown to be a flawed assumption; that is, certain subtasks increase risk while other subtasks do not. Therefore, the term "use" is inappropriate and fails to acknowledge these subtask risk differences. As such, without making a distinction between subtasks and risk, the NTSB recommendation is not sufficiently precise and the data from this study do not support it. It is important to note that the current research only focuses on CMV drivers, but the recommended policy would apply to all drivers, including light-vehicles.

The following table summarizes the above policy evaluation.

Table 36

Summary of Policy Evaluation

Rule	Purpose	Supported	Result from Current Research
Hours of Service of Drivers (2011)	Requires CMV drivers be off-duty for 2 periods between 1:00 a.m. and 5:00 a.m.	Potentially	More mobile device use between 2:00 a.m. and 3:59 a.m. than all other times of day examined.
Limiting the Use of Wireless Communication Devices (2010)	Bans CMV drivers from texting while driving when on duty.	Potentially	SCE risk increased significantly when drivers were text messaging as compared to BLs.
Drivers of CMVs: Restricting the Use of Cellular Phones (2010)	Bans CMV drivers from reaching for, dialing, and holding a cell phone.	Potentially for dialing and reaching for a cell phone.	SCE risk increased significantly when drivers were dialing as compared to BLs. "Reaching for" was included in the subtask definition
NTSB (2011)	Recommends all portable electronic devices be banned.	Potentially for visual-manual mobile device use subtasks.	SCE risk increased significantly when drivers were performing a visual-manual subtask as compared to BLs.

Technology evaluation. As noted, as workload increases performance decreases because attentional resources are limited. There are technologies that aim to help regulate the workload of drivers in order to decrease the occurrence of performance decrements (Broström, Engström, Agnvall, & Markkula, 2006; Uchiyama, Kojima, Hongo, Terashima, & Wakita, 2002; Piechulla, Mayser, Gehrke, & König, 2003). Toyota used measures of mental workload to determine when voice messages with traffic and road information should not be presented in a prototype system (Uchiyama et al., 2002). BMW also created a prototype system that estimates workload based on various sensors and sends phone calls to voicemail if the estimation was above a certain threshold (Piechulla et al., 2003).

Volvo Cars has introduced a similar technology to that prototyped by BMW called the Intelligent Driver Information System (IDIS), which has been released in select models (Broström et al., 2006). IDIS uses information from the vehicle's communication and sensor system to determine workload and may suppress presenting incoming information (calls and texts) to drivers in high workload situations (e.g., intersection). A phone call will be held for a maximum of 5 s; if the high workload situation is not passed in that amount of time, the caller will either receive a busy signal or will be sent to voicemail ("Volvo 'IDIS'", 2006). In addition, a message will be given to the driver that he/she missed a call after the high workload situation is over.

The current research can be used to evaluate workload technologies; however, it is important to remember that the current research dealt with CMV data and these technologies are being tested and implemented in light vehicles. Kahneman (1978) described human attention as limited; depending on how many resources a task requires, it may be difficult to perform any additional tasks. The current research found that visual-manual tasks, such as text messaging, increased SCE risk, which may support workload technologies holding text messages in general. Fitch and Hanowski (2011) used the same data as the current research and found CMV drivers text more during moderate and high workload areas, which reflects an even greater need for technologies to hold text messages in high workload areas. Given the fact that there are bans on texting while driving, perhaps text messages should be held until the car is in park.

In addition to workload technologies, there are also collision (or crash) avoidance technologies that have been implemented in vehicles, such as rear-end collision avoidance systems (Lee, McGehee, Brown, & Reyes, 2002). Over half of rear-end collisions have been attributed to driver inattention (report from Knipling et al. [as cited in Lee et al., 2002]). One such technology was created at VTTI in 2009; it included a radar, algorithm, and rear-lighting that was fixed on the rear of the trailer on a heavy truck and intended for the following vehicle driver (Schaudt et al., in press). Through preliminary algorithm testing, there were issues found regarding false alarms (Toole, 2010); however, those issues have been addressed and the technology is being prepared for a field operational test (W. Schaudt, personal communication, October 31, 2012). The current research may support the need for such technologies given that visual-manual subtasks increased SCE risk. Perhaps technologies that draw drivers' eyes back to the forward roadway, when distracted, would help mitigate the risk associated with the visual-manual tasks investigated in the current study.

Conclusion

The results from the current research indicate time of day was related to driver mobile device use. Drivers had a higher percent of mobile device use during the circadian rhythm low morning bin than any other bins. In addition, visual-manual subtasks increased SCE risk, compared to normal driving, individually and when combined. Subtasks that do not have visual requirements either had no impact or, in one case, decreased SCE risk. It is interesting to note that the percentage of time drivers were using mobile devices in all the data was similar to past findings from a national survey, NOPUS.

These results were used create a recommended update of an educational tool and evaluate current policy and technologies available on the market. Results from the current research may support a provision of the hours of service rule, which requires drivers to be off duty between 1:00 a.m. and 5:00 a.m. two days in a row. In addition, it is possible that the policies that have been enacted by FMCSA that ban text messaging and reaching for, dialing, or holding a cell phone during a call were supported. With regards to technologies, functions of workload technologies, such as holding text messages, were most likely supported by the SCE risk findings. There are limitations of this research that will be important to address in future research. However, the current research has helped close the gap in the literature regarding CMV driver fatigue, drowsiness, and distraction.

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Appendix A: IRB Form

VirginiaTech

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24060
540/231-4606 Fax 540/231-0959
e-mail irb@vt.edu
Website: www.irb.vt.edu

MEMORANDUM

DATE: March 12, 2012

TO: Gregory Fitch, Laura Toole, Richard J. Hanowski, Susan Soccolich, Julie A. McClafferty

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

PROTOCOL TITLE: Adaptive Behavior

IRB NUMBER: 12-266

Effective March 12, 2012, the Virginia Tech IRB Chair, Dr. David M. Moore, approved the new protocol for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at http://www.irb.vt.edu/pages/responsibilities.htm (please review before the commencement of your research).

PROTOCOL INFORMATION:
Approved as: **Expedited, under 45 CFR 46.110 category(ies) 5**
Protocol Approval Date: **3/12/2012**
Protocol Expiration Date: **3/11/2013**
Continuing Review Due Date*: **2/25/2013**
*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:
Per federally regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Date*	OSP Number	Sponsor	Grant Comparison Conducted?
3/8/2012	10275606	Fed Motor Carrier Safety Admin	yes on 3/8/2012

*Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.

cc: File
Department Reviewer:Julie Cook

Appendix B: Recommended Training

Driver Distraction, Fatigue, and Drowsiness

Driver distraction is known to be caused by something or someone inside or outside the vehicle that shares the driver's attention along with the task of driving.[1, 2] For example, a billboard, a crash on the side of the road, food, or a phone could all be distracters. Driver fatigue and drowsiness are similar ideas; however, drowsiness is defined as the want to sleep and fatigue is defined as a loss of attention or physical rejection that continues as a person performs a task.[3, 4, 5] Some studies have found drivers have methods to deal with feelings of fatigue and drowsiness.[6, 7] It is key to make sure methods you choose are not more distracting than alerting.

The tips below will help you be more aware of fatigue and drowsiness and make better choices when feeling effects.

TIP # 1: AVOID TASKS THAT ARE VISUALLY DEMANDING

Focus all of your visual attention on the roadway or anything driving related, such as the speedometer. Avoid dialing a cell phone, text messaging on a cell phone, using your dispatching device, or anything similar.

Did you know? Driving is mainly a visual task and it has been recognized that performance will get worse if two tasks that use the same resource, like two visual tasks, are being performed at the same time.[8]

Did you know? A study found drivers were about 11 times more likely to be in a crash while texting. It also found drivers were about 5 times more likely to be in a crash while dialing a cell phone or interacting with/looking at a dispatching device.[9]

Did you know? There is a federal rule that bans CMV drivers from texting while driving on the job.[10]

TIP # 2: USE A HANDS-FREE PHONE

If you need to talk on your cell phone, use a headset or Bluetooth. It is important to have the headset already connected to your phone and Bluetooth already connected to the vehicle or else searching for, reaching for, or setting up becomes a visually demanding task and will increase risk.[11, 12]

Did you know? There is a federal rule that bans CMV drivers from reaching for, dialing, or holding a cell phone while on a call.[13]

TIP # 3: BE MINDFUL OF THE TIME

People are more naturally drowsy or alert at specific times of the day.[14] It is important to pay attention to how drowsy you feel at all times, but be especially aware of how you are feeling in the evening and early morning.

Did you know? Drivers were found to use some type of mobile device more in the early morning than the hours of mid-morning, afternoon, and evening.[9] This could be a sign that they were feeling more drowsy in the early morning hours; it is the time when people typically feel the drowsiest during a 24 hour period.[15]

Did you know? The time when people are feeling most alert is typically in the mid-morning and in the evening. A study found that drivers used a of mobile device use more during the period in the evening than the period in the morning.[9] This could be a sign that drivers were feeling drowsier in the evening than in the morning.

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1. Pettitt et al., 2005
2. Hanowski et al., 2005a
3. Stutts et al., 1999
4. Desai and Haque, 2006
5. Brown, 1994
6. Williamson et al., 2001
7. Baker et al., 2008
8. Wickens and Hollands, 2000
9. Toole et al., 2012 (this report)
10. Limiting the use of wireless communication devices, 2010
11. Olson et al., 2009
12. Hickman et al., 2010
13. Drivers of CMVs: Restricting the use of cellular phones, 2010
14. NSF, n.d.
15. Hanowski et al., 2008, Figure 35