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Characteristics of Fatigued Commercial Motor Vehicle Drivers -- A Preliminary Investigation

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16. Abstract

The goal of this research was to identify and correlate easily observable characteristics of drivers to different levels of fatigue, thus enabling state patrol officers to make more judicious decisions related to driver fatigue. A literature review was conducted pertaining to the characteristics of fatigued drivers. Next, a nationwide survey was administered to state patrol agencies to assess their practices regarding fatigue-involved driving. To explore relationships between state patrol agency practices and vehicular safety, data collected from the telephone survey were merged with data from different states on fatigue-involved vehicle fatalities and vehicle miles traveled. Analysis revealed that states with greater numbers of vehicle miles traveled reported higher numbers of fatigue-related fatalities, while relatively fewer fatigue-involved fatalities were reported in states where patrol agencies provided formal fatigue identification training to officers, where public service announcements and educational programs to counter fatigued driving were implemented, and where patrol officers used driving cues to stop commercial motor vehicles for fatigue-related issues. A plan was prepared for future research that will develop a tool kit for the field measurement of fatigue. The tool kit will be based on input from driver facial clues, physiological aspects, and steering cues, and will include field measurement techniques and criteria for identifying fatigue. When fully developed, the tool kit will give patrol officers the flexibility of using one or more means of fatigue identification in the field. The research plan also includes an exploration of practices of those agencies that make fatigue-related training available to patrol officers, as well as an exploration of the role of public service announcements in relation to fatigued driving.

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Abstract

The goal of this research was to identify and correlate easily observable characteristics of drivers to different levels of fatigue, thus enabling state patrol officers to make more judicious decisions related to driver fatigue. A literature review was conducted pertaining to the characteristics of fatigued drivers. Next, a nationwide survey was administered to state patrol agencies to assess their practices regarding fatigue-involved driving. To explore relationships between state patrol agency practices and vehicular safety, data collected from the telephone survey were merged with data from different states on fatigue-involved vehicle fatalities and vehicle miles traveled. Analysis revealed that states with greater numbers of vehicle miles traveled reported higher numbers of fatigue-related fatalities, while relatively fewer fatigue-involved fatalities were reported in states where patrol agencies provided formal fatigue identification training to officers, where public service announcements and educational programs to counter fatigued driving were implemented, and where patrol officers used driving cues to stop commercial motor vehicles for fatigue-related issues. A plan was prepared for future research that will develop a tool kit for the field measurement of fatigue. The tool kit will be based on input from driver facial clues, physiological aspects, and steering cues, and will include field measurement techniques and criteria for identifying fatigue. When fully developed, the tool kit will give patrol officers the flexibility of using one or more means of fatigue identification in the field. The research plan also includes an exploration of practices of those agencies that make fatigue-related training available to patrol officers, as well as an exploration of the role of public service announcements in relation to fatigued driving.

Executive Summary

Driving while fatigued is fairly common amongst drivers and each year numerous crashes occur due to fatigue resulting in loss of valuable life and property. An effective way to reduce such crashes is to remove fatigued drivers from the highways; however, identifying fatigued drivers is prerequisite to this method. The goal of this research was to identify and correlate easily observable characteristics of drivers to different levels of fatigue, thus enabling Nebraska State Patrol officers to make more judicious decisions relating to driver fatigue. As a first step, research was undertaken to review the current state of information pertaining to the characteristics of fatigued drivers; further, a nationwide, telephone-based survey was administered to state patrol agencies to assess their practices regarding fatigue-involved driving.

A review of published literature indicated that drivers' facial characteristics (e.g., rapid eye blinking and eyelid droop), steering cues (e.g., slow drifting followed by fast correction), and physiological characteristics (e.g., heart rate and respiratory pattern) provide clues indicating fatigue. To explore relationships between state patrol agency practices and vehicular safety, data collected from the telephone survey were merged with data from different states on fatigue-involved vehicle fatalities and vehicle miles traveled. The analysis revealed that states with greater numbers of vehicle miles traveled reported higher numbers of fatigue-related fatalities, while relatively fewer fatigue-involved fatalities were reported in states where patrol agencies provided formal fatigue identification training to officers, where public service announcements and educational programs to counter fatigued driving were implemented, and where patrol officers used driving cues to stop commercial motor vehicles for fatigue-related issues.

A plan was prepared for future research that will develop a tool kit for the field measurement of fatigue. The tool kit will be based on input from driver facial clues,

physiological aspects, and steering cues, and will include field measurement techniques and criteria for identifying fatigue. When fully developed, the tool kit will give patrol officers the flexibility of using one or more means of fatigue identification in the field. The research plan also includes an exploration of the practices of those agencies that make fatigue-related training available to patrol officers, as well as an exploration of the role of public service announcements in relation to fatigued driving.

Chapter 1 Introduction

Driving under fatigued mental conditions is fairly common among drivers, and especially among drivers of commercial motor vehicles. Each year, numerous crashes occur due to driver fatigue resulting in loss of valuable life and property. An effective way to reduce such crashes is to remove fatigued drivers from the road; however, identifying fatigued drivers is prerequisite to this method. To keep Nebraska's highways safe, the Nebraska State Patrol Carrier Enforcement Division routinely conducts inspections of commercial vehicles to ensure compliance with the Federal Motor Carrier Safety regulations and/or hazardous materials regulations. These inspections involve different levels of driver and vehicle scrutiny. Many times, the inspecting officer is guided by signs that may lead to a closer examination of possible issues; for example, a driver's slurred speech may convince the officer to administer field sobriety tests. However, the Nebraska State Patrol currently lacks concrete information on drivers' physiological signals or other signs indicating fatigue.

The goal of this research was to identify and correlate easily observable drivers' signs and signals to different levels of mental fatigue, e.g., normal, confused, disoriented, sleepy, impaired, etc. As a first step in this direction, research was undertaken to review the current state of information pertaining to the characteristics of fatigued drivers, and a nationwide survey of relevant enforcement agencies was conducted in order to assess their practices regarding driver fatigue.

Presented in this report are: 1) a review of published literature pertaining to fatigued driving; and 2) the results of a telephone-based survey of state patrol agencies regarding their practices in dealing with fatigued commercial motor vehicle drivers. Additionally, results from the telephone survey were compared to multi-year fatigue-involved crashes reported in each state to determine whether correlations between these factors existed. The analysis showed that fatigue-involved crashes were fewer in states that offered formal fatigue identification training for officers; that mentioned the use of public service announcements and educational programs to counteract fatigued driving; and where patrol officers used driving cues to stop commercial motor vehicles for fatigue-related issues. As expected, the analysis showed that fatigue-involved crashes increased with greater vehicle miles traveled in each state, i.e., a measure of exposure.

This report also presents a plan for future research to develop tools that will enable Nebraska State Patrol officers to make more judicious decisions in the field regarding fatigued driving.

Following the current introduction, this report is organized in four sections: the first section includes a review of pertinent literature on fatigued driving followed by a description of the telephone survey of state patrol agencies that was conducted for this research; next, the fatigue-involved crash analysis conducted for the current research is described; finally, plans for future research are detailed.

Chapter 2 Literature Review

Driver fatigue is a major concern, especially pertaining to commercial motor vehicle drivers. Fatigue is difficult to evaluate, as there is a continuous scale that lies between being awake and being asleep; fatigue itself comprises levels in-between wakefulness and sleep. Fatigue can have many causes, ranging from sleep problems to the road environment. Sagberg and Bjornskau (2007) surveyed 4,448 crash-involved drivers in Norway. Of those questioned, 6% admitted to falling asleep at the wheel in the past year, and 22% reported they had fallen asleep at the wheel while driving. Fever and Williamson (2001) estimated that 40-50% of fatal single-vehicle semitrailer crashes in Australia were caused by fatigue. This problem is prevalent in the United States as well. Morrow and Crum (2004) surveyed 116 trucking firms in the United States to determine how driver fatigue affected accidents and near-accidents for commercial drivers. They concluded that fatigued driving greatly increased the number of accidents and near-accidents for commercial drivers.

While the dangers of fatigued driving are well-understood, there is currently no accepted method for evaluating and quantifying a driver's drowsiness level. Multiple measures have been suggested, all of which recognize a range of fatigue levels which may be difficult to distinguish and difficult to implement outside of a laboratory environment. Wierwille and Ellsworth (1994) utilized an observer rating of drowsiness. In their study, trained observers evaluated driver drowsiness from video recordings of the drivers' faces. Trained observers gave repeatable results, however, other studies or non-research settings may not have sufficient resources to use this rating system.

Miyake et al. (2010) differentiated specific levels of fatigue in a study of 21 middle-aged and 10 college-aged males. Participants were asked to report their own sleepiness on a scale of 1 to 5 (1: awake, 2: slightly sleepy, 3: very sleepy, 4: almost asleep). However, having participants rate themselves introduced the possibility of different perceptions of the definition of “very” versus “slightly” sleepy. In an attempt to avoid subjectivity or personal bias, the International Association for Accident and Traffic Medicine delineates fatigue into four categories based upon a person’s ability to do mental calculations (1983). Mental calculations describe a person’s concentration level, and may be effective in determining fatigue if each level is well-defined. This approach may be easier to implement in the field by law enforcement agencies, as little training may be necessary to utilize a comparable system.

Driver fatigue may have numerous causes, which can be considered either physical or psychological in nature (International Association for Accident and Traffic Medicine 1983). Physical fatigue is most often caused by a lack of sleep. A Norwegian study found that drivers reported some kind of a sleep problem in approximately 40% of crashes involving fatigued driving (Sagberg 2008). A study by Wijesuriya, Tran, and Craig (2007) of 50 participants in a driving simulator determined various potential causes of psychological fatigue. Outcome measures included sleepiness, low healthy lifestyle status, an extroverted personality, and negative mood states. In a 20-participant study, Nakayama (2002) found the primary cause of psychological fatigue to be long driving workload.

Limiting driver workload through Federal Hours of Service (HOS) regulations is the primary means of control currently used to discourage fatigued driving among commercial drivers. There is evidence suggesting that driver workload has a critical influence on driver fatigue. Nakayama (2002) found a dramatic increase in fatigue after 12 hours of driving time. Jovanis, Wu, and Chen (2011) analyzed carrier-supplied driver logs to determine the probability of a crash after a certain amount of driving time. A consistent increase in the odds of a crash was found with increased driving time. This increase was particularly evident after 6 hours of continuous driving. These odds decreased if breaks were taken during driving. Taking two breaks reduced the odds of a crash by 32% for those driving truckload vehicles, and by 51% for those driving less than truck load vehicles.

While federal regulations focus upon limiting workload to counteract fatigue amongst commercial drivers, factors aside from the length of drive time can also induce fatigue. Research by Sagberg and Bjornskau (2007) indicated that the time of day when driving took place may have had a greater impact on fatigue than did workload. Oron-Gilad and Hancock (2005) proposed two main causes of fatigue: a driver's mental state before the drive began, the characteristics of the drive, and road environment. Sagberg and Bjornskau (2007) reported that drivers more often fell asleep in situations with low traffic, high speed limits, straight roadways, and good weather—characteristics that are commonly experience by drivers of commercial motor vehicles.

Feyer and Williamson (2001) suggested that night work, the timing of successive work periods, and time off between work periods also influence long-distance driver fatigue. These factors were previously investigated by Wiley et al. (1996). Eighty commercial drivers in the United States and Canada were monitored for 16 weeks. Driver fatigue was measured with video recordings of the drivers' faces. Driver workload, consecutive driving days, time of day, and schedule regularity were all considered as potential influences on fatigue. The most consistent influence on fatigue was found to be the time of day during which the driving took place.

Similar results were reported in a study by Barr et al. (2005) of 900 hours of naturalistic driving. The study aimed to determine operational or driving environment related influences on fatigue. The time of day of a driving shift had the greatest impact on a driver's potential to become fatigued. The study found that a driver was twice as likely to become drowsy between 6:00 am and 9:00 am. Approximately 30% of all drowsiness incidents occurred during the first hour of the work shift. These conclusions were reiterated by the results of a questionnaire distributed in Norway by Sagberg and Bjornskau (2007), which found that the risk of falling asleep was 17 times greater during the hours between midnight and 6:00 am than between 6:00 am and noon.

Even if the causes of fatigue are known, recognition of fatigue is still an issue. Several technologies have been introduced to detect driver fatigue, the majority relying on visual cues from the drivers. Some of these technologies aim to alert the driver of a possible unsafe situation. Kaneda et al. (1995) created a detection method to measure driver drowsiness. A video camera captured images of a driver's face and detected limited alertness by monitoring the driver's eyes. The device emitted an audible warning if the system considered a driver to be fatigued, followed by a menthol scent spray to wake the driver. The study reported that a menthol scent in addition to an audible warning was more than twice as effective as the audible warning alone.

Drivers' eye closure is commonly utilized by driver fatigue detectors. A study performed at the University of Iowa by Bishop and Evans (2001) used video recording to follow a driver's face. Algorithms were used to automatically locate a driver's eyes. Visible eye features were monitored, and an alarm sounded if the eyes were closed for longer than 1.5 seconds. This process also monitored the area of exposed eye features, and an alarm sounded if there was a sustained reduction in the area, i.e., eyelid droop. Singh and Papanikolopoulos (1999) recommend a similar system that focused on drivers' eyes. The researchers presented a system that tracked a driver's pupils and monitored the eyes for micro-sleeps by counting video frames when the eyes were closed. Lal and Craig (2000) found drowsiness to be easily recognized by a subject's fast, rhythmic blinking and relatively little eye movement.

While eye closure may be an effective method to determine driver fatigue, other symptoms may additionally be used. De Rosario et al. (2010) investigated biomedical and biomechanical signals that may indicate driver drowsiness. Specifically these factors included biomedical signals, eye closure, pressures on the driver's seat, and control of the vehicle. Electroencephalogram (EEG) readings and the percent of eye closure were used as primary indicators of drowsiness and compared to other factors. The study reported heart rate variability and respiration to be the most promising indicators of drowsiness. Lal and Craig (2000) also reported heart rate to be a good indicator of fatigue. As subjects performed in a driving simulator, a reduced heart rate was observed in all participants as they became fatigued.

Heart rate has been used in numerous studies as an indicator of fatigue. In a study of volunteers by Nakayama (2002), a high correlation between pulse rate and fatigue was reported. For this reason, Nakano et al. (2008) introduced a drowsiness detector that relied on a measurement of the driver's heart rate taken through a sensor on the steering wheel. Heart rate may be used in addition to other physiological symptoms. Mao et al. (2008) successfully used heart rate, skin conduction, electromyogram, skin temperature, and respiration measures in eight simulations to judge driving fatigue based on physiological signals.

While physiological symptoms are commonly used to diagnose fatigue, some detection methods adopt a different approach. Patterns of slow drifting and fast correction were used as clues of fatigued driving in a driving simulator during a sleep deprivation study of 12 participants by Krajewski et al. (2009). They reported an 86.1% recognition rate for classifying slight from strong fatigue. Mortazavi et al. (2009) also reported steering behaviors to be sufficient indicators of drowsiness. In a driving simulator study with commercial motor vehicle driver participants, lateral position variations and steering corrections were observed. Significant patterns were observed and deemed sufficient by the authors to identify driver drowsiness.

Though steering patterns or physiological symptoms may indicate fatigue, Kircher et al. (2002) indicated the non-availability of a sufficiently reliable commercial system for detecting driver drowsiness, as no single indicator is sufficient to indicate drowsy driving. Instead, the authors suggested a combination of eye blink pattern and lateral control performance.

While progress has been made in the ability to detect driver fatigue, many drivers themselves are aware when they are becoming fatigued. A questionnaire distributed to drivers in Norway found that most drivers who fell asleep at the wheel reported feeling tired beforehand and attempted to stay awake by implementing practices such as listening to music, opening a window, or putting on the fan (Sagberg and Bjornskau 2007). Gershon et al. (2011) distributed a survey to 100 professional and 90 non-professional drivers to evaluate the perceived effectiveness of fatigue coping mechanisms. Both professionals and non-professionals considered listening to the radio and opening windows as the most effective approaches. Commercial drivers also considered planning ahead for rest stops, stopping for short naps, and drinking coffee to be effective fatigue coping measures.

Federal Motor Carrier Safety Administration (FMCSA) regulations consider fatigue to be a safety concern in the case of commercial motor vehicle drivers. The following is an excerpt of FMCSA regulation §392.3 regarding ill or fatigued drivers:

No driver shall operate a commercial motor vehicle, and a motor carrier shall not require or permit a driver to operate a commercial motor vehicle, while the driver’s ability or alertness is so impaired, or so likely to become impaired, through fatigue, illness, or any other cause, as to make it unsafe for him/her to begin or continue to operate the commercial motor vehicle. In accordance with this regulation, a commercial vehicle inspection may include checking the driver for signs of fatigue. However, no guidance is readily available for identifying and distinguishing among different levels of fatigue.

States have the ability to determine specific procedures for vehicle inspections. These procedures mimic the Level 1 Inspection described above. Fatigue is often mentioned in these procedures, but identification of fatigue is usually not well defined. The state of Ohio's Commercial Motor Vehicle Inspection Process instructs inspectors to check the condition of the driver "for signs of fatigue" (Public Utilities Commission). However, no specifics are given on what constitutes signs of fatigue.

2.1 Pertinent Findings of the Literature Review

Figure 2.1 presents a graphical summary of the findings of the literature review. Driver fatigue has long been considered a safety concern. Though it is difficult to quantify, fatigue is understood to occur at a range of severity levels and may have physical or psychological origins. While the primary countermeasure used to combat commercial motor vehicle driver fatigue has been to limit driver workloads, evidence suggests that the time of day of driving may have a more significant impact. Numerous methods have been used to detect driver fatigue, the majority of which rely on visual cues such as eye closure and blinking pattern. Heart rate, respiratory pattern, and steering variations have also shown promise as indicators of fatigue. Driver facial characteristics, physiological aspects, steering cues, and driving related characteristics may be used by law enforcement to more successfully detect situations of driver fatigue.

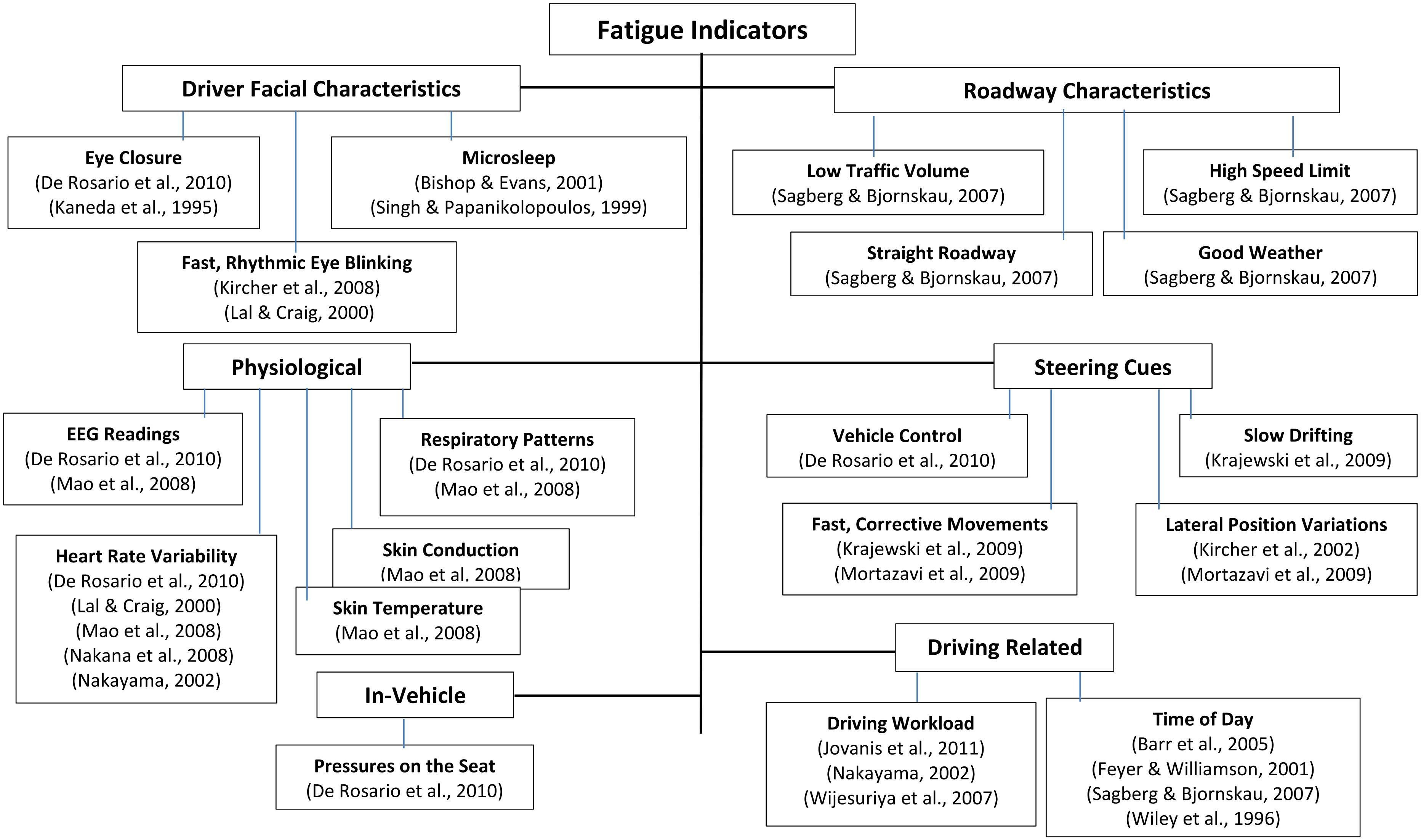

Figure 2.1 Graphical summary of literature review

Visual cues from a driver’s face may be utilized by law enforcement to detect driver fatigue. Fast eye blinking patterns and eyelid droop can be seen during a traffic stop, but may not be sufficient to detect driver fatigue. Speaking during the stop may be sufficient to temporarily raise a driver’s alertness and reduce these symptoms. Further, individuals vary in their natural blinking patterns, and an officer would not normally have a good base line for comparison.

Physiological aspects such as respiration could potentially be used as an indicator of fatigue by law enforcement. A driver’s heart rate might also be used effectively, though field measurement would require proper equipment and training. Both methods could potentially be problematic, as a traffic stop may be stressful and might temporarily speed up a driver’s heart rate and respiration, thus masking fatigue symptoms. Steering cues may be good indicators for law enforcement, as lane position variation and slow drifting followed by quick corrective steering movements can be readily observed in the field.

Chapter 3 Survey of State Patrol Agencies

A telephone survey was designed by the University of Nebraska-Lincoln (UNL) to investigate policies and procedures related to driver fatigue amongst state patrol agencies across the country. The complete survey instrument can be found in Appendix A. The survey was administered by the University of Nebraska-Lincoln Bureau of Sociological Research (BOSR) BOSR is a department that specializes in survey-related research. This survey was performed by professional interviewers, which ensured that it was properly executed in a timely manner with minimal errors.

State patrol agency contact information was obtained from the respective agency web sites. Each state was contacted individually—excluding Hawaii, which does not have a state patrol agency—using the contact information found on the websites. If necessary, interviewers contacted different personnel or departments within an agency to obtain responses to the survey questions.

Once a survey was completed, the results were summarized. During the initial fielding of the surveys, it was found that some questions were subject to multiple interpretations. For example, Question 5 states, “Does your agency have published rules and regulations dealing with the issue of fatigue in commercial motor vehicle drivers?” Of the respondents, 46 mentioned federal regulations in addition to their “yes” or “no” response to this question. But some respondents considered federal regulations to qualify as a “yes” response, while others considered it a “no,” as they did not have state-specific regulations. In such instances, the responses were clarified from the respondents and accordingly entered in the database.

3.1 Summarized Survey Results

Several questions in the survey requested qualitative information. To summarize these answers, responses were grouped by theme. All responses with more than one occurrence are listed in the following section from most to least common. Responses may add up to more than 49, since a single agency may have mentioned multiple parts of their procedures. In the case of a “yes” or “no” question, the results are represented graphically in GIS to illustrate states’ responses.

Question 5. Does your agency have published rules and regulations dealing with the issue of fatigue in commercial motor vehicle drivers?

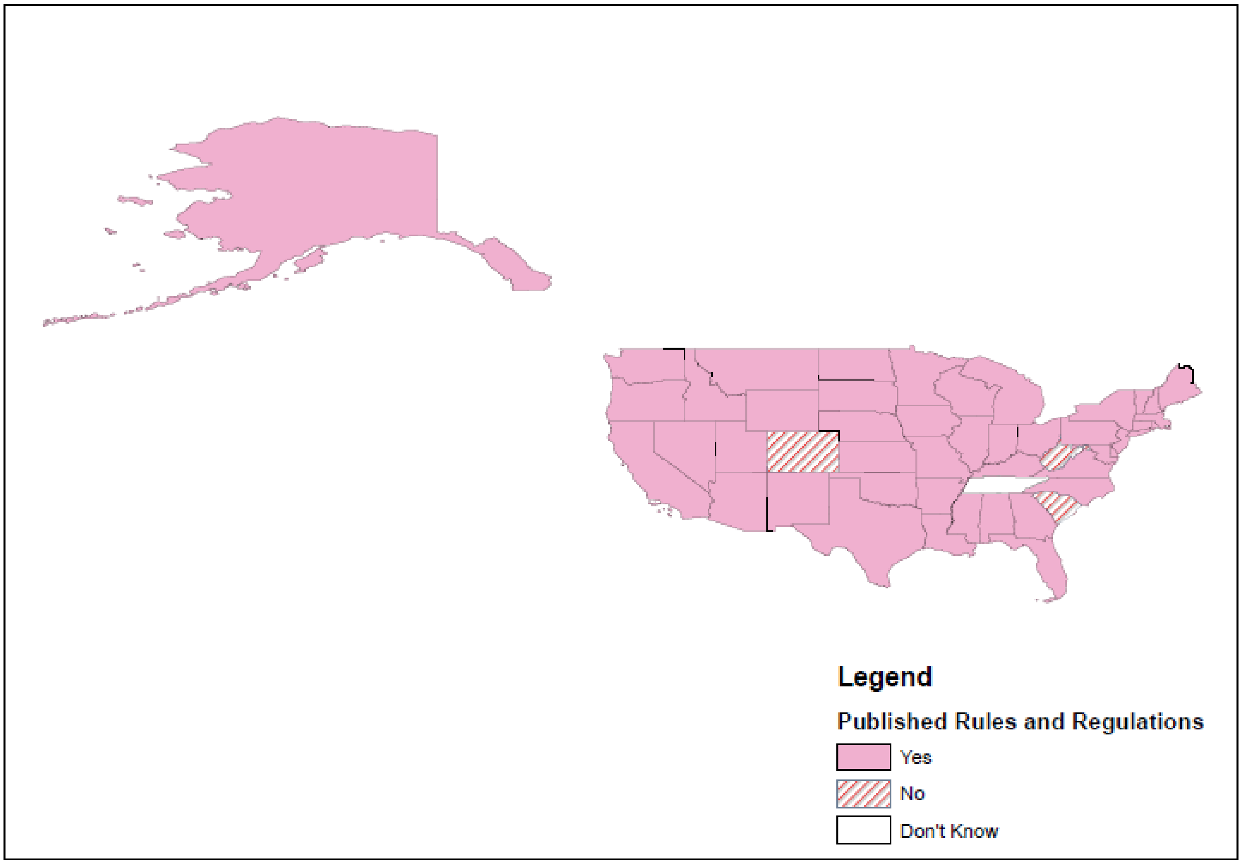

Figure 3.1 Question 5 responses

Yes – 45

No – 3

Don’t Know – 1

Qualitative Responses:

Federal regulations – 43

State regulations – 7

Question 6. Does your agency have any specific program that deals with the issue of fatigued motor vehicle drivers?

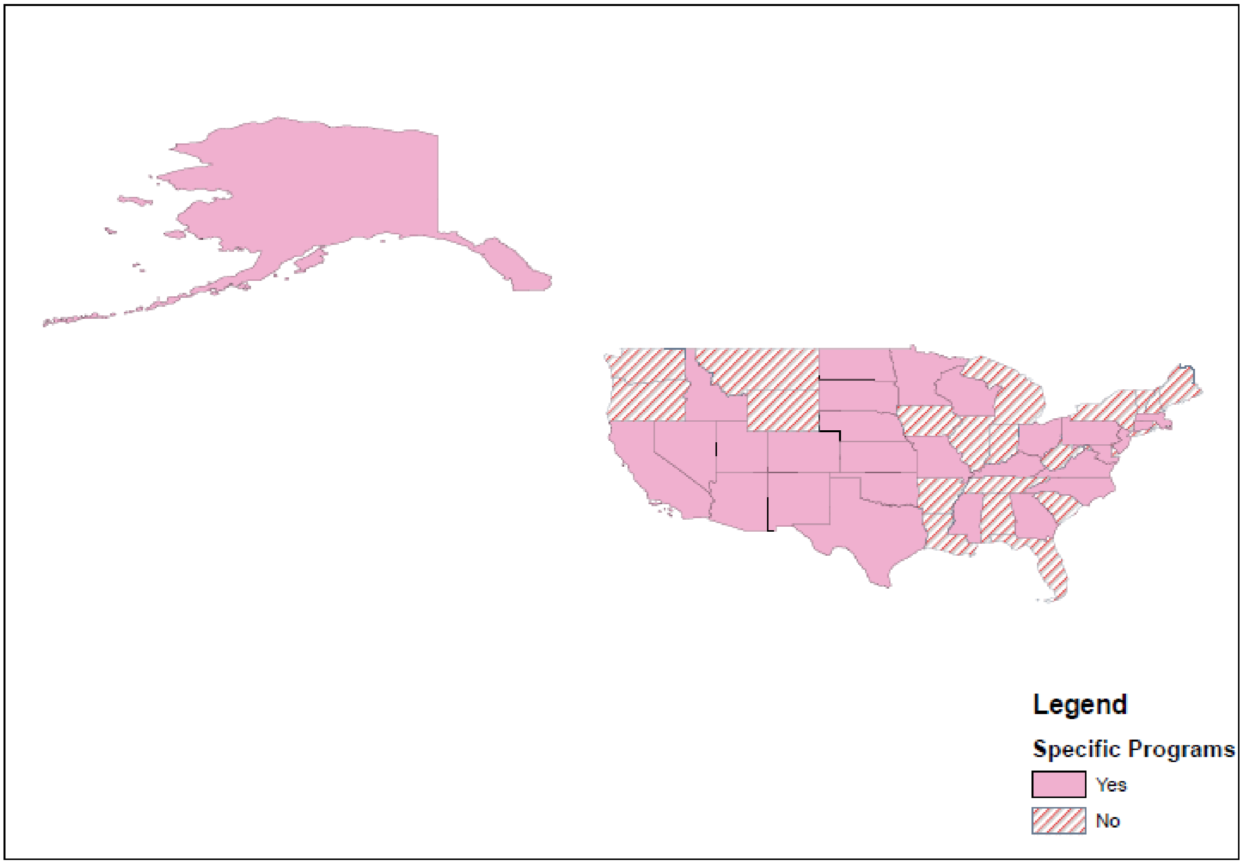

Figure 3.2 Question 6 responses

Yes – 28

No – 21

Qualitative Responses:

Federal regulations and inspection criteria – 15

Public outreach and education – 8

Other programs – 7

Seven states responded to this question by mentioning other programs which did not fit into the categories of federal regulations or public outreach. These states were: Arizona, Connecticut, Florida, Georgia, Idaho, Kansas, and Oklahoma. To provide more information on other types of programs, each state's response is shown below. While these states did mention another program, no details about program specifics were given.

Arizona: Defeating Distracted Driving

Connecticut: Motor Vehicle Assistance Program

Florida: Work in conjunction with DUI checkpoints

*Georg*ia: Targeting Aggressive Cars and Trucks

Idaho: Specific regulations for farmer-based products

Kansas: Quarterly rotating training which includes an out of service unit

Oklahoma: Driver behavior training

Question 7. Do officers in your agency receive formal training identifying fatigue in motor vehicle drivers?

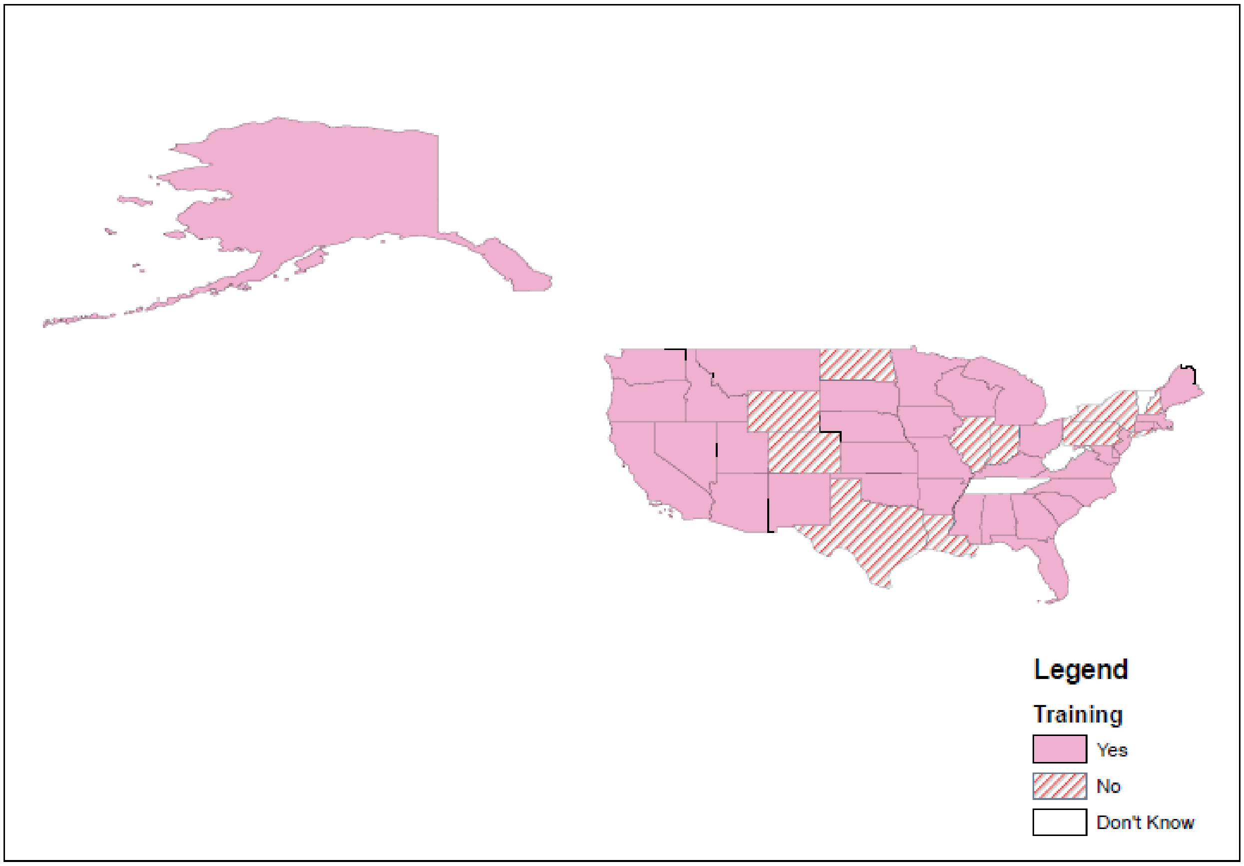

Figure 3.3 Question 7 responses

Yes – 36

No – 10

Don't Know – 3

Qualitative Responses:

Federal training for North American Standard Level 1 Inspection – 27

Other training – 14

Question 8. Do officers in your agency stop vehicles if they believe drivers are fatigued?

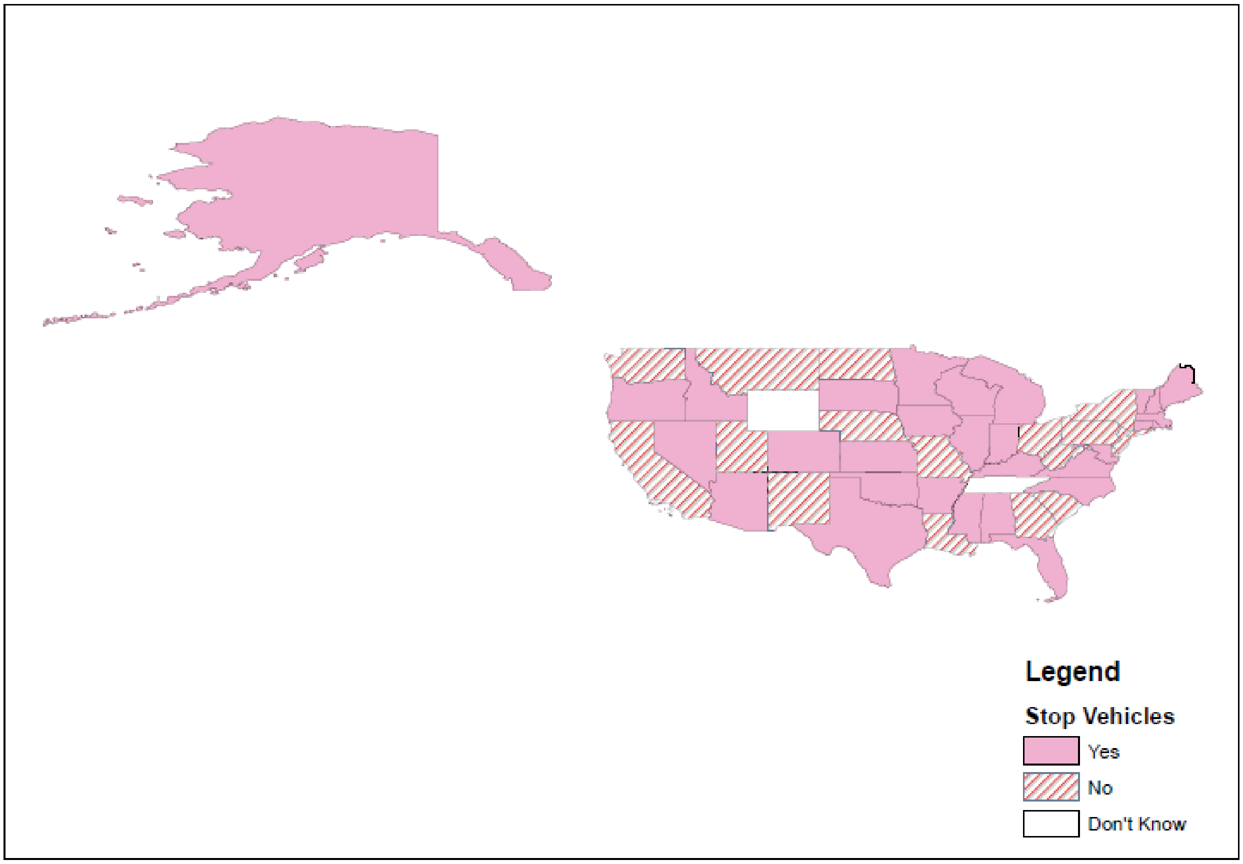

Figure 3.4 Question 8 responses

Yes – 30

No – 17

Don’t Know – 2

Question 9. What procedure is followed when an officer stops a driver believed to be fatigued?

Place CMV out of service – 21

Driver interview/behavior – 18

Check for other impairments – 17

Check log books and driving times – 15

Officer discretion – 11

Federal regulations – 8

Enforce other traffic violations – 6

Driving cues – 5

Question 10. How is fatigue determined to be an issue in a motor vehicle crash?

Driver/witness statements – 30

Log books – 19

Crash characteristics – 10

Officer observations – 6

Crash reconstruction – 4

The summarized results indicated that most state patrol agencies did not have specific procedures or training programs related to fatigue identification beyond those stipulated by federal regulations. Driver interviews and hours of service appeared to be the most commonly used tools for identifying fatigue. Most agencies did not provide details as to how fatigue is actually identified in the field; subjectivity appears to be an issue for agencies nationwide.

In addition to the questions shown above, the survey requested statistics related to the number of CMV inspections, any legally challenged fatigue citations, and the number of fatigue-attributed crashes (questions 11-16, as shown in Appendix A). Very few states responded to these questions, as the interviewees did not know the answers or the states did not track statistics in this manner. Inspection information for 2011 was retrieved from the Federal Motor Carrier Safety Administration website. Figure 3.5 provides a map of the number of CMV inspections.

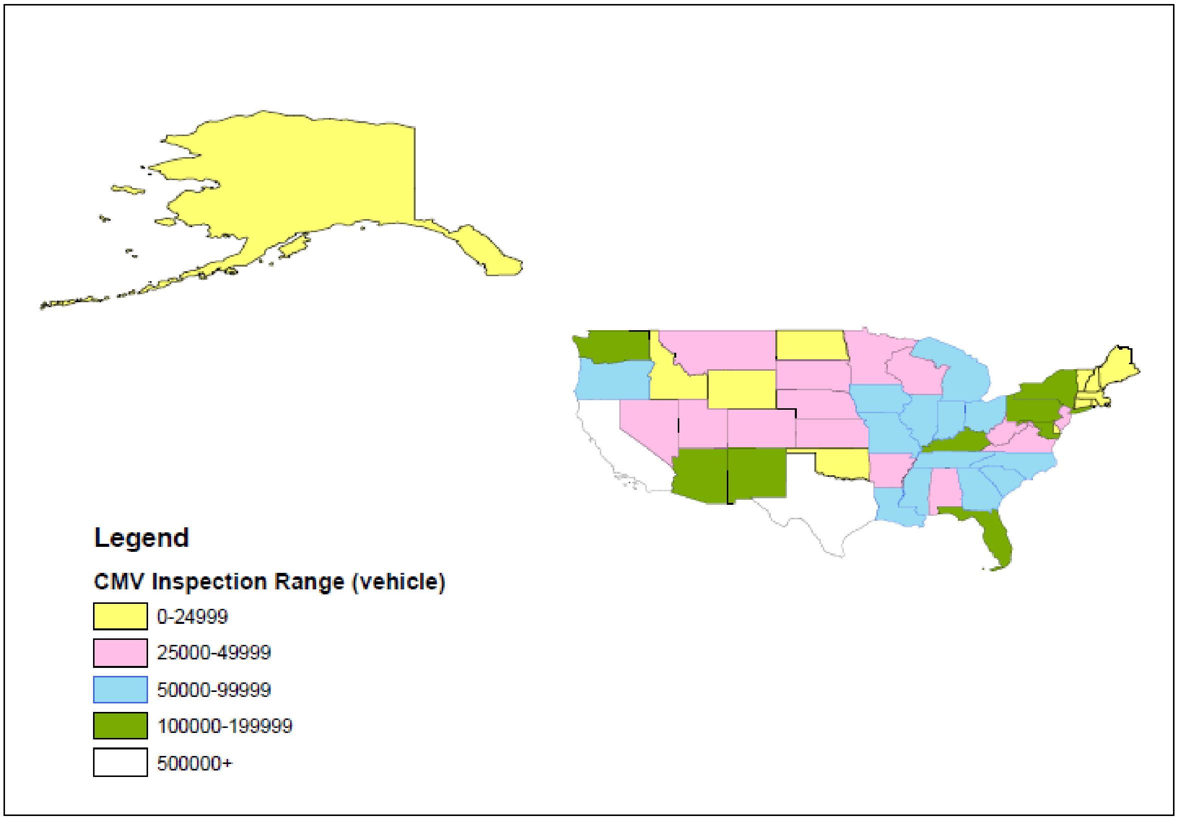

Figure 3.5 2011 CMV roadside inspections

Chapter 4 Data Analysis

The survey responses were coded in a spreadsheet for further analysis. Various indicator variables were created for the most common qualitative survey responses. Relationships between fatigue-involved fatal crashes reported in each state and the various elements collected via the telephone survey were explored. The dataset collected via the telephone survey was fortified with additional data for improved analysis. State by state vehicle miles traveled information was found for 2002 to 2010 from the Federal Highway Administration yearly reports and added to the telephone dataset. Similarly, data on commercial motor vehicle inspections in 2011 was retrieved from the Federal Motor Carrier Safety Administration Roadside Inspection Summary and added to the analysis dataset.

The numbers of fatigue-involved fatal crashes were retrieved from the Fatality Analysis Reporting System (FARS) database for each state from 2002 to 2010. The sum of these crashes was used as the dependent variable during model estimation. Fatigue-involved fatal accidents were chosen as enforcement techniques are intended to create a safer driving environment by removing impaired drivers from the roadway and therefore such crashes are an objective way to model the fatigue aspect of roadway safety. Fatigue-involved fatal crashes are less likely to suffer from reporting bias than less severe crashes and state-wide information regarding fatal crashes is readily available and was therefore chosen for data analysis. The variables in the analysis dataset with their respective coding are shown in table 4.1.

Table 4.1 Variable list and coding

Related Survey Question Number	Variable Name	Variable Description	Coding
5	PubReg	Published rules and regulations for fatigued commercial motor vehicle drivers	1=Yes 0=No -999=Don't Know
5	FedReg	Mentioned federal regulations	1=Yes 0=No
5	StateReg	Mentioned specific state regulations	1=Yes 0=No
6	SpecProg	Specific program dealing with fatigued driving	1=Yes 0=No -999=Don't Know
6	FedProg	Mentioned federal programs	1=Yes 0=No
6	PSA	Mentioned public service announcements and education	1=Yes 0=No
6	OtherProg	Mentioned some other program	1=Yes 0=No
7	Train	Officers receive formal fatigue identification training	1=Yes 0=No -999=Don't Know
7	FedTrain	Mentioned federal training programs	1=Yes 0=No
7	OtherTra	Mentioned some other training program	1=Yes 0=No
8	Stop	Officers stop vehicles if they believe drivers are fatigued	1=Yes 0=No -999=Don't Know
9	StopFed	Mention federal regulations as part of stopped vehicle procedure	1=Yes 0=No
9	StopLog	Mention checking log books as part of stopped vehicle procedure	1=Yes 0=No
9	DriverIn	Mentioned driver interview as part of stopped vehicle procedure	1=Yes 0=No
9	CMVOos	Mentioned taking fatigued CMV driver out of service as part of stopped vehicle procedure	1=Yes 0=No
9	Driving	Mentioned driving cues as part of stopped vehicle procedure	1=Yes 0=No
9	Impair	Mentioned checking for drug, alcohol, etc. impairment first in stopped vehicle procedure	1=Yes 0=No
9	TrafficViol	Mentioned citing other traffic violations in stopped vehicle procedure	1=Yes 0=No
9	Discret	Mentioned officer discretion as part of stopped vehicle procedure	1=Yes 0=No
10	CrshLog	Mentioned checking log books as part of fatigue determination in a crash	1=Yes 0=No
10	CrshChar	Mentioned checking crash characteristics as part of fatigue determination in a crash	1=Yes 0=No
10	DrverState	Mentioned taking driver and witness statements as part of fatigue determination in a crash	1=Yes 0=No

Table 4.1 (cont.) Variable list and coding

10	Observ	Mentioned officer observations as part of fatigue determination in a crash	1=Yes 0=No
10	Recon	Mentioned crash reconstruction as part of fatigue determination in a crash	1=Yes 0=No
11	Inspec	Number of commercial vehicle inspections in fiscal year 2011	Numerical value
11	LnInspec	Natural log of number of commercial vehicle inspections in fiscal year 2011	Numerical value
N/A	DOosR	Driver inspection out of service rate in fiscal year 2011	Numerical value
N/A	VoosR	Vehicle inspection out of service rate in fiscal year 2011	Numerical value
N/A	V9Sum	Sum of VMT (in millions) from 2002 to 2010	Numerical value
N/A	LnV9	Natural log of sum of VMT from 2002 to 2010	Numerical value
N/A	V5Sum	Sum of VMT (in millions) from 2006 to 2010	Numerical value
N/A	LnV5	Natural log of sum of VMT from 2006 to 2010	Numerical value
N/A	F9Sum	Sum of fatigue-involved fatal crashes from 2002 to 2010	Numerical value
N/A	F5Sum	Sum of fatigue-involved fatal crashes from 2006 to 2010	Numerical value

Data analysis was carried out in the software program NLOGIT. The sum of fatigue-involved fatal crashes was used as the dependent variable in the model. Both five-year and nine-year crash sums were considered as dependent variables in the model estimation. The remaining variables were modeled as independent variables.

4.1 Model Estimation

A Poisson model was originally used, as it is the traditional choice for modeling counts of events such as yearly reported crashes. However, due to overdispersion of the dependent variable, a negative binomial model was estimated instead, because such a model accounts for overdispersion of the dependent variable. The analysis process began by modeling each variable with a vehicle miles traveled variable, either V9Sum or V5Sum. Variables which were statistically significant at a 95% confidence level remained in consideration for the final model.

The trial period of individual variables made it obvious that the nine year sums of vehicle miles traveled and fatigue-involved fatal crashes were better choices for the model. Therefore, V9Sum was used as an independent variable and F9Sum was used as the dependent variable in the final model. For both vehicle miles traveled and number of commercial motor vehicle inspections, the natural logarithmic transformation was also considered. For vehicle miles traveled, the non-transformed variable provided a better fit than the model with the log-transformed variable.

Creation of the final model began by including variables that were statistically significant on their own. The remaining variables were added one by one. If a variable's statistical significance varied with the addition of other variables, it was removed from the model. This variance implied that the variable was not independent of the others, and perhaps should not be included in the model specification.

4.2 Variable Exclusion

Upon further inspection, certain variables were excluded from the model. All variables related to Question 10 in the survey (involving how fatigue is determined as the cause of a crash) were excluded from the analysis. This was done because these variables describe the situation after a crash has already occurred. The procedure after a crash would not impact the likelihood of a future crash. The only plausible relationship would be an increased number of crashes if certain identification techniques are used. These procedures may make it more likely that fatigue would be correctly identified as the cause of a crash. Instead of affecting the actual number of crashes, these procedures may affect the reporting of a crash. This relationship was not observed in the analysis, so these variables were excluded from the final model.

Moreover, variables related to federal regulations and federally administered training were excluded. This step was taken because all states abide by federal rules and regulations, even though a respondent may not have listed these regulations in their response. There was little variation in the responses to these questions; therefore, including them did not improve the model.

Taking into account the variable significances and the McFadden pseudo r-squared value, a final model was created. Table 4.2 details this model.

Table 4.2 Estimated model parameters for nine-year fatigue-involved crash frequency

Variable	**Coefficient**	**Significance**	**R-squared**
Constant	5.70376888	0.0000	0.8715940
V9Sum	0.788515D-06	0.0000	
Train	-0.86683568	0.0003	
PSA	-0.23849687	0.2440	
Driving	-0.65548262	0.0473	

The equation for the estimated model is of the form:

$$F9Sum = e^{(0.7885\times10^{-6}V9Sum - 0.8668Train - 1.2385PSA - 0.6555Driving + 5.7308)} \tag{4.1}$$

The complete model estimation output from NLOGIT software is available in Appendix B.

4.3 Model Discussion

The variable coefficients implied some positive and some negative correlations with fatigue-involved fatal crashes. A positive coefficient implied a positive correlation with crashes: as the value of the variable increased, the expected number of fatigue-involved fatal crashes increased. A negative coefficient implied the opposite: as the value of the variable increased, the number of expected crashes decreased.

4.3.1 V9Sum

V9Sum represents the nine-year sum (2002 to 2010) of vehicle miles traveled for a specific state. The estimated coefficient for this variable was 0.788515X10-6. The vehicle miles traveled sum was a large value, therefore a small coefficient was expected. The positive sign of the coefficient was intuitive, as more vehicle miles travelled implied greater exposure and a greater possibility of crashes. V9Sum was statistically significant at a 95% level.

4.3.2 Train

Train is a variable that describes whether or not officers of a state patrol agency received formal training in fatigue identification. This variable took a value of 1 if officers received training and 0 otherwise. The estimated coefficient in the model was -0.86683568. The negative sign implied a reduced number of fatigue-involved fatal crashes in a state where officers received formal training related to fatigue. The variable Train was statistically significant at a 95% confidence level.

4.3.3 PSA

The variable PSA describes whether or not a state patrol agency used public service announcements and driver education in their programs related to fatigued driving. This was a common, qualitative response to question six. The variable took a value of 1 if a respondent mentioned these programs and 0 if the respondent did not mention these programs. The estimated coefficient in the model was -0.23849687, the negative sign implying a reduction in the expected number of fatigue-involved fatal crashes in a state with such programs. Public service announcements and driver education may be effective means of improving safety. The magnitude of the coefficient was smaller than that of the variable Train. This designated a smaller crash reduction resulting from public service announcements than from officer training. PSA was statistically significant at a 75% confidence level.

4.3.4 Driving

Driving is a variable related to the qualitative answers to question nine (involving the procedure for stopping a vehicle when a driver was believed to be fatigued). Driving took a value of 1 if the respondent said that driving cues were used to determine whether a driver was fatigued during a stop. If this fact was not mentioned, Driving took a value of zero. The negative estimated coefficient (-0.65548262) in the model implied the expected number of fatigue-involved fatal crashes was reduced in states where patrol officers used driving cues to determine whether drivers were fatigued. Checking driving cues appeared to improve safety, possibly due to more officers correctly identifying fatigue and removing impaired drivers from the roadway. Driving cues had a smaller impact on safety than fatigue training programs, and a greater impact than public service announcements and driver education. This was exemplified by the magnitude of the coefficient. The variable Driving was statistically significant at the 95% level.

4.4 Review of Enforcement Techniques

With the data and resources available to this project, it was not possible to assess the effects of fatigue-related enforcement techniques and policies on non-fatal fatigue-involved crashes or on severity reduction among fatigue-involved crashes. Regardless, evidence of safety improvement in terms of fewer fatal fatigue-involved crashes was uncovered by the statistical model. Spreading awareness through public service announcements and driver education appeared to improve safety. Safety was also improved through training officers in fatigue identification. Finally, fatigue-related highway safety was improved when driving cues were taken into consideration by patrol officers.

Other techniques are commonly utilized across the country by state patrol agencies. In particular, driver interviews and driver behaviors are often utilized as part of the procedure to determine whether or not a driver is fatigued. Most respondents did not provide any extra information about how fatigue is determined during a driver interview. However, some mentioned specific cues, such as trouble articulating, slurred speech, mixing up words, watery or bloodshot eyes, yawning, and the ruling out of other types of impairment, e.g., drugs, alcohol, etc. These methods overlap with those found during the literature review.

Chapter 5 Future Research Plan

This chapter presents a research plan with the objective of developing effective means for the field measurement of driver fatigue using relatively easily observable characteristics. Tools to identify fatigued drivers on highways are needed as a step toward improving public safety. The research presented in this report has uncovered promising leads in developing such tools. However, more work is needed to identify and correlate easily observable characteristics to different levels of driver fatigue.

Findings from the literature review indicated several categories of factors that can be used for the identification of fatigue. However, only three categories hold promise for the development of means that patrol officers may effectively use in the field. These categories include physiological factors, driver facial characteristics, and steering cues. Factors from other categories, e.g., seat pressure from the in-vehicle category and driving workload from the driving times category, are either not practical for patrol officers, or are already in use for fatigue identification (e.g., workload assessment from drivers' log books).

Figure 5.1 provides a graphical representation of the plan to develop the necessary tools for the field identification of driver fatigue, as well as likely disciplines from which expertise would be needed. At the center of the plan is a tool kit for the field measurement of fatigue, which would be facilitated by expertise from the disciplines of law enforcement, medicine, and engineering. This kit might consist of paper or electronic forms for recording data, as well as devices for measuring a driver's physiological and facial characteristics.

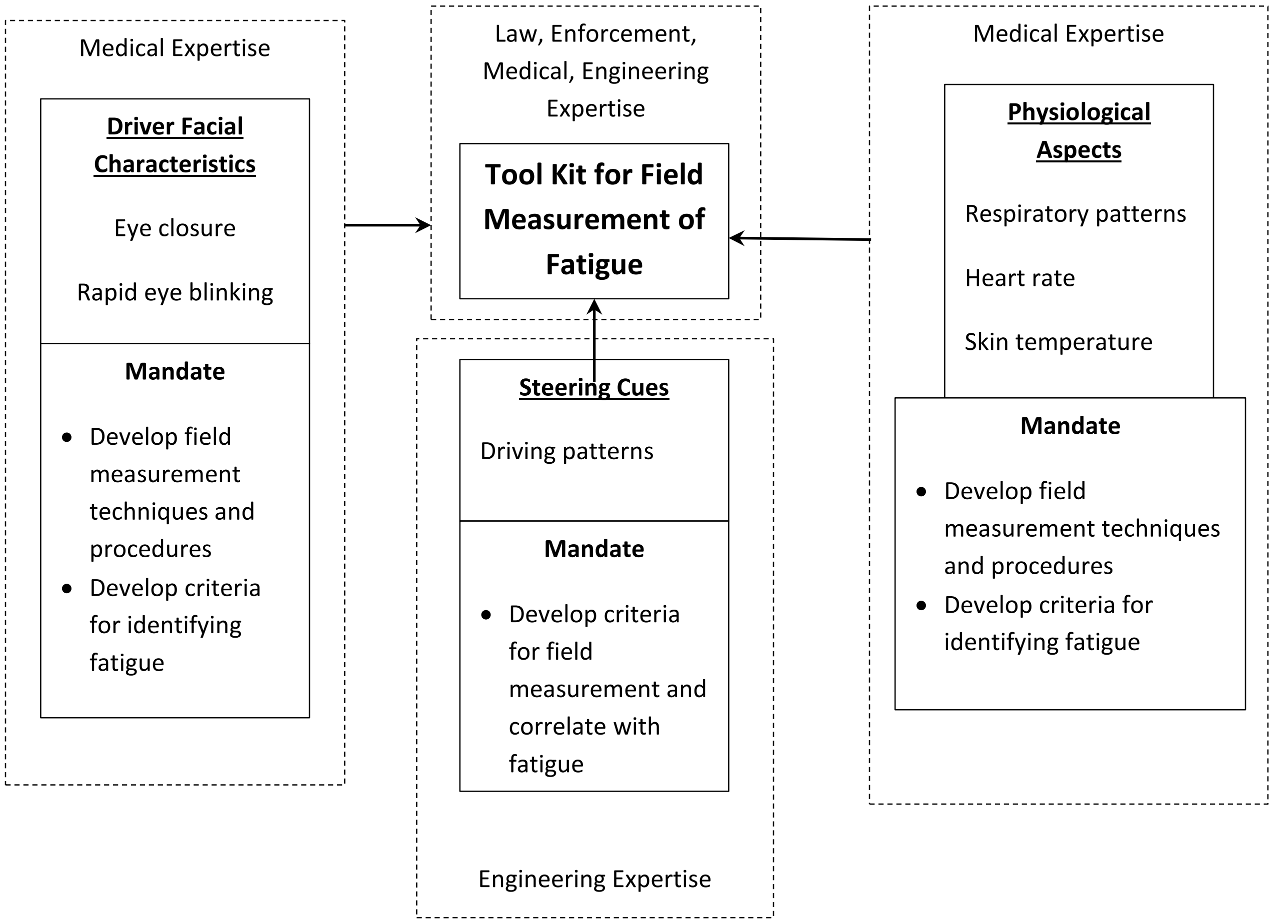

Figure 5.1 Graphical representation of plan to develop fatigue identification tools

The tools will be developed based on input from the three major categories of factors that published literature has shown to be effective means of fatigue identification. The first, driver facial characteristics, will mainly involve experts from the medical discipline, whose mandate will be to develop field measurement techniques and procedures for measuring drivers' eye-related features (e.g., blinking). This portion of the research will also involve the development of criteria for relating eye characteristics to different levels of fatigue. The second category, steering cues, will mainly require expertise from the engineering discipline, and will involve correlating driving patterns with different levels of fatigue.

The third category of factors providing input toward the development of fatigue measurement tools consists of drivers' physiological aspects, mainly requiring expertise from the medical discipline. This facet of the research will involve developing the means to measure respiratory patterns, heart rate, and skin temperature in the field, and associating these measured variables with different levels of fatigue.

Patrol officers will have the flexibility of using one or more means of fatigue identification from the tool kit. For example, if an officer wishes to use respiratory patterns to judge a driver's fatigue level, the officer could use the appropriate device, available in the tool kit, to measure a driver's respiration pattern and then relate it to some pre-determined level of fatigue. Alternatively, an officer could use steering cues by counting slow drifting of a vehicle, followed by quick corrective steering maneuvers per unit distance, and then relate the frequency of such maneuvers to a pre-determined fatigue level.

The plan for future research also includes examination of the practices of agencies that offer fatigue-related training for patrol officers, as well as analysis of the role of public service announcements in relation to fatigue driving. Any insights gleaned from this exercise will be useful for the development of standard operating procedures for dealing with possible cases of driving while fatigued, as well as for the development of training materials.

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Appendix A

Telephone Survey Instrument

The University of Nebraska-Lincoln is conducting a survey in partnership with the Nebraska State Patrol to find out how different state enforcement agencies deal with the issue of fatigued motor vehicle driving. The questions merely pertain to policies and procedures for your state. The information will be used to help us design a more effective strategy to deal with the issue of driver fatigue. Are you the best person to answer a few questions in this context?

[If yes] This survey should take less than 15 minutes and I am grateful for your assistance.

[If not the correct person] Who would be the best person to speak with?

1. Responding Agency:

2. Agency contact information:

Address ____

____

Phone: ____________________ Email: ____________________

3. Respondent Name:

4. Respondent contact information (if different from above):

Address ____

____

Phone: ____________________ Email: ____________________

5. Does your agency have published rules and regulations dealing with the issue of fatigue in commercial motor vehicle drivers?

1 Yes
2 No
3 Don't know

If yes, can I access it online or receive it via email or postal mail?

6. Does your agency have any specific program that deals with the issue of fatigued motor vehicle drivers?

1 Yes
2 No
3 Don't know

If yes, can I access it online or receive it via email or postal mail?

7. Do officers in your agency receive formal training about identifying fatigue in motor vehicle drivers?

1 Yes
2 No
3 Don't know

If yes, can I access it online or receive it via email or postal mail?

8. Do officers in your agency stop vehicles if they believe drivers are fatigued?

1 Yes
2 No
3 Don't know

9. What procedure is followed when an officer stops a driver believed to be fatigued?

10. How is fatigue determined to be an issue in a motor vehicle crash?

The next section of the interview asks questions concerning available statistics about commercial vehicle inspections and citations. I realize that you may not have these statistics readily available, so please let me know where I may be able to access the statistics.

11. How many commercial motor vehicle inspections were carried out in the last year for which statistics are available?

Number of inspections: ___________

Year of inspections: ___________ (e.g., 2011)

If not known, is there a website or other place where I can find information on citations?

12. How many citations were issued by your agency for fatigued driving (both commercial and non-commercial drivers) in the last year for which statistics are available?

If not known, is there a website or other place where I can find information on citations?

13. Of these, how many citations were to commercial motor vehicle drivers?

If not known, is there a website or other place where I can find information on citations?

14. How many of these citations were challenged in the court?

If not known, is there a website or other place where I can find information on the court challenges?

15. Of those that were challenged, how many were successfully prosecuted?

If not known, is there a website or other place where I can find information on the successful prosecutions?

16. How many highway crashes were attributed to fatigue in the last year for which statistics are available?

Number of fatigue-involved crashes: ___________

Year of those crashes: ___________ (e.g., 2011)

If not known to the respondent, is there a website or other place where I can find information on crashes involving fatigue?

That is all the questions I have. Thank you again for your help. If you have any questions about the how this information will be used you can contact Dr. Aemal Khattak of the University of Nebraska-Lincoln at 402-472-8126 or if you think of any other information or resources that will help us understand how this is handled in your state, please feel free to email [BOSR email].

Appendix B

Software Output For the Estimated Model

```
+---------------------------------------------+
| Negative Binomial Regression                |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 14, 2012 at 10:49:03AM.|
| Dependent variable               F9SUM      |
| Weighting variable                None      |
| Number of observations              45      |
| Iterations completed                 1      |
| Log likelihood function      -278.6038      |
| Number of parameters                 6      |
| Info. Criterion: AIC =        12.64906      |
|   Finite Sample: AIC =        12.69818      |
| Info. Criterion: BIC =        12.88995      |
| Info. Criterion:HQIC =        12.73886      |
| Restricted log likelihood    -2169.709      |
| McFadden Pseudo R-squared     .8715940      |
| Chi squared                   3782.211      |
| Degrees of freedom                   1      |
| Prob[ChiSqd > value] =        .0000000      |
| NegBin form 2; Psi(i) = theta               |
+---------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|   5.70376888      .25256314     22.584   .0000
 V9SUM   |  .788515D-06    .157835D-06      4.996   .0000   557910.178
 TRAIN   |  -.86683568       .23937758     -3.621   .0003    .80000000
 PSA     |  -.23849687       .20471158     -1.165   .2440    .17777778
 DRIVING |  -.65548262       .33040337     -1.984   .0473    .11111111
---------+Dispersion parameter for count data model
 Alpha   |   .28414342       .06562979      4.329   .0000
```