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IMPACT OF LOCAL/SHORT HAUL OPERATIONS ON DRIVER FATIGUE

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16. Abstract

Though they comprise the largest segment of the trucking industry, research involving local/short haul (L/SH) operations has been scant. In fact, little is known about the general safety issues in L/SH operations. As a precursor to the present research, Hanowski, Wierwille, Gellatly, Early, and Dingus (1998) conducted a series of focus groups in which L/SH drivers provided their perspective on safety issues, including fatigue, in their industry. As a follow-up to the Hanowski et al. work, the effort presented here consisted of an on-road field study where L/SH trucks were instrumented with data collection equipment. Two L/SH trucking companies and 42 L/SH drivers participated in this research. To the author's knowledge, this is the first in-situ data collection effort of its kind with L/SH drivers. The analyses focused on determining if fatigue is an issue in L/SH operations. Of primary interest were critical incidents (near-crashes) where drivers were judged to be at fault. The results of the analyses indicated that fatigue was present immediately prior to driver involvement in at-fault critical incidents. Though it is difficult to determine why fatigue was present, the results seem to indicate that much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job. The results of this research culminate in a set of guidelines to address fatigue and other safety issues in L/SH operations.

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Final Report

Impact of Local Short Haul Operations On Driver Fatigue

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ABSTRACT

The United States Department of Transportation (1996) lists a multitude of past research efforts and future research endeavors aimed at trucking operations. Despite comprising a smaller part of the trucking industry, the majority of this research has been directed at long-haul operations. Massie, Blower, and Campbell (1997) indicate that trucks that operate less than 50 miles from the vehicle's home base comprise approximately 58 percent of the trucking industry. However, despite being the largest segment of the trucking industry, research involving local/short haul (L/SH) operations has been scant. In fact, very little is known about the general safety issues in L/SH operations.

One of the few research efforts to investigate safety issues in L/SH operations was recently conducted by Hanowski, Wierwille, Gellatly, Early, and Dingus (1998). As a precursor to the present research, Hanowski et al. conducted a series of focus groups whereby L/SH drivers provided their perspective on safety issues, including fatigue, in their industry. As a follow-on to the Hanowski et al. work, the effort presented here consisted of an on-road field study where L/SH trucks were instrumented with data collection equipment. To the authors' knowledge, this was the first *in-situ* data collection effort of its kind with L/SH drivers. Data gathered from the drivers, as they worked their normal routes, were analyzed. For this research effort, the analysis focused on determining if fatigue is an issue in L/SH operations.

There are six basic outputs stemming from this research: (1) a description of the L/SH drivers who participated in the study and of their workday, (2) a description and categorization of "critical incidents," (3) a determination if fatigue is an issue in L/SH trucking using a five-factor analytical model, (4) an analysis focusing on critical incidents occurring while making lane changes and backing maneuvers, (5) the validation of the fatigue factors cited in Hanowski et al. (1998) using a proposed fatigue model, and (6) pragmatic guidelines to address fatigue and other safety issues in L/SH operations.

Based on the results of the statistical analyses that were conducted on a number of data sets collected during the field study, five guidelines are proposed. The first guideline pertains to driver education with regard to on-the-job drowsiness/inattention. Results from the data analysis

indicated that driver fatigue and inattention were over-represented to a statistically significant degree during an interval immediately preceding driver-at-fault critical incidents. The second guideline is directed at driver education with regard to sleep hygiene. The recommendation was made because the data from this study suggest that drivers who showed signs of fatigue, and were involved in a driver-at-fault critical incident, had less sleep and poorer quality sleep than drivers who did not show outward signs of fatigue. The third guideline is directed at improved driver training, particularly for novice L/SH truck drivers. This guideline was developed based on the numerous statistically significant findings showing that young age and inexperience were important factors in drivers being involved in critical incidents where they were judged to be at fault. The fourth guideline addresses the idea of driver screening whereby L/SH companies could identify unsafe drivers prior to hire. The results from the data collected here indicated that the majority of critical incidents were caused by very few drivers. The fifth, and last, guideline pertains to the public monitoring of L/SH driver performance. Similar to the practice instituted by many long-haul trucking companies, it is recommended that L/SH companies solicit feedback on L/SH driver performance from the general motoring public by using "how's my driving" stickers on the back of trucks. Though neither of the L/SH companies that participated in the field study used such stickers, drivers in the Phase I focus groups suggested that signs on the back of trailers are an effective way to communicate and interact with the motoring public.

Generally speaking, the results of this study found that drivers demonstrated characteristics of fatigue on the job. Because this was a field study, it is difficult to determine with certainty *why* fatigue was present. However, based on the results of multiple analyses that were conducted, it seems apparent that much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job. That is, poor sleep quantity/quality were prominent for drivers who demonstrated signs of fatigue on the job. Therefore, it is suggested that the off-duty behavior of the drivers was the primary contributing factor in the level of fatigue that was demonstrated during the workday. In addition, it is suggested that because of the sleep habits of those L/SH drivers who typically demonstrated fatigue on the job, these same drivers/workers would likely show fatigue on the job regardless of their profession.

EXECUTIVE SUMMARY

PROJECT OVERVIEW

The U.S. Department of Commerce's (1994) *Truck Inventory and Use Survey* (TIUS) provides definitions for the trucking industry based on "range of operation." Range of operation refers to the type of trip (e.g., distance traveled) in which the vehicle typically operates. TIUS does not provide a definition for local/short-haul operations per se; however, definitions are provided for local operations and short-range operations. A local range of operation is defined as an operation that makes trips less than 50 miles from the vehicle's home base. Short-range, or short-haul, involve trips between 50 and 100 miles from the home base. Based on these two definitions, local/short-haul (L/SH) operations can be defined as those that primarily engage in trips of 100 miles or less from the home base. To provide some perspective on this definition, long-haul operations, or those that likely come to mind when one thinks of "trucking," make trips that are over 500 miles or more from the home base.

The United States Department of Transportation (1996) lists a multitude of past research efforts and future research endeavors aimed at trucking operations. Despite comprising a smaller part of the trucking industry, the majority of this research has been directed at long-haul operations. Massie, Blower, and Campbell (1997) indicate that trucks that operate less than 50 miles from the vehicle's home base comprise approximately 58% of the trucking industry. However, despite being the largest segment of the trucking industry, research involving L/SH operations has been scant. In fact, very little is known about the general safety issues in L/SH operations.

The research that has been aimed at long-haul operations has focused on hours-of-service (HOS) regulations and driver fatigue. One reason for this focus is the work routine of long-haul drivers. That is, the primary task for long-haul drivers is operating the vehicle. As such, their workday consists mainly of sitting behind the wheel and driving. On the other hand, the workday tends to be more varied for L/SH drivers. For example, in addition to driving, a L/SH driver may receive the day's driving schedule, load and unload the vehicle, get in and out of the vehicle numerous times, lift and carry packages, engage in customer relations, and perform other miscellaneous tasks. For L/SH drivers, driving is only part of their daily work routine. In addition to different daily work routines, another major difference between long-haul and L/SH drivers is that L/SH drivers typically start and end their workday at their home base. This allows L/SH drivers to return to their homes after their shift and sleep in their own beds at night. Contrast this with long-haul drivers who may be on the road for several days or weeks at a time, who drive and sleep at irregular times, and who may sleep in the truck's cab or sleeper-berth during off-hours. Given the typical work routine of long-haul drivers, it is not surprising that HOS and driver fatigue have been research areas of focus. Because fatigue is such a prevalent research topic for long-haul operations, the question arises as to whether fatigue is also an issue in L/SH. Additionally, taking a more general perspective, it is important to gain a better understanding of what the safety issues are in L/SH operations.

To investigate these issues, a two-phased research effort was conducted (figure ES-1). As can be seen, Phase I involved focus groups that were conducted with L/SH drivers, while Phase II consisted of a field study in which L/SH trucks were instrumented with data collection equipment and driven by L/SH drivers as they worked their normal delivery routes. The next sections describe each research phase in more detail.

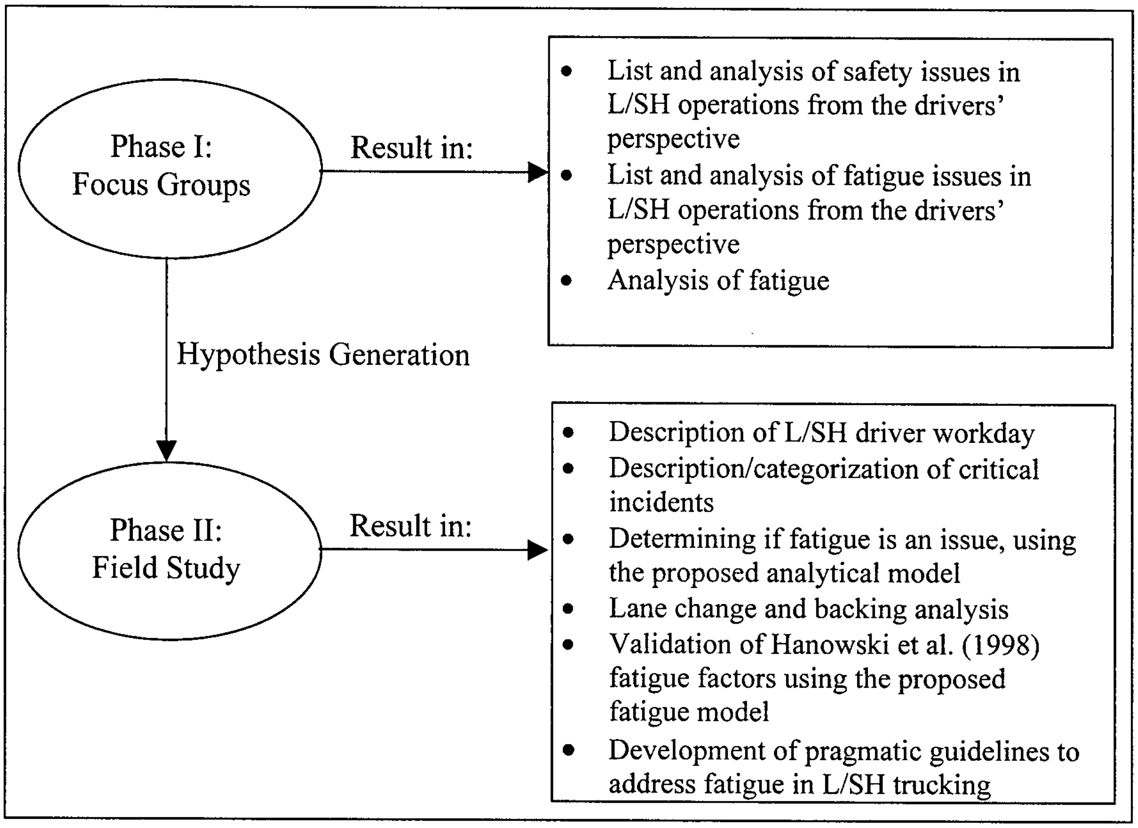

Figure ES-1. Project overview.

PHASE I: FOCUS GROUPS

Focus groups were conducted to gain an understanding, from the local/short haul (L/SH) drivers' perspective, of the general safety concerns related to L/SH trucking and, specifically, the degree to which fatigue plays a role. Eleven focus groups were held in eight cities, across five states. Eighty-two L/SH drivers participated. Much of the focus group activity involved discussions of critical incidents that drivers had either learned about or had personally experienced. One of the purposes of this discussion was to generate a list of causal factors that would highlight safety-critical issues in the L/SH industry. Across all sessions, the top five critical issues/causal factors, ranked in terms of importance, were: (1) Problems Caused by Drivers of Light Vehicles, (2) Stress Due to Time Pressure, (3) Inattention, (4) Problems Caused by Roadway/Dock Design, and (5) Fatigue.

After the drivers finished talking about general safety issues, the discussion then shifted to fatigue in L/SH operations. The drivers were asked to think about times when they have been fatigued on the job, and list the reasons why. Across all sessions, the top five fatigue-related issues, ranked in terms of importance, were: (1) Not Enough Sleep, (2) Hard/Physical Workday, (3) Heat/No Air Conditioning, (4) Waiting to Unload, and (5) Irregular Meal Times.

The findings from the focus group effort suggest that although drivers report that fatigue is an issue in L/SH trucking, they do not think is as critical an issue as it is in long-haul trucking. In discussing the impact of fatigue, drivers provided several reasons why fatigue is not as critical in L/SH as it is in long-haul. For example, unlike long-haul drivers, L/SH drivers typically work during daylight hours, have work breaks that interrupt their driving, end their shift at their home base, and sleep in their own beds at night. It appears that for L/SH drivers, fatigue results from a normal day's work and is impacted by their personal lives (e.g., not getting enough sleep at night). A thorough discussion of the Phase I focus groups is presented elsewhere (Hanowski, Wierwille, Gellatly, Early, & Dingus, 1998).

As indicated in figure ES-1, the results from the focus group effort led to the development of a field study and aided in the research design. For example, the finding that

"Drivers of Light Vehicles" was the primary safety issue listed by L/SH drivers in the focus groups led to the video camera arrangement that was used to record truck-car interactions.

PHASE II: FIELD STUDY

Phase II of this research, which is the focus of the current report, consisted of an on-road study where in-service L/SH trucks were instrumented with data collection equipment and driven by L/SH drivers. Both quantitative and qualitative data were collected and used to determine the safety issues in L/SH operations and the extent to which fatigue is an issue.

Two L/SH trucking companies participated in the field study. One company hauls beverages, while the other company hauls snack foods. Both trucking companies were paid for their participation. Two L/SH trucks from each company were instrumented with a variety of data collection equipment. Driver performance data were collected as the drivers drove the instrumented vehicles and worked their normal delivery routes. Forty-two L/SH drivers participated in the study. The average age of the drivers was 31. Each driver drove an instrumented truck for approximately two weeks. All drivers were volunteers and were paid for participating.

To investigate safety issues in L/SH operations, including fatigue, the data collection equipment was designed to capture "critical incidents." Briefly, critical incidents are defined as near-crash events. The analysis phase of the project was directed at driver performance associated with critical incidents. Data used in the analysis were collected from three general sources: (1) truck instrumentation, (2) questionnaires, and (3) wrist activity monitors. Regarding the truck instrumentation, data were collected either directly from the equipment (e.g., forward velocity, lateral acceleration, and braking sensors), or by means of an analyst reviewing composite-image video tapes of the driver and the driving environment. For the questionnaires, drivers completed demographic forms, and pre- and post-shift questionnaires. Finally, the wrist activity monitors were used to collect physiological data on driver sleep quantity and sleep quality.

Referring to figure ES-1, it can be seen that there are six outputs stemming from the Phase II research: (1) a description of the L/SH driver workday, (2) a description/categorization of critical incidents, (3) a determination if fatigue is an issue in L/SH operations, (4) a lane change and backing analysis, (5) validation of the focus group results, and (6) the development of pragmatic guidelines aimed at reducing L/SH driver-at-fault critical incidents. Each of these outputs are discussed in detail in the body of the report.

As suggested, the results from this study culminate in a set of guidelines aimed at reducing the frequency with which L/SH drivers are involved in at-fault critical incidents (i.e., critical incidents where the L/SH driver is judged responsible). Highlighted below are some of the main study findings, followed by the set of proposed guidelines.

Field Study Main Findings

1. The data set contained 249 critical incidents, with 137 attributed to "other" drivers, 77 attributed to the L/SH drivers, 20 attributed incidents in which the L/SH driver was not involved (except as an observer), and 15 in which the L/SH driver responded to another type of situation, such as an animal in the road.
2. Fatigue was determined to be a contributing factor in 20.8 percent of the incidents where the L/SH driver was judged to be at fault.
3. When L/SH drivers were at fault in critical incidents, their PERCLOS values prior to the incidents were significantly higher than for other types of critical incidents. (PERCLOS is a validated indicator of driver drowsiness based on slow eyelid closure.)
4. When L/SH drivers were at fault in critical incidents, their OBSERV values prior to the incidents were significantly higher than for other types of critical incidents. (OBSERV is a validated indicator of driver drowsiness based on an observer rating of drowsiness, as determined by facial expression.)
5. Younger and less experienced drivers were significantly more likely to be involved in critical incidents than were older and more experienced drivers. In addition, younger and less experienced drivers exhibited higher on-the-job drowsiness. These results

were demonstrated both for PERCLOS as the measure of drowsiness and for OBSERV as the measure of drowsiness.

6. Drivers tended to be involved in fatigue-related incidents earlier in their workweek. There were no fatigue-related critical incidents after the fourth day of the workweek.
7. Of the 77 incidents that were attributed to the 42 L/SH drivers, 2 drivers (4.8 percent of the driver participants) accounted for 25.97 percent of the incidents, and 8 drivers (19.05 percent of the driver participants) accounted for 59.74 percent of the incidents. Put another way, the majority of driver-at-fault critical incidents involved a minority of the participating drivers.
8. Of the 77 incidents that were attributed to the L/SH drivers, 13 (17 percent) involved running a late-yellow or red light.
9. 15.4 percent of the lane change critical incidents had drowsiness as a contributing factor. This compared to 6.9 percent for non-critical incident lane changes.

Based on the results of this study, five guidelines are proposed that are aimed at reducing critical incidents that are caused by L/SH drivers. Because this project focuses on driver fatigue, two of the five guidelines highlight results relating to fatigue.

Guideline 1: Driver Education with Regard to On-the-Job Drowsiness/Inattention

L/SH companies should encourage drivers to monitor their level of drowsiness and inattention and should make them aware of strategies to reduce drowsiness and inattention. L/SH companies should institute policies that allow drivers to recover from fatigue/inattention without reprimand. Driver fatigue and inattention were found, to a statistically significant degree, during the interval preceding driver-at-fault critical incidents. It is recommended that L/SH drivers should be educated on the dangers of driving fatigued and should be encouraged to remedy such situations before continuing to drive.

Guideline 2: Driver Education with Regard to Sleep Hygiene

L/SH drivers should be encouraged to come to work well-rested. It is suggested that most people have felt the fatiguing effects of not getting enough sleep. However, most have not had to operate a heavy vehicle with less-than-adequate rest. L/SH drivers should be trained with respect to the hazards of operating heavy equipment when tired and reminded that sufficient sleep at night will reduce fatigue during the day. The data from this study suggest that drivers who show signs of fatigue, and are involved in an at-fault critical incident, had less sleep and poorer quality of sleep than drivers who do not show outward signs of fatigue. The findings certainly agree with the common sense notion that sleep quantity and sleep quality influence the level of fatigue experienced the next day.

Guideline 3: Driver Training

A mandatory driver training program should be set up for all younger and/or inexperienced drivers. At a minimum, training programs should be carried out by individual L/SH companies for their drivers. Consideration should also be given to requiring all L/SH drivers to obtain special licenses to operate L/SH trucks. It is suggested that because the level of difficulty is arguably greater in operating a L/SH vehicle when compared to a passenger vehicle, a training/licensing/permit program should be implemented in order to educate young/inexperienced drivers who are unfamiliar with operating a larger vehicle. The impetus for this recommendation is the prominent involvement of younger/inexperienced drivers in at-fault critical incidents (see figure 41). In addition, though research has yet to investigate it, it is hypothesized that younger truck drivers may be over-represented in crashes in a similar fashion to their younger passenger vehicle driver counterparts (Cirelli, 1992).

Guideline 4: Driver Screening

A driver screening program should be in place within L/SH companies so that unsafe drivers can be identified prior to being hired. The results of this research found that the majority of critical incidents were caused by very few L/SH drivers. Further research is required to determine methods to identify unsafe drivers. Suggested research would closely examine common characteristics of unsafe drivers. For example, it is hypothesized that unsafe and improper driving of passenger vehicles is likely to be correlated with unsafe and improper driving of L/SH vehicles. As such, screening should include, if it does not already, consideration of a driver's passenger vehicle record.

As a further means of screening for unsafe drivers, consideration should be given to implementing on-board safety monitoring devices in commercial vehicles. This idea is similar to that suggested elsewhere (Knipling and Olsgard, 2000) where real-time in-vehicle displays of driver alertness levels (i.e., "alertometers") are present in the truck cab. Taking this idea one step further, data on driver alertness, as well as other measures of driver performance such as speed, headway, and lateral acceleration, could be collected and used to identify, and screen for, unsafe L/SH drivers. These monitoring devices can be thought of as "black box" systems, installed in the L/SH vehicle, that monitor and record driver performance. Knipling and Olsgard (2000) note that one such system, called the Accident Prevention Plus™, is currently being tested.

Guideline 5: Public Monitoring of L/SH Driver Performance

It is suggested that companies should consider implementing a program whereby the general public has a way to report drivers who drive safely and do not drive safely. This suggestion follows the practice implemented by many long-haul trucking companies where a "how's my driving" sticker is placed on the back of the truck. The sticker has a phone number for the public to call. Though not based on any of the results from the field study, some drivers who participated in the focus groups mentioned that they have such stickers on their trucks. The drivers in the focus groups also suggested that signs on the back of trailers would be an effective way to communicate with the motoring public. Neither of the companies that participated in the field study had signs or stickers on their trucks or trailers.

SUMMARY

The current report provides much needed data on safety-issues in L/SH trucking, an industry that, up until now, has been neglected by the research community. Specifically, this report provides:

- Detailed descriptions of L/SH drivers and their workdays.
- A breakdown of the various critical incidents that were recorded.
- A thorough analysis to determine if fatigue is evident is L/SH operations.

- The results of analyses directed at lane change and backing events. Note that these analyses are directed at both critical incidents and non-critical incidents (i.e., "normative" driving).
- A comparison of the focus group results with data collected in the field.
- Guidelines aimed at reducing the involvement of L/SH drivers in at-fault critical incidents.

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INTRODUCTION

A substantial amount of research has been aimed at trucking operations. In the *Federal Register*, the U.S. Department of Transportation (1996) outlines the recent trucking-related research efforts sponsored by the Federal Highway Administration (FHWA). Much of this research has been, or is being, directed at long-haul trucking and is concerned with hours-of-service (HOS) and driver fatigue. The *Federal Register* indicates that the first research that investigated HOS was performed in the late 1930's. After 60 years, HOS research is still on going. For example, the Walter Reed Army Institute of Research and the University of Michigan Transportation Research Institute are both currently conducting separate research efforts related to HOS (United States Department of Transportation, 1997).

Given that HOS and driver fatigue have been the two primary research areas related to the trucking industry, the trucking operation of most interest has been long-haul operations. As will be detailed later, long-haul operations are those that most likely come to mind when one thinks of "trucking." Long-haul truckers are those who typically drive 18-wheel tractor-trailer units and are on the road for an extended period of time. These are the drivers for whom the HOS regulations were designed. Despite long-haul trucking being the type of operation that tends to define trucking, local/short haul (L/SH) operations are more prevalent. However, despite the fact that there are substantially more L/SH operations than long-haul operations, very little research has gone into examining L/SH safety issues.

The general goal of this research is to determine, through the collection of on-road data, the impact of L/SH trucking operations on driver fatigue. As will be discussed, this research is a follow-up to an earlier phase of this research project (Hanowski, Wierwille, Gellatly, Early, Dingus, 1998). In this earlier phase, subjective data were collected from L/SH drivers to gain their perspective on safety and fatigue issues in their industry. In the research presented here, objective and subjective data were collected to further investigate safety and fatigue in L/SH trucking.

Before detailing the purpose of this data collection effort, it is worthwhile to outline some of the background information on this topic. By developing this background, it is believed that the rationale for conducting this research will become apparent. There are eight main sections that comprise the background information. Specifically, the background information will:

1. Define trucking operations and outline the differences between long-haul and L/SH operations.
2. Outline the safety and fatigue issues prevalent in the trucking industry.
3. Describe the Phase I focus group study (Hanowski et al., 1998) that lead to the Phase II field study.
4. Provide a rationale for the use of field data collection, which was the chosen methodology for this research.
5. Describe how data have been collected efficiently in transportation safety research by targeting near-accidents and critical incidents.
6. Revisit the factors of driver fatigue outlined by Hanowski et al. (1998) and present a research model that is used to validate these factors. In addition, an analytical model is presented that is used to help answer the question, "is fatigue an issue in L/SH trucking?"
7. Outline the problem statement for this effort and the research questions being addressed.

DEFINING TRUCKING OPERATIONS

The 1992 version of the U.S. Department of Commerce's (1994) *Truck Inventory and Use Survey* (TIUS) provides definitions for the trucking industry based on "range of operation." Range of operation refers to the type of trip (e.g., distance traveled) in which the vehicle typically operates. As shown in table 1, TIUS has seven truck operation classifications based on range of operation. TIUS also classifies trucks based on their size or average vehicle weight (e.g., light, medium, heavy) and by their operator's status (e.g., not-for-hire, for-hire, daily rental, mixed). For the purpose of this research, the classification scheme of most relevance is range of operation.

Table 1. Trucking operation classification scheme based on range of operation. Data from U.S. Dept. of Commerce (1994).

Range of Operation	Definition
Local	Less than 50-miles from vehicle's home base.
Short Range	Trips between 50 and 100 miles from vehicle's home base.
Short Range-Medium	Trips between 100 and 200 miles from vehicle's home base.
Long Range-Medium	Trips between 200 and 500 miles from vehicle's home base.
Long Range	Trips beyond 500 miles from vehicle's home base.
No Home Base	Vehicle not operating from a home base.
Off-the-Road	Minimal use of public roads (usually involves construction or farming).

Long-Haul Operations

When one thinks of "trucking," the image that first might come to mind may be of 18-wheel semi-tractor trailers cruising the highway and hauling goods over long distances. This image would describe a typical long-haul (or long-range) trucking operation. As indicated in table 1, long-haul operations are defined as those that make trips that are over 500 miles from the vehicle's home base. Because the distances traveled in long-haul operations are so great, large articulated trucks (i.e., tractor-trailer) are typically used.

The primary task of long-haul drivers is, not surprisingly, operating the vehicle. Some long-haul drivers will pick up a load of goods (that may be loaded for them) by hooking the trailer to the tractor, driving to a destination, and then unhooking the load. In some operations, long-haul drivers will make one delivery at their destination and one delivery on the return trip. Based on the task routine of many long-haul operations, it is often referred to as "hook-and-drop." Therefore, the task of the long-haul driver is, for the most part, to drive the truck. (This point becomes important later when discussing the different safety issues inherent to long-haul and local/short-haul drivers.)

Local/Short Haul Operations

TIUS does not provide a definition for local/short-haul operations per se; however, definitions are provided for local operations and short-range operations. A local range of operation is defined as an operation that makes trips less than 50 miles from the vehicle's home base. Short-range, or short-haul, involve trips between 50 and 100 miles from the home base. Based on these two definitions, local/short-haul (L/SH) operations can be defined as those that primarily engage in trips of 100 miles or less from the home base. It is important to include the term "primarily" in this definition since many trucking companies routinely mix trucking operations consisting of local, short-range, medium-range, and long-range trips.

Though the concept of "trucking" may be most associated with long-haul operations, most vehicles in the trucking industry are of the L/SH variety. As shown in table 2, local operations account for 73.3 percent of all trucks in operation, while short-range operations account for 16.5 percent. Contrast this with long-haul operations, which account for 4.6 percent of trucks, and it becomes evident that L/SH operations comprise, by far, the largest segment of the trucking industry (i.e., roughly 90 percent). Note that this data *does* include light trucks. A more representative estimate of the number of L/SH trucks can be found in Massie, Blower, and Campbell (1997), who indicate that of the large truck population (light trucks excluded), trucks that operate under 50 miles from the vehicle's home base represent approximately 58 percent of the trucking industry.

Table 2. Number of trucks per range of operation. Data from the U.S. Department of Commerce (1994).

Range of Operation	Trucks Registered in 1992 (thousands)	Percentage of Industry
Local	1,111.4	73.3%
Total Short Range	250.3	16.5%
Short Range	194.2	12.8%
Short Range-Medium	56.0	3.7%
Total Long Range	69.0	4.6%
Long Range-Medium	37.7	2.5%
Long Range	31.3	2.1%
Off-the-Road	85.6	5.7%

To get a better picture of the L/SH industry, it is worthwhile to explore what types of cargo L/SH trucks haul. Jim York (personal communication, March 28, 1997) of the National Private Truck Council has developed a taxonomy that outlines the types of hauling involved in L/SH operations. This taxonomy is shown in table 3. As can be seen, L/SH trucks haul a variety of goods. It must be noted that the type of goods hauled does not differ, to any great extent, from goods hauled by other ranges of operation. The only difference that there might be is in hauling highly perishable goods. For example, one might postulate that there might be more L/SH carriers than long-haul carriers involved in hauling goods such as dairy products.

Table 3. L/SH industry taxonomy from Jim York (personal communication, 3/28/97).

Classification	Example Companies
I: For-hire	U-Haul
Parcel Delivery	United Parcel Service
Drayage or cartage	Estes Trucking
II: Private industry	
A. Construction & Mining	
1.Building/General Contractors	Hartford Concrete Products
2.Road/Utility Contractors	VDOT
B. Retail & Wholesale Delivery	
1. Retail	
i. Department/General Merchandise Store	Wal-Mart Stores, Inc.
ii. Hardware/Lumber/Building Materials	Payless Cashways, Inc.
iii. Pharmacies/Drug Stores	Eckerd Drug Company
iv. Furniture/Household Durables	Heilig-Meyers Furniture

v. Newspaper/Books	Chicago Sun Times
vi. Office	Staples Office Products
2. Wholesale	
i. Paper	Paper Corporation of America
ii. Hardware/Lumber/Building Materials	Cotter and Company
iii. Medical Supplies/Equipment	Baxter Healthcare
iv. Truck/Auto Repair	South Main Auto Service
C. Lease/Rental	Ryder Dedicated Logistics
D. Food/Food Distribution	
1. Agriculture	Green Products Company
2. Food Processing	Smithfield Foods
3. Processed Goods	
i. Dairy	Borden, Inc.
ii. Baked Goods	Pepperidge Farms, Inc.
iii. Candy/Confections	Russel Stover Candies, Inc.
iv. Poultry	Perdue Farms, Inc.
4. Beverages	
i. Wineries	Gallo Wineries
ii. Breweries	Anheuser-Busch Co. Inc.
iii. Soft Drinks	Coca-Cola Bottling Co.
5. Food Wholesalers	US Foodservice
6. Food Service Distributors	Domino's Pizza
7. Retail Grocery/ Convenience Stores	Giant Food, Inc.
E. Manufacturing & Processing	
1. Farm/Agricultural Equipment	Case Corporation
2. Machinery/Industrial Equipment	The Gates Rubber Co.
3. Automobiles/Trucks/Vehicle Parts	Eaton Corporation
4. Garden Equipment/Supplies	The Scotts Company
5. Clothing/Fabrics/Textiles	Lee Apparel Company, Inc.
6. Plastics/Rubber	Oliver Rubber Company
7. Building Materials (Non-wood)	Senco Products
8. Paper/Forest Products	Ailing and Cory Company
9. Furniture/Household Durables	Ashley Furniture Ind., Inc.
10. Glass	American Flat Glass
11. Metal/Steel	Lone Star Steel Company
12. Appliances/Electrical Products	Circuit City Stores, Inc.
F. Petroleum and Chemicals	
1. Oil/Petroleum Products	
i. Manufacturer	B. P. Oil Company
ii. Wholesale/Retail	CITGO Petroleum Co.
2. Industrial Gases	B.O.C. Gases
3. Chemicals	Occidental Chemical Corp.
G. Sanitation & Refuse	BFI
H. Other Services	
1. Landscaping/Lawn/Tree Maintenance	Davey Tree Expert Co.
2. Home Improvement/Repair/Maintenance	NRV Construction Co.
3. Commercial Building Services	Hill-Thomas Builders, Ltd.
4. Printer/Mailing Services	Print Pack, Inc.
5. Vehicle Repair Services	Shelor Automotive
6. Airline Support	Signature
III. Private Type	
A. Government	
1. Federal	U.S. Postal Service

2. State	VDOT
3. Local	Town of Blacksburg
B. Public Utility	Public Works Dept.
C. Schools	Montgomery County Public Schools
D. Buses	Blacksburg Transit

The tasks of L/SH drivers are typically more extensive and varied than the task responsibilities of long-haul drivers. The primary task for long-haul drivers is driving, and long-haul drivers may make only one delivery in a single trip. Contrast this with L/SH drivers who typically make multiple deliveries in a single trip. In addition to driving, L/SH drivers typically perform a variety of tasks. For example, during the course of a day, a L/SH driver may receive the day's driving schedule, load and unload the vehicle, get in and out of the vehicle numerous times, lift and carry packages, engage in customer relations, and perform other miscellaneous tasks. For L/SH drivers, driving is only part of their daily work routine.

Another major difference between long-haul and L/SH drivers is that L/SH drivers typically begin and end their day at their home base. This allows L/SH drivers to return to their homes after their shift and sleep in their own beds at night. In contrast, long-haul drivers may be on the road for several days or weeks at a time, may drive and sleep at irregular times, and may sleep in the truck's cab or sleeper-berth during off-hours.

Contrast of Long-Haul vs. Local/Short Haul

Several differences between long-haul and L/SH operations were highlighted in the previous section. To get a better understanding of these differences, it is worthwhile to detail the tasks performed by long-haul drivers and compare these to the tasks performed by L/SH drivers. Jim York (personal communication, March 28, 1997) has explored this topic in some detail and has outlined these differences. Table 4 provides a breakdown of the on-duty cycles of long-haul and L/SH drivers in the beverage industry. As can be seen, aside from driving a truck, the tasks performed by these two groups of drivers vary substantially. The next section discusses how these task differences relate to different safety issues for each group of drivers.

Table 4. Contrast of the on-duty cycles of long-haul and L/SH drivers in the beverage industry. Data from Jim York (personal communication, 3/28/97).

Typical On-Duty Cycle of Long-Haul Driver in the Beverage Industry	Typical On-Duty Cycle of L/SH Driver in the Beverage Industry
Arise from sleeper-berth at 5:00 AM.	Report to work at 5:00 AM and review daily route assignment sheet.
Perform pre-trip inspection and update record of duty status (logbook).	Inspect beverage bays to ensure the proper loading of product.
Drive 50-100 miles to consignee's delivery facility.	Correct any product shortages or overages.
Notify consignee of shipment arrival and provide appropriate shipping papers.	Conduct pre-trip vehicle inspection.
Supervise unloading of the vehicle.	Complete necessary pre-trip paperwork.
Obtain load delivery receipt from consignee and complete appropriate paperwork.	Drive 15-30 miles to first delivery stop (e.g., small grocery or convenience store).
Drive 30-50 miles to beverage bottling facility.	Check route assignment sheet to verify quantity and type of requested delivery.
Provide order information to beverage shipping department.	Unload product from beverage bays onto two-wheel cart.
Supervise loading of the vehicle and ensure load is adequately secure.	Rotate display stock as required.
Obtain shipping papers and complete appropriate paperwork.	Place delivered product on display shelves.
Drive 300-400 miles to beverage distribution facility or to the end of a ten-hour duty cycle.	Collect recycled cans and bottles and load in appropriate truck bay.
Notify consignee of shipment arrival.	Complete sales invoice and give copy to customer.
Supervise the unloading of the vehicle.	Drive on; perhaps three miles to next stop.
Update record of duty status and end of shift at approximately 6:00 PM.	Repeat steps 7-13 for the balance of assigned route (e.g., 30-50 stops per on-duty cycle is not uncommon).
	Drive 30-50 miles back to terminal.
	Unload recycled containers, and empty pallets/waste from beverage bays.
	Assist in reloading as necessary (Note: many beverage operations have dedicated crews to reload these vehicles during the evening hours. However, the driver may perform some or all of the reloading in some instances.)
	Complete daily route summary and other required paperwork.
	Depart for home sometime after 6:00 PM.

SAFETY ISSUES IN TRUCKING

Much of the research that has involved safety in the trucking industry has been directed at long-haul operations. Specifically, this research has primarily focused on HOS, fatigue, and the implications of driving for long distances over extended periods of time. Recall from table 4 that the primary task for long-haul drivers is driving. Add to this that the driving task may follow a night's sleep in the cab or sleeper berth of a truck, and it seems logical to assume that long-haul drivers who follow the on-duty cycle as shown in table 4 may not be well rested before beginning their workday. As such, the focus on fatigue in long-haul trucking has been well founded. Research in the L/SH industry, on the other hand, has been very limited. In fact, only a handful of studies exist. The two sections that follow will, first, highlight a select set of studies related to the long-haul industry and, second, describe the available L/SH-specific research that is related to driver safety.

Long-Haul Research

As indicated, fatigue (and the related topic of HOS) has been the primary area of focus for research related to safety in the trucking industry (e.g., Beilock, 1995; Mackie & Miller, 1978; National Transportation Safety Board, 1995). Statistics indicate that in 1998, 412,000 large trucks were involved in traffic crashes in the U.S. (USDOT, FMCSA, 2000). Though it is difficult, if not impossible, to determine the true extent that fatigue is a causal factor in these crashes, researchers have suggested that fatigue may be involved in as many as 56 percent of all traffic crashes in the U.S. (Mitler, Miller, Lipsitz, Walsh, and Wylie, 1997).

Recent research by Mitler et al. (1997) closely examined the problem of fatigue in trucking. In their study, the researchers gathered electrophysiologic and performance-related measurements for 24-hour intervals on four groups of truck drivers. Each group had 20 male drivers. Four demanding long-haul driving schedules were compared. Two of these schedules involved 10-hours (U.S. regulations) of day driving, while the other two schedules involved 13-hours (Canadian regulations) of late-night-to-morning driving. The results of this research indicated that drivers averaged 5.18 hours in bed per day (i.e., 24-hour period) and 4.78 hours of electrophysiologically verified sleep per day. For drivers on the 13-hour night driving schedule, the mean hours of sleep was 3.83 hours. For drivers on the 10-hour daytime driving schedule, the mean hours of sleep was 5.38 hours. These actual sleep times were compared to drivers' own self-reported ideal amount of sleep, which was 7.1 ± 1 hours. Forty-four percent of the drivers supplemented their sleep with naps. These naps ranged from approximately 30 minutes to 45 minutes. There were no incidents of crashes during the study. More than half of the drivers experienced at least one six-minute interval of drowsiness while driving.

Based on the Mitler et al. (1997) findings, it is not surprising, due to the work/sleep routine of long-haul drivers, that fatigue has been an issue in the long-haul industry. It might be expected that the monotony of long-haul driving, coupled with a lack of quality sleep, would lead to driver fatigue. Wylie, Shultz, Miller, Mitler, and Mackie (1996) cited this factor as an important issue. In a technical report for the Federal Highway Administration, Wylie et al. (1996) provided an overview of the conclusions that have been drawn from the literature regarding fatigue in long-haul trucking. These conclusions are summarized as follows:

- Though drowsiness/fatigue are noted on police accident reports, it is believed that fatigue may be under-reported and may play a significant role in injury/fatality accidents.
- Driver fatigue can be defined as including time-correlated deterioration in driving performance, physiological state of arousal, and subjective feelings of sleepiness.
- Driver fatigue is believe to lead to increases in:
    - lapses of attention,
    - INFORMATION PROCESSING AND DECISION MAKING TIME,
    - reaction time to critical events,
    - SUBJECTIVE FEELINGS OF FATIGUE.
- Driver fatigue is believed to lead to decreases in:
    - motivation to sustain performance,
    - psychophysical arousal,
    - vigilance,
    - alertness.
- Driver fatigue is believed to lead to more variable and less effective control responses.
- Primary causes of driver fatigue include time-on-task, circadian low points, and sleep debt.
- In trucking, fatigue is associated with:
    - rotating schedules,
    - team sleeper operations,
    - monotonous driving environments,
    - driving in darkness,
    - adverse weather,
    - alcohol and drugs,

- physical work,
- noise, vibration, and heat.

In furthering the understanding of truck driver fatigue, Wylie et al. (1996) conducted research in which their goal was to establish quantitative relationships between fatigue and driving-related task proficiency (i.e., decrease in proficiency). The three primary independent variables of interest were (1) time-on-task, (2) driving-cycle start time (time-of-day), and (3) amount of sleep. Though the first two independent variables, time-on-task and start time, were varied, the amount of sleep obtained was measured but not manipulated. Participants in the study drove a loaded tractor/trailer on the open road. The driving schedules were either a 10-hour driving schedule or a 13-hour driving schedule. Each driver drove a pre-determined route for one week. A number of driving performance measures were collected, including lane tracking, steering wheel movement, speed, and distance traveled. Other cognitive and psychomotor performance tests were also conducted during the data collection phase. In addition, video data of the driver's face and of the road were collected. The main purpose of the video data was to obtain subjective researcher opinions of driver drowsiness as per Wierwille and Ellsworth (1994). Physiological measures of fatigue were also collected, including body temperature, polysomnography, and quantitative EEG.

The results of this research indicated that the most important factor affecting fatigue was time-of-day due to circadian rhythm effects. That is, fatigue was most prevalent during late evening and at night (midnight to dawn). Time-on-task, or driving duration, was not found to be as important a factor as time-of-day. Though a strong relationship was found between time-on-task and self-ratings of fatigue, no obvious performance decrements were found. The authors note that this finding should not dismiss time-on-task as irrelevant. However, they do suggest that time-on-task is probably not as important as time-of-day.

The results also suggested a cumulative effect of fatigue across days. That is, there was evidence to suggest that fatigue was more prevalent during the last days of driving. During the course of the study, it was determined that drivers averaged 4.8 hours of sleep per sleep period. This compared to their self-reported ideal amount of sleep of 7.2 hours (as an aside, this result is consistent with the 7.1$\pm$1 hours of sleep reported by Mitler et al., 1997). The authors suggest that this "sleep debt" may have lead to the finding that fatigue was most prevalent during the last days of driving. Though sleep quantity was found to be low, the quality of sleep, as measured by "sleep efficiency" (sleep time/time-in-bed), was high.

Local/Short-Haul Research

As noted, unlike long-haul drivers where the primary task is driving, L/SH drivers perform a variety of tasks. As listed in table 4, these tasks include, but may not be limited to, receiving the day's driving schedule, driving, loading and unloading the vehicle, getting in and out of the vehicle numerous times, lifting and carrying packages, and engaging in customer relations. For L/SH drivers, driving is only part of their daily work routine.

Another major difference between long-haul and L/SH drivers is that L/SH drivers typically begin and end their day at their home base. This allows L/SH drivers to return to their homes after their shift and sleep in their own beds at night. Contrast this with long-haul drivers who may be on the road for several days or weeks at a time, who drive and sleep at irregular times, and who may sleep in the truck's cab or sleeper-berth during off-hours. As indicated in the previous section, the typical long-haul truck driver's work/sleep cycle is apt to result in fatigue. Also, as previously indicated, perhaps the biggest causal factor of fatigue is working at night. Unlike long-haul driving, L/SH drivers typically work daytime hours. As such, we might hypothesize that fatigue may be less problematic for L/SH drivers.

The literature on L/SH operations is scant. In fact, a literature review for research specific to L/SH operations found only two published efforts. Because these efforts were recently conducted/published, it suggests that safety issues in L/SH operations have generally not received emphasis.

Massie, Blower, and Campbell (1997) conducted research on the L/SH trucking industry. There were two primary objectives of their research. The first objective was to develop a definition of "short-haul" trucks. The second objective was to determine the prevalence of driver fatigue in short-haul trucking. The research effort involved reviewing truck databases for relevant information. To this end, three databases were used: the Truck Inventory and Use Survey (TIUS), the Trucks Involved in Fatal Accidents (TIFA) file, and the SafetyNet file. Based on a review of these databases, several alternative definitions for "short-haul" were developed and consisted of: (1) Class 3-6 single-unit straight trucks in local service, (2) Class 3-6 single-unit straight trucks, and (3) Local service trucks.

As noted previously, the work/sleep cycles of long-haul vs. L/SH drivers are such that one might hypothesize that fatigue would not be an issue for L/SH drivers to the extent that it is for long-haul drivers. In the research conducted by Massie, Blower, and Campbell (1997), an attempt was made to determine the prevalence of driver fatigue in L/SH operations. In their research, they compared crash data for different types of trucking operations. One finding that echoed one of the Wylie et al. (1996) results was that the distributions of fatigue-related involvement in fatal and injury crashes peaked in the early morning hours. Massie, Blower, and Campbell found that fatal crashes involving fatigue were highest from 4-7 AM, and less severe crashes peaked from 3-7 AM.

In further analysis of the crash data, Massie, Blower, and Campbell (1997) examined fatigue-related fatal crashes as a function of intended trip distance. In the crash-data sample that they used, they found that driver fatigue was a causal factor in 0.4 percent of fatal crashes for trucks making trips of 50 miles or less and 3.0 percent for trucks making longer trips. Recall that the U.S. Department of Commerce's (1994) definition of local trucking operations is "less than 50-miles from vehicle's home base." Based on this finding, it appears that fatigue is likely to be a more important issue in long-haul as compared to local operations. Note that this result does not imply that fatigue is a non-issue in L/SH. Rather, it merely suggests that fatigue is likely a more important issue in long-haul.

A second study directed at the L/SH industry involved researchers administering a cross-sectional questionnaire to 317 package truck drivers (i.e., L/SH drivers) (Orris, Hartman, Stauss, Anderson, Collins, Knopp, Xu, & Melius, 1997). The drivers who participated in this study worked out of distribution centers in New Jersey, Wisconsin, Texas, and California. Each participant was given a packet that included six self-administered questionnaires. Each of the questionnaires was related to stress in one way or another. The questionnaires consisted of: (1) the Symptom Checklist, which reflects psychological and psychosomatic problems; (2) the Daily Stress Inventory, which assesses an individual's ability to cope with daily events; (3) the Occupational Stress Inventory, which surveys occupational adjustment factors; (4) the Minnesota Multiphasic Personality Inventory (MMPI-2), which allows researchers to identify exaggerated responses; (5) an alternative scale on the MMPI-2, which allows researchers to determine if respondents are defensive about revealing symptoms; and (6) a demographic questionnaire. The results indicated that the package drivers had significant elevation of stress-related symptoms over the general adult population. That is, drivers perceived significantly more daily stressful events than the norm. The authors' note that the best scale used for assessing stress, the Symptom Checklist, placed the package drivers at the 91st percentile. This indicates that these package drivers were substantially more stressed as compared to the general adult working population. Further analyses indicated that one reason for the stress might have been that the drivers believed that their workload was unreasonable and that they were faced with rigid deadlines.

It is evident that because these two research efforts comprise the known available published research on driver safety in L/SH operations, a large opportunity exists to conduct additional research in this field. The next section outlines a focus group effort, conducted by the authors of this research, to investigate safety issues in L/SH operations. The focus group study served as a precursor to the field study described later.

L/SH FOCUS GROUP RESEARCH

Rationale

The two L/SH driver studies described in the previous section involved (1) a crash-database analysis and (2) the administration of a questionnaire. What has been learned from these two efforts? First, fatigue does not seem to be as prevalent an issue in L/SH as it is in long-haul, and second, stress may be a prominent factor in L/SH operations. At this point, it is important not to eliminate fatigue as a possible safety issue in L/SH. Recall that fatigue can be attributed to lack of sleep, adverse weather, alcohol and drugs, physical work, noise, vibration, and heat. Based on the previous research, the extent that each of these factors might be present in L/SH operations is unknown. Therefore, the true impact of fatigue on L/SH operations is still unknown.

Just as there is information lacking on fatigue as a safety issue for L/SH drivers, there is not enough reliable information on the extent to which stress is a problem for L/SH drivers. Therefore, to gain a better understanding of the safety issues in L/SH trucking, more fact-finding efforts, such as those conducted by Massie, Blower, and Campbell (1997) and Orris et al. (1997), are required. To this end, a focus group effort was conducted to assess the drivers' perspective of safety issues in L/SH operations. Though a fairly detailed description of this study is outlined in the paragraphs that follow, full discussions of this effort are published elsewhere (Hanowski, Wierwille, Gellatly, Early, & Dingus, 1998).

Overview

Stewart and Shamdasani (1990) note that focus groups are useful for collecting data at all levels of research, but they are particularly useful for exploratory data gathering where little is known about an area of interest. Given that very little is known about the issues surrounding safety in L/SH operations, which is evident by the minimal published research efforts that exist, focus groups were thought to be an appropriate tool for learning more about this topic.

Between May and August of 1997, eleven focus groups were held in eight cities, across five states. The states involved were New Jersey, North Carolina, Pennsylvania, Virginia, and Washington. The purpose of these sessions was to gain an understanding, from the L/SH drivers' perspective, of the general safety concerns related to the L/SH trucking industry. Since the overall focus of the project was investigating fatigue in L/SH trucking, a significant portion of the focus group questions were directed at answering one basic question: "What is the extent of driver fatigue in the L/SH industry?" In addition to questions pertaining to general safety issues and driver fatigue, questions were posed to drivers concerning the L/SH industry in general. The results presented here describe the discussions pertaining to both general safety issues and fatigue issues.

Subjects

Eighty-two L/SH drivers participated in the focus groups. The number of participants in each session ranged from five to ten. Each driver was paid $60. Sessions lasted between 2.5 and 3 hours. Seventy-six drivers were male, and six were female. The mean age of participants was 38.9 years and ranged from 24-64 years. The mean number of years of L/SH driving experience was 9.5 years, and ranged from 2 months to 40 years. The average self-reported workweek was 48.9 hours, and ranged from 20-65 hours. The mean number of miles driven per day was 162 miles, but varied markedly from 3 miles to 425 miles. As outlined in table 5, participants represented a variety of L/SH industries. Drivers were recruited using three methods: (1) advertisements placed in local newspapers, (2) flyers sent to L/SH companies, and (3) via direct contact with L/SH company management.

Table 5. Alphabetical listing of the trucking industries that were represented across the eleven focus group sessions.

Trucking Industries
Air Freight
Beverage/Beer
Building Materials
Bus
Chemicals/Fertilizers
Concrete/Dirt/Gravel
Construction/Heavy Equipment
Gas/Oil
Less than-Truck-Load (LTL) Common Carrier/General Commodities
Pizza Products
Produce
Seafood
Snack Foods

Procedure

Each focus group session began with the drivers introducing themselves to the group. Afterwards, drivers provided a general description of their job and the tasks that they typically performed. Following this introduction, drivers were asked to recall and describe critical incidents (i.e., crashes and close calls) that they had either personally experienced or heard about. Drivers were asked to describe both driving and non-driving incidents. As part of describing the incidents, drivers were asked to indicate what they believed to be the cause(s) of the incident. Similar causal factors were grouped to form categories of safety issues. For example, drivers listed “snow,” “rain,” and “wind” as causal factors. These were then grouped into a general safety issue called “Weather.” After a list of safety issues had been generated, drivers ranked them in order of perceived importance (this was completed by driver consensus). Drivers were then asked to discuss fatigue-related incidents that they have experienced and list the causal factors involved. As appropriate, these causal factors were grouped into fatigue-related issues. Again, by consensus, drivers ranked each issue in terms of perceived importance. To avoid biasing the participants, drivers were first asked to describe general critical incidents and, afterwards, incidents related to fatigue.

In addition to the focus group discussion, drivers were administered paper-and-pencil questionnaires that queried them on a variety of topics. Questions included those pertaining to their job (e.g., How long have you been a L/SH driver?) and to fatigue (e.g., How many hours of sleep do you get per night?).

Results and Discussion

Data from each of the eleven focus groups were analyzed individually and collectively. Results from the collectively-conducted analyses are presented here.

First, to gain a better understanding of what is involved in L/SH trucking, drivers were asked to list the tasks that they perform in a typical workday and indicate the percentage of time spent on each task. Averaged across all focus groups, participants indicated that "driving" constituted their primary task and accounted for approximately 40 percent of their day. "Loading/unloading" accounted for approximately 26 percent of their day. "Miscellaneous tasks" and "waiting" (for a variety of reasons including waiting to load/unload) accounted for 22 percent and 12 percent, respectively. Caution must be used in interpreting these results as there were substantial differences for drivers between industries. For example, one group of drivers, who worked for a public utility company, reported spending approximately 70 percent of their day driving. In contrast, the group of drivers who hauled snack foods reported spending about 34 percent of their day driving.

General Safety Issues

Across all eleven sessions drivers were able to generate causal factors that were grouped into 15 general safety issues. The list of safety issues is presented in table 6. Accompanying each issue is a brief definition and/or example to highlight it. It should be noted that the drivers generated the terms used in this list.

Although each of the safety issues listed in table 6 was discussed in one or more of the sessions, the frequency with which each was described varied substantially. Table 6 indicates this frequency in the parentheses following the factor. As can be seen, Problems Caused by Drivers of Light Vehicles (i.e., Other Drivers) was listed as an issue in all eleven focus group sessions.

Table 6. List and definition of the general safety causal factors discussed in the focus group sessions. Frequency with which each issue was raised across the eleven focus group sessions is indicated in parentheses.

General Safety Causal Factor	Definition
Drivers of Light Vehicles (11)	For example, problems caused by drivers of cars, (i.e., "other drivers," "four-wheelers) (e.g., cut-ins, not yielding to trucks as they back up).
Stress Due to Time Pressure (10)	L/SH driver stress caused by having too many orders to do in a limited amount of time (e.g., rushing to get work completed, meeting a delivery time).
Inattention (8)	L/SH drivers' inattention to the road. Often caused by thinking about the next delivery while driving.
Roadway/ Dock Design (6)	Poor roadway design (e.g., narrow road, low bridge) or poor dock design (e.g., poorly lit, difficult to back into).
Fatigue (4)	Fatigue on the part of the L/SH driver.
Weather (2)	Poor weather (e.g., snow, rain, wind).
Carelessness (2)	On the part of the L/SH driver, not taking the time to follow proper protocol (e.g., not checking behind truck before backing).
Vehicle Design (2)	Includes poor arrangement of displays and controls in the truck cab.
Mirrors (1)	Includes bad mirror placement that makes merging difficult.
Road Construction(1)	Includes construction that restricts and/or narrows lanes.
Store Location (1)	Includes stores that are in downtown locations that make delivering difficult.
Poor Signs (1)	Poor roadway signs (e.g., weight restriction signs posted on a road after the driver has committed to it).
Driver Education (1)	Lack of driver education (e.g., defensive driving) on the part of the L/SH driver.
Traffic Congestion (1)	Being stopped by high volume traffic results in L/SH drivers' rushing/driving too fast to make up time.
Over-Confidence (1)	L/SH drivers' over-confidence in their own driving ability.

The next step in the analysis was to combine the rankings from the eleven focus group sessions to determine a consensus of the top-priority safety issues from the drivers' perspective. A weighting factor was applied to each issue to account for the frequency with which it was mentioned. Issues that were mentioned less frequently were considered less important than issues that were mentioned more frequently.

There were three possible outcomes regarding the ranking of each issue. First, an issue could be given a unique ranking. For example, one group of drivers may have agreed that the most important general safety issue was "Inattention" and, subsequently, ranked this issue as "Number 1." The second possible outcome for a ranked issue was that two or more issues could have been determined to be at the same level of priority. Put another way, two or more issues could have been ranked a tie. The third possible outcome was that an issue was listed but not ranked. If this was the case, it was typically because the group of drivers felt that a particular issue was a relatively rare occurrence. A hypothetical list of factors and their initial rankings is shown in table 7.

A method was devised for analyzing the data that would account for (1) the frequency with which an issue was raised across groups, (2) non-unique rankings, and (3) un-ranked issues. First, the data were consolidated from all eleven sessions (i.e., collapsed across session number). Then un-ranked issues were treated as a tie. All tied items were then re-ranked based on their mean position in the ranking order. As an example, compare the initial ranking column of table 7 with the transformed rank column. As can be seen, the first two issues are ranked 1-2, and no transformation is necessary. The third, fourth, and fifth issues were originally ranked as a tie. They are re-ranked to account for their mean position in the ranking order, such that each is assigned a rank of 4 (i.e., the mean of 3-4-5 is 4). The drivers did not rank the sixth and seventh issues in the original ranking. As such, they are treated as a tie and then re-ranked based on their mean position in the ranking order. Issues 6 and 7 are given a rank of 6.5 (i.e., mean of 6-7 is 6.5). This method of transforming the original rankings allowed further analysis of the issues and accounted for both the ranks assigned by the drivers and the number of issues mentioned in a session.

Table 7. Hypothetical List of Factors and Their Mean Rankings of Importance, Generated by Drivers after Group Discussion. NR Refers to "Not Ranked."

General Safety Issues		
Issue	Initial Rank	Transformed Rank
Issue 1	1	1
Issue 2	2	2
Issue 3	3	4
Issue 4	3	4
Issue 5	3	4
Issue 6	NR	6.5
Issue 7	NR	6.5

Table 8 shows the results of applying this method. As can be seen, the top five issues ranked in order of importance and weighted for frequency were: (1) Problems Caused by Drivers of Light Vehicles, (2) Stress Due to Time Pressure, (3) Inattention, (4) Problems Caused by Roadway/Dock Design, and (5) Fatigue.

Table 8. Rank of importance for general safety issues.

General Safety Issues	
Issue	Mean Ranking Of Importance
Drivers of Light Vehicles	1
Stress Due to Time Pressure	2
Inattention	3
Roadway/ Dock Design	4
Fatigue	5
Carelessness	6
Traffic Congestion	7
Weather	8.5
Vehicle Design	8.5
Over-Confidence	10
Poor Signs	11
Mirrors	12
Road Construction	13.5
Store Location	13.5
Driver Education	15

The highest-ranked critical issue, and the only issue mentioned in all eleven sessions, was Problems Caused by Drivers of Light Vehicles (i.e., Other Drivers). According to focus group participants, the problems caused by these drivers stem from two sources. The first is a poor driver attitude, where light vehicle drivers are discourteous to truck drivers and show them little respect. The second source is a lack of education on the part of light vehicle drivers. As one L/SH driver noted, "four-wheelers need to be educated on how to interact with trucks."

Stress Due to Time Pressure was the second highest-ranked issue and was raised in all but one of the sessions. This finding of the high importance of stress echoes the results of Orris et al. (1997), who found that package drivers had significantly higher measures of psychological distress as compared to the U.S. working population. A number of comments highlighted the stressful nature of the L/SH industry. One such comment was, "[We are] always working against the clock."

Inattention was the third highest-ranked issue and was mentioned in 73 percent of the focus group sessions. Drivers commented that they experience inattention while driving when they think ahead to their next stop/delivery. In addition, drivers suggested that the inattention they experience can result from eating while driving, using in-vehicle dispatch systems, and using computers to print orders.

Problems Caused by Roadway/Dock Design was the fourth highest-ranked critical issue, and was mentioned in 55 percent of the focus group sessions. Over the course of the eleven sessions, drivers reported several critical incidents that had been caused by poor roadway design or poor dock design. In terms of poor roadway design, drivers mentioned examples of short merge lanes, narrow roads, and closely positioned on- and off-ramps. Drivers also noted problems with loading docks, and indicated that they believed that many newer buildings had docks that were designed more for aesthetics than for function.

Fatigue was the fifth highest-ranked issue, and was raised in 36 percent of the focus group sessions. In general, drivers indicated that fatigue was considered an issue of only moderate importance in L/SH operations. Drivers pointed out that fatigue is more important in long-haul operations where drivers drive longer distances and get tired due to inactivity. The results of a more detailed examination of fatigue are highlighted in the next section.

Fatigue Issues

As indicated, during the focus group sessions, discussion revolved not only around general safety issues, but also around issues specific to driver fatigue. Drivers were asked to think about and describe incidents related to times when they were fatigued on the job and to discuss how they believe fatigue impacts the L/SH industry.

As in the discussion of general safety issues, drivers were asked to list and rank causal factors of on-the-job fatigue. Drivers were able to generate causal factors that were grouped into 22 fatigue-related issues. Figure 1 illustrates these issues and the frequency with which each issue was raised. As can be seen, the frequency with which each issue was raised varied substantially across groups. For example, the issue "Hard/Physical Workday" was raised in eight of the eleven sessions. "Working Two Jobs," on the other hand, was raised in only one of the sessions.

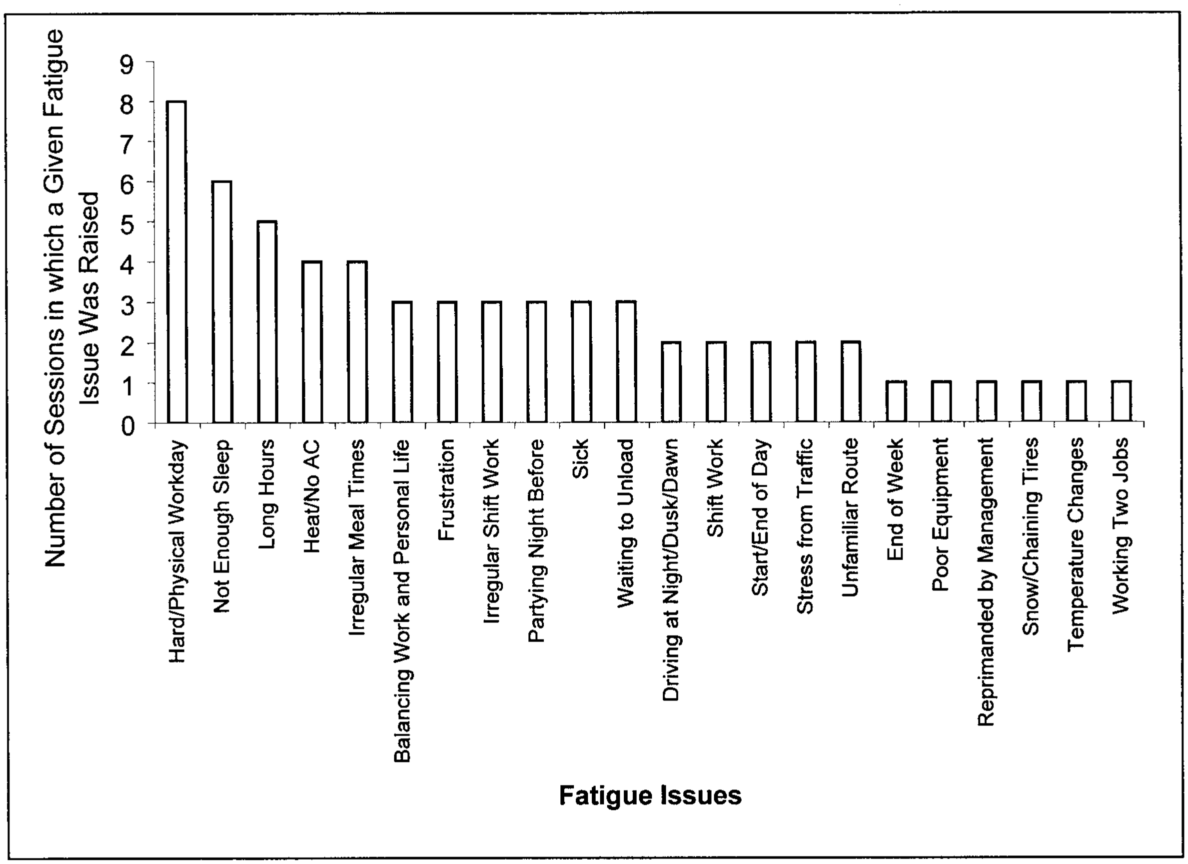

Figure 1. Frequency with which each of the 22 fatigue issues was raised across the eleven focus group sessions.

After discussing incidents related to fatigue and generating a list of fatigue issues, the drivers were asked to provide a consensus ranking for each issue. A discussion followed and each issue was prioritized and ranked in terms of importance. The same method used for reranking the general safety issues, based on the initially assigned rank and the frequency with which an issue was mentioned across sessions, was implemented with the fatigue issues. Table 9 shows the results of applying this method. As can be seen, the top five fatigue-related issues, ranked in order of importance, were: (1) Not Enough Sleep, (2) Hard/Physical Workday, (3) Heat/No Air Conditioning, (4) Waiting to Unload, and (5) Irregular Meal Times.

Table 9. Rank of importance for fatigue-related issues.

Fatigue-Related Issues	
Issue	Mean Ranking Of Importance
Not Enough Sleep	1
Hard/Physical Workday	2
Heat/ No A/C	3
Waiting to Unload	4.5
Irregular Meal Times	4.5
Long Hours	6.5
Irregular Workshift	6.5
Sick	8
Frustration	9.5
Balance Work/Personal Life	9.5
Partying Night Before	11
Unfamiliar Route	12
Stress from Traffic	13
Temperature Changes	15.5
Poor Equipment	15.5
Reprimanded by Management	15.5
Driving in Snow/Putting Chains on Tires	15.5
Start/End of Day	18
Driving at Night/Dusk/Dawn	19
Shift Work	21
End of Week	21
Working Two Jobs	21

To examine the importance of fatigue more closely, an analysis was conducted that compared the drivers within the groups who listed Fatigue as an issue with the drivers who did not list Fatigue as an issue. Note that Fatigue was raised as a general safety issue in four of the eleven focus group sessions. On a questionnaire, drivers were asked about the amount of sleep they typically obtained each night. A distribution of the hours of sleep for the groups of drivers that did raise Fatigue as a general safety issue was compared with the groups of drivers who did not raise Fatigue as a general safety issue. These distributions are shown in figure 2. Note that the mean number of hours of sleep for drivers who did raise Fatigue as an issue was 6.1 hours, as compared to 6.7 hours for drivers who did not raise Fatigue as a general safety issue. A two-sample t-test that assumed unequal variances was conducted on the two groups and proved to be significant, $t[58] = 2.00$, $p = 0.03$. This finding suggests that drivers who have more sleep at night are less likely to cite Fatigue as an issue during the workday.

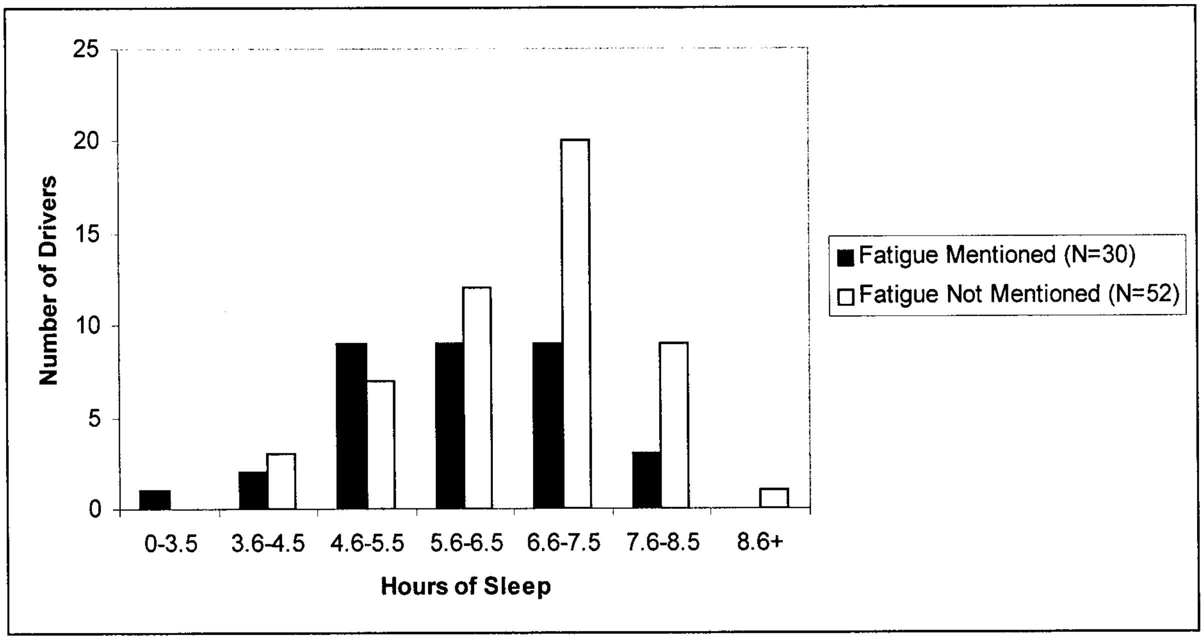

Figure 2. Distribution of hours of sleep as a function of whether or not fatigue was raised as a general safety issue.

To support the finding that less sleep at night impacted drivers' opinions of Fatigue as an issue in L/SH, an analysis was conducted on drivers' responses to a fatigue-related question that was administered as part of a paper-and-pencil questionnaire. The question asked drivers to remember a time when they were tired/fatigued at work and to write down the reason for being tired. Sixty-nine percent of the first responses given were "not enough sleep." This result is consistent with other research that has indicated that the best countermeasure for fatigue and drowsiness is adequate sleep (Tepas and Monk, 1987).

One final result that merits highlight is in reference to a question asked as part of a Likert-type questionnaire administered during the session. A statement read, "I feel tired when I'm on the job." Drivers provided their response on a scale from 0 (Strongly Disagree) to 100 (Strongly Agree). Across all eleven sessions, the drivers' mean response to the this Likert-type question was 35.3 (i.e., moderately disagree). This finding, in combination with other results related to fatigue, suggests that fatigue may not be the most critical issue in L/SH. Nonetheless, across all eleven sessions, Fatigue was viewed as being of moderate importance and ranked as one of the top five general safety issues.

Summary

Based on the results of these focus groups, it appears that although drivers report that fatigue is an issue in L/SH trucking, they do not think is as critical an issue as it is in long-haul trucking. In discussing the impact of fatigue, drivers provided several reasons why fatigue is not as critical in L/SH as it is in long-haul. For example, unlike long-haul drivers, L/SH drivers typically work during daylight hours, have work breaks that interrupt their driving, end their shift at their home base, and sleep in their own beds at night. It appears that for L/SH drivers, fatigue results from a normal day's work and is impacted by their personal lives (e.g., not getting enough sleep at night). It is suggested that this is not unlike the fatigue experienced by day-shift workers of non-driving professions.

The results of this focus group effort provide an indication of what the drivers view as the important safety issues in the L/SH industry. Although the data from the focus groups are important in understanding what the safety issues are in L/SH trucking, one may argue that the subjective nature of the approach could have lead to biased and/or inaccurate findings. As such, to complement the focus group effort, it is important to collect objective data on the topic. Findings from an objective study might confirm, or possibly refute, the subjective results. Additional insight might also be gained from an objective study. To this end, a two-phased, complementary research approach was developed that would provide multiple sets of measures. This method of collecting multiple measures to investigate a single issue has proven effective in previous research efforts (Bittner, 1992; Hanowski & Kantowitz, 1997).

The focus group effort, therefore, comprised the first phase of research for this project. The second phase involved conducting a field study. Before presenting the details of the Phase II field study, it is worthwhile to describe what field studies are and why this data collection strategy was well suited for the current project.

FIELD STUDIES

As outlined in Kerlinger (1986), "field studies are ... scientific inquiries aimed at discovering the relations and interactions among...variables in real social structures" (p. 372). Typically, no independent variable is manipulated and randomization is not required. This differs from field experiments where (1) causal variables are manipulated, (2) effect variables are measured, (3) extraneous variables are controlled for, and (4) subjects are randomly assigned to conditions.

As described in Kerlinger (1986), field studies can be used for exploratory purposes or hypothesis testing. Used for exploratory purposes, field studies can help in discovering significant variables in the field, discovering relationships between variables, and in laying the groundwork for further, more rigorous hypothesis testing. Field studies that are used for hypothesis testing have the goal of discovering relationships between variables.

Kerlinger (1986) notes that field studies are "strong in realism, significance, strength of variables, theory orientation, and heuristic quality" (p. 374). Perhaps the greatest strength of field studies is the realism of the study in that subjects are being observed and measured in their natural environment. The lack of control is one of the biggest weaknesses of field studies. The balance between the strength of measuring behavior in the natural environment and the weakness of not being able to control that environment is a trade-off that must be considered. Generally, the objectives of the research will dictate which of these data collection methods is most appropriate. For example, as in the present effort, a research objective aimed at maximizing generalizability is well served by either a field experiment or field study. If, for this same research effort, randomization was not feasible, as was the case in the current effort, a field study would be opted for over the field experiment.

Recall that the emphasis of this research effort is on L/SH trucking safety in general, and driver fatigue, specifically. The next section describes how researchers conducting field studies can use data collected from near-accidents or "critical incidents" to explore safety issues.

NEAR-ACCIDENTS

One of the most obvious methods of collecting safety data is to gather information after an accident has occurred. The problem with this, however, is that accidents are generally a rare occurrence. As Chapanis (1959) notes, the disadvantages of collecting accident data are that (1) an accident has to occur before you can investigate it, (2) an accident type that is of low frequency may be lacking in associated data, and (3) people are often reluctant to report accidents. To get around some of these problems, researchers have begun to study near-accidents (also referred to as "near-misses," though the term "near-accidents" is more accurate). The benefit of studying near-accidents is that they occur more frequently than accidents do. As described by Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman (1995), Heinrich's triangle illustrates this point nicely (figure 3).

Heinrich's triangle was developed for industrial accidents and indicates that for every catastrophic accident or fatality, there are 10,000 near-accidents. Given that there are substantially more near-accidents than there are accidents, researchers do not have to wait for an accident to occur to study the underlying phenomenon. As Chapanis (1959) points out, the severity of an accident is largely fortuitous. He cites an example in which one investigator found that out of 330 accidents of a particular type, 300 resulted in no injury, 29 resulted in minor injuries, and one resulted in a fatal injury. This suggests that it is the situation related to the accident that is most important and not the severity of the accident.

Figure 3 also shows estimates made by Dingus et al. (1995) regarding the frequency of critical-incidents (i.e., accidents and near-accidents) where an error occurred and a hazard was present, and when an error occurred and a hazard was not present. Dingus et al. estimate that "Error, Hazard Present" incidents occur 100,000 times for every fatality. For "Error, No Hazard Present," the estimate is 1,000,000 times for every fatality.

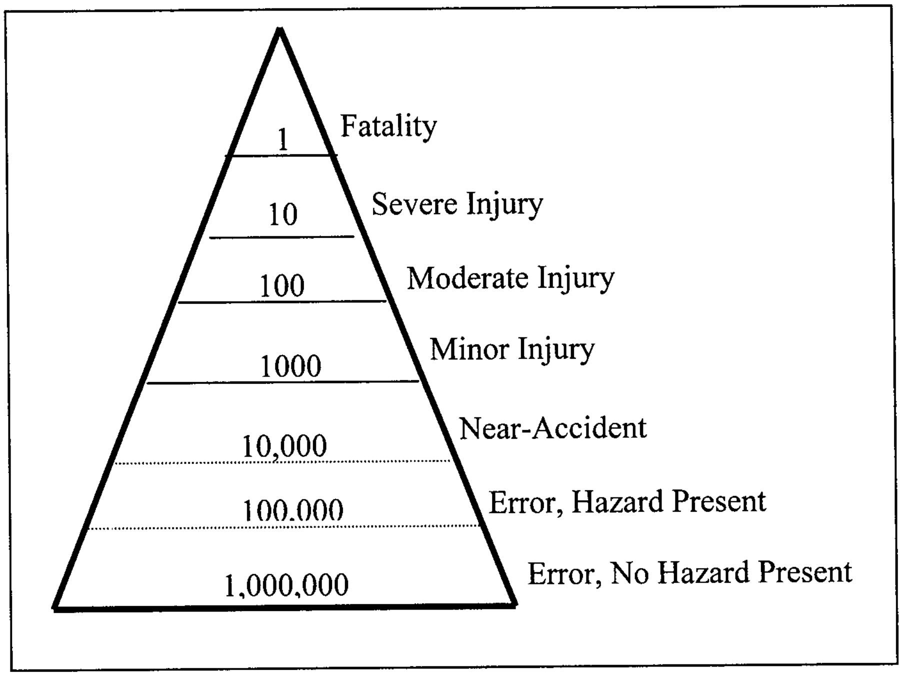

Figure 3. Example of Heinrich's triangle with modifications suggested by Dingus, et al. (1995).

Mollenhauer (1998) (also see, Dingus, Hetrick, and Mollenhauer, 1999) followed up on the Dingus et al. (1995) estimates in a recent on-road data collection effort where he studied near-accidents in the automobile/driving environment. He applied Heinrich's triangle to the data, supplemented by data retrieved from an accident data base, and came up with the following modification (figure 4). Comparing the original Heinrich's triangle to the one modified by Mollenhauer (1998), it can be seen that there were substantially more near-accidents per injury in the driving environment (2,838:1) as compared to those found in industrial accidents (10,000:1110 or 9:1).

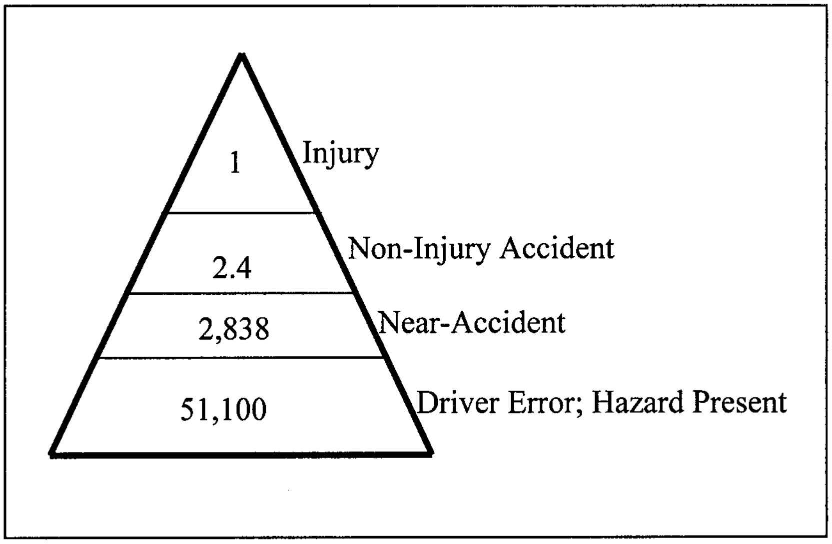

Figure 4. Modified version of Heinrich's triangle using automobile driver error data from Mollenhauer (1998).

A Field Study Analyzing Near-Accidents

McFarland and Moseley (1954) conducted a near-accident investigation in long-haul trucking operations. The purpose of their study was to identify the types of near-accidents that occur in long-haul trucking, their frequency, and the conditions under which they take place. The data were collected by a trained observer who road with 17 different drivers on 20 trips totaling 5,000 miles. The observer watched for critical incidents that could have lead to crashes. For each incident, the observer diagrammed the characteristics of the incident, and noted the time of day, the weather conditions, visibility, the type of road, the elapsed time since the start of the trip, and the estimated speed of the vehicle(s) involved. Across the 5000 miles, 48 near-accidents were recorded (approximately one near-accident for every 100 miles). Table 10 shows the errors and the frequency with which they occurred.

Table 10. Errors observed in the near-accidents (McFarland and Moseley, 1954).

Errors Resulting in Near-Accidents	Frequency
Dangerous Assumptions	13
Errors in Passing	7
Operator Unprepared	5
Operator Taking Complete Defensive Action	5
Gross Negligence	4
Operator Inattention	3
Operator Indecision	3
Highway Maintenance	3
Operator Taking Partial Defensive Action	2
Failure to Observe Posted "Danger" Signs	1
Failure to Help Other Operator	1
Situations Deliberately Caused by Drivers	1
Total	*48*

Descriptive analyses were conducted on the frequency of near-accidents in relation to the elapsed time of the trip, the speed of the vehicles, the visibility, and the type of roadway. For the elapsed time of the trip, it was found that 46 percent of the near-accidents occurred during the first two hours of the trip. The authors suggest that this may have been a result of the drivers' coming to work improperly rested and/or emotional problems from the drivers' personal or company relations that were brought to the job. The observer noted that both of these factors were present for some drivers.

For near-accidents in relation to vehicle speed, it was found that in 72 percent of the incidents, the vehicles were traveling 35 mph or faster. In terms of visibility, 90 percent of the near-accidents occurred in poor visibility (either by obstructions such as blind curves, or weather). Finally, in terms of the roadway, 44 percent of the near-accidents occurred on straight roads, 27 percent occurred on curves, and 29 percent occurred at intersections. Of course, driving conditions in the 1950's were quite different from those of today, both in terms of traffic density and roadway structure.

In a review of this study, Chapanis (1959) notes that in addition to several interesting findings, the method of examining near-accident data proved to be an efficient data collection technique. The disadvantages of the study, Chapanis indicates, are twofold. First, the definition of a near-accident depends upon the judgment of an observer. The second disadvantage is that the presence of a trained observer riding inside the vehicle with the driver may have impacted the driver's behavior. Since the 1950's when these data were collected, an enormous amount of technology has been introduced that improves the method in which this study could now be carried out. Dingus et al. (1995) and Mollenhauer (1998) outline research efforts that have collected data on near-accidents in the field using instrumented vehicles equipped with computers and video cameras. Computers equipped inside the vehicle serve to help provide an unbiased judgment of near-accidents. In addition, small, unobtrusive video cameras positioned inside the cab (where the driver's face and the driver's view of the roadway are recorded) obviate the need for a ride-along observer. Given these technological advances, the disadvantages that Chapanis described are now, perhaps, not as severe.

DRIVER FATIGUE

As outlined in the reviewed literature, there are a number of factors that contribute to the fatigue experienced by long-haul truck drivers. The primary causal factors in long-haul trucking as outlined by Wylie et al. (1996) are:

- Time-on-task,
- Circadian low points,
- Sleep debt,
- Rotating schedules,
- Team sleeper operations,
- Monotonous driving environments,
- Driving in darkness,
- Adverse weather,
- Alcohol and drugs,
- Physical work,
- Noise,
- Vibration,
- Heat.

Though issues pertaining to driver fatigue in long-haul trucking have been established and well-researched, this is not the case for L/SH operations. As outlined previously in table 9, the research from Hanowski et al. (1998) provided a preliminary list of potential fatigue-related factors as cited by L/SH drivers. For convenience, the list of the highest ranked factors is repeated below:

- Not enough sleep,
- Hard/physical workday,
- Heat and/or no air conditioning in cab,
- Waiting to unload,
- Irregular meal times,
- Long hours,
- Irregular workshift,
- Sickness,
- Frustration,
- Balance between work and personal life.

As will be outlined later, one of the goals of the present research was to validate the factors cited by Hanowski et al. (1998). This was accomplished by characterizing the instances of driver fatigue in the field study. The categories provided by Wylie et al. (1996) and Hanowski et al. (1998) were used to aid in this characterization. It was hypothesized that many of the driver fatigue incidents captured in the field study would fit into one or more of the categories presented above.

Is Fatigue an Issue in L/SH Operations?

The primary question being asked in this research is, "is fatigue an issue in L/SH trucking operations?" To answer this question, and to help guide the analysis effort, a model outlining the relationship between critical incidents, measures of driver fatigue and inattention, and factors contributing to critical incidents and driver fatigue/inattention is presented (figure 5). As can be seen, this model indicates that the focus of the analyses is on critical incidents and that three groups of contributing factors are investigated that may either directly impact critical incidents or may influence driver fatigue/inattention which, in turn, could impact critical incidents. Operational definitions for each factor are presented in table 11.

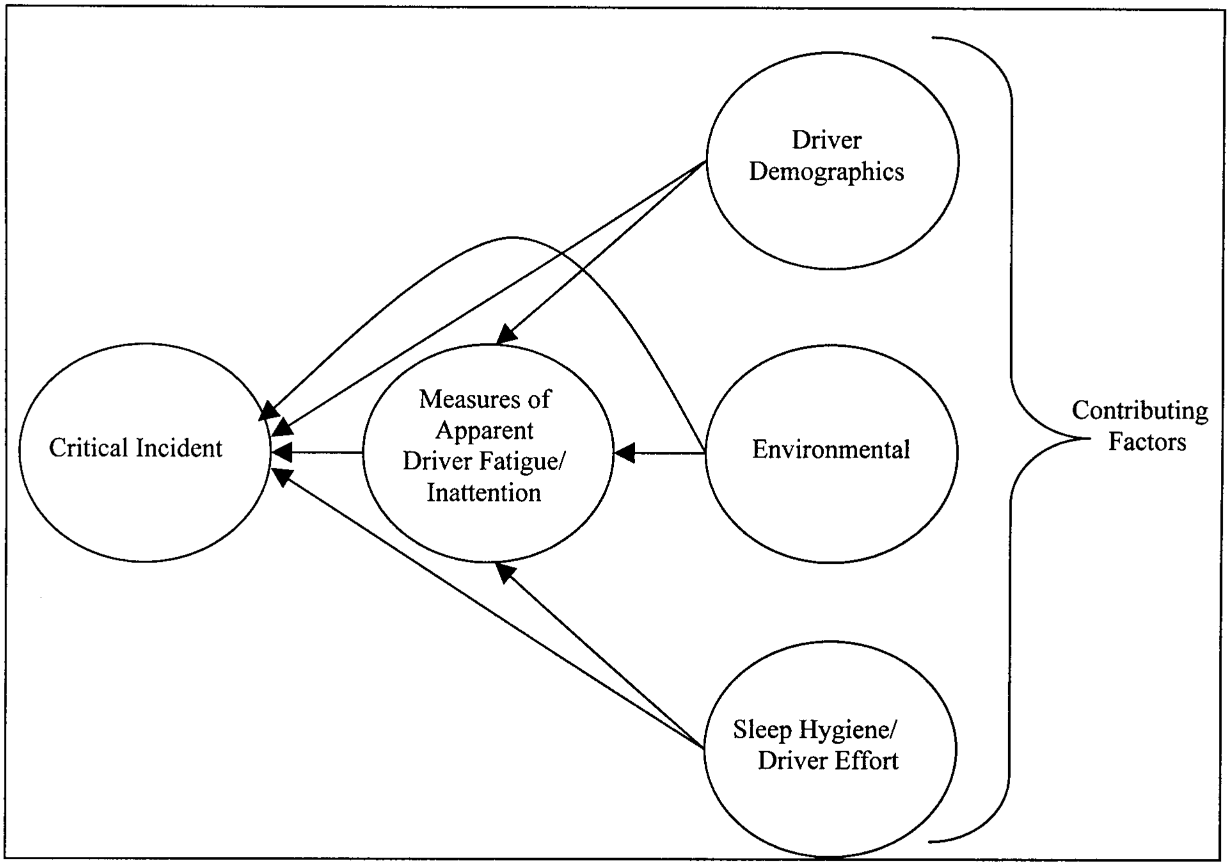

Figure 5. Five-factor analytical model.

Table 11. Operational definitions of five factors shown in Figure 5.

Factor	Summary of Measures Included
Critical Incident	Near-accident event.
Measures of Apparent Driver Fatigue/ Inattention	Measures of driver fatigue include analyst rating of fatigue (OBSERV) and a measure of the percentage of time that the driver's eyes are closed or nearly closed (PERCLOS). Measures of driver inattention include number of eye transitions and proportion of time the driver's eyes are off of the roadway.
Driver Demographics	Common measures of driver personal information such as age, experience, training, etc.
Environmental	Environmental measures include day-of-the-week, time-of-day, illumination, weather, etc.
Sleep Hygiene/Driver Effort	Measures of sleep hygiene include sleep quantity and sleep quality. Measures of driver effort includes measures of stress, physical demand, hours worked, hours driving, total miles driven, number of delivery stops, etc.

Model of Driver Fatigue

To understand how L/SH operations might impact driver fatigue, a model of driver fatigue has been developed. This model, shown in figure 6, is used as a way to validate the factors cited by Hanowski et al. (1998).

Cameron (1973) suggests that "fatigue" can be viewed as a composite variable comprised of multiple components that are both identifiable and measurable. Identifiable components include physiological aspects of fatigue such as muscular exertion (Kroemer, Kroemer, and Kroemer-Elbert, 1990), and psychological aspects such as visual sensitivity and vigilance (Hockey, 1983). For transportation-specific applications, fatigue has been defined as including time-correlated deterioration in driving performance, reduction in the physiological state of arousal, and subjective feelings of sleepiness (Wylie et al., 1996). This concept matches the early fatigue-related research findings of Bills (1931) who noted that fatigue can be measured through objective measures, physiological measures, and subjective measures. As suggested previously, it can be argued that the benefit of using several measurement techniques to measure the same construct (i.e., fatigue) is that converging data from multiple measures would provide a strong indication of the presence or absence of driver fatigue.

Figure 6 presents the model of driver fatigue that is, in part, guiding this research effort. As can be seen, the concept of "fatigue" is being treated as a "composite-latent variable." In other words, fatigue is viewed as: (1) a composite variable that is comprised of several components (Cameron, 1973), and (2) a latent variable, or "unobserved entity" that is believed to underlie observed variables (Kerlinger, 1986). Recall that the primary research question being asked is, "what is the impact of L/SH operations on driver fatigue?" Based on this research question, and as shown in the model, the causal construct of L/SH operations is defined as the activities that comprise the L/SH driver's work day. Fatigue as a composite-latent variable is hypothesized to result from the activities performed by the L/SH driver, and to be involved, to an unknown degree, in critical incidents. For this research effort, the effect construct of driving performance is being constrained to critical incident events.

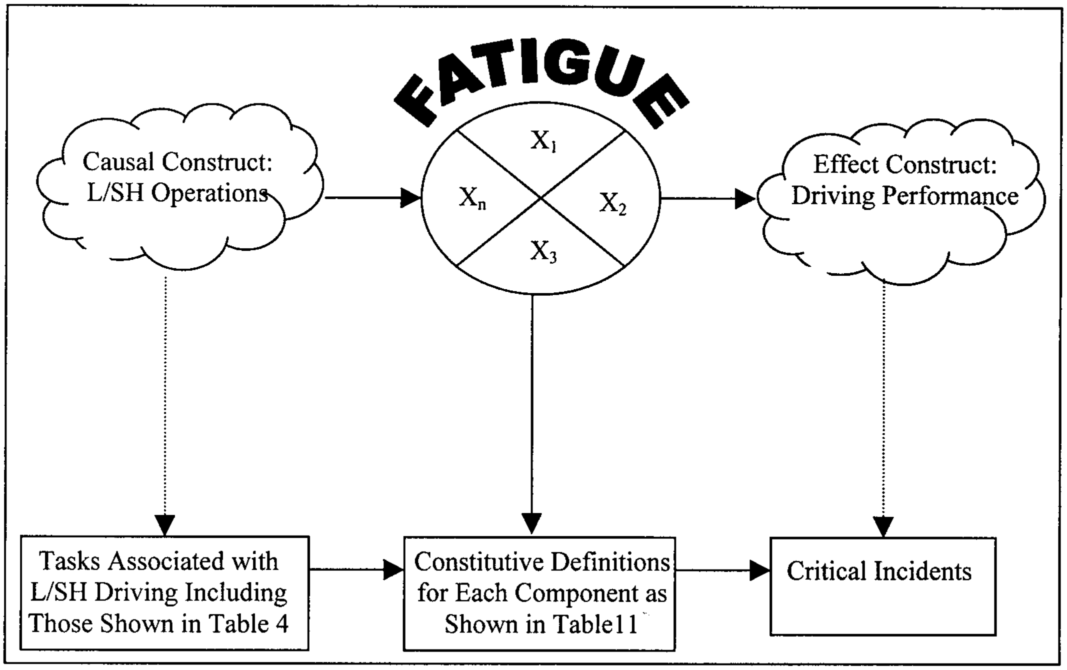

Figure 6. Model of L/SH driver fatigue.

As suggested, the fatigue component of the model follows the notion that fatigue is a variable comprised of several components (Cameron, 1973). A sample of the hypothesized components of fatigue as they relate to L/SH operations, and example definitions for each component, are highlighted in table 12. Note that the hypothesized components that are included in the model of fatigue are based on the results of the Hanowski et al. effort (1998).

Table 12. Sample of the fatigue components that will be examined in this research.

Components	Constitutive Definitions
Not Enough Sleep	Insufficient Sleep Quantity
	Poor Sleep Quality
Hard/Physical Workday	Long Hours Driving
	Many Stops/Deliveries
Heat/No A/C	Warm Weather
Start or End of Day	Early Morning Start Time
Long Hours	Atypically High Number of Hours Worked in a Single Day
Stress	High Stress Score on Subjective Questionnaire

Using this model, if it can be determined, for example, that drivers do not achieve sufficient sleep quantity and have poor sleep quality, then evidence would be gained to support the notion that Not Enough Sleep is a factor impacting fatigue in L/SH operations. This would then support the validity of the L/SH drivers' claims from the focus groups (Hanowski et al., 1998).

PROBLEM STATEMENT

The general goal of this research was to add to the limited body of knowledge pertaining to fatigue issues in L/SH trucking. As shown in figure 7, this was accomplished by executing a two-phased research approach. In the first phase, focus groups were conducted. As described previously, the data from these focus groups resulted in a list of safety issues and a list of fatigue-related issues in L/SH operations. Recall that up until this focus group effort, very little information was available with regard to the safety issues in L/SH operations and the extent to which fatigue is an issue. As a result of the successful completion of the Phase I research, a better understanding of the drivers' perspective on safety issues in L/SH operations has been gained. As suggested previously, the information related to fatigue obtained in Phase I was used to generate hypotheses and develop the methodology for Phase II. In terms of hypothesis generation, the components of L/SH driver fatigue were based on the results of the Phase I effort (as shown in table 12).

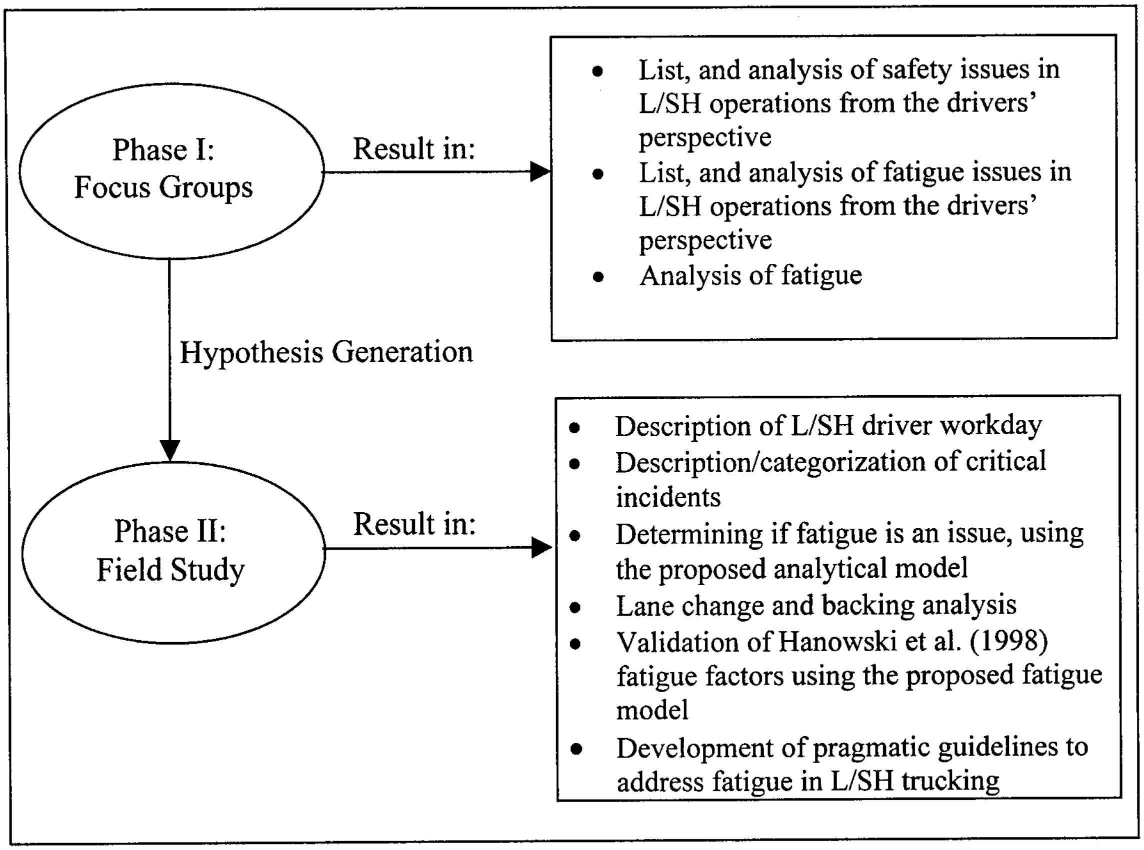

Figure 7. Research effort entails a two-phased approach.

As indicated in figure 7, there are six basic outputs stemming from the Phase II research: (1) a description of the L/SH drivers who participated in the study and of their workday, (2) a description and categorization of critical incidents using the strategies similar to those used by McFarland and Moseley (1954) and Mollenhauer (1998), (3) a determination if fatigue is an issue in L/SH operations using the proposed five-factor analytical model shown in figure 5, (4) an analysis focusing on critical incidents occurring while making lane changes and backing maneuvers, (5) the validation of the fatigue factors cited in Hanowski et al. (1998) using the proposed fatigue model shown in figure 6, and (6) pragmatic guidelines to address fatigue, and other safety issues, in L/SH operations. The following sections describe the major elements associated with each set of analysis.

1. Description and Categorization of L/SH Drivers and Their Workday

A characterization of the L/SH drivers who participated in this study is provided. This description includes a breakdown of the drivers' workday in terms of the tasks performed and the amount of time spent on each task. In addition, the description of the drivers includes means and standard deviations on a number of measures including number of miles driven, the number of deliveries made, the load weight, and the total hours worked. All measures are presented based on a per workday basis. It is suggested that such a description of the drivers who participated in the study is important, as the results and guidelines can be put into context in regard to the drivers who participated in the study.

2. Categorization and Description of Critical Incidents

Critical incidents are grouped into one of four categories: (1) L/SH driver at fault, (2) L/SH reacting to an error made by another driver, (3) L/SH driver not involved, but driver reports witnessing a critical incident, and (4) L/SH driver reacting to a situation not including errors made by other drivers (e.g., animal in road). Examples of the written descriptions, made by the analyst for events in each category, are also presented. In describing the incidents, a format similar to that described in McFarland and Moseley (1954) is used where potential causal factors, and the frequency of those factors, are assessed. In addition, Heinrich's triangle, as adapted by Dingus et al. (1995) and Mollenhauer (1998), is used to categorize the incidents. A comparison is made between the results from the Mollenhauer (1998) car study and the results from the current research.

3. Is Fatigue an Issue in L/SH Trucking?

To determine if fatigue is an issue in L/SH trucking, statistical analyses were conducted to examine the relationship between the five factors outlined in the analytical model (i.e., Critical Incident, Driver Demographics, Environmental, Apparent Fatigue/Inattention, and Sleep Hygiene/Driver Effort). The tests were devised in such a way that significant relationships between these factors would suggest that fatigue is evident in the data that were collected for this research. For example, a significant relationship between insufficient sleep quantity and

PERCLOS (defined later in table 13) would suggest that drivers who do not get enough sleep at night exhibit drowsiness on the job.

4. Lane Change and Backing Analysis

This analysis focuses on critical incidents that occurred while L/SH drivers made lane change and backing maneuvers, along with an assessment of fatigue during these events. In addition, a description of general lane change and backing performance (i.e., non-critical incident) is presented. In describing the general lane change and backing events, referred to as "normative" events, taxonomies that categorize these events are presented along with various descriptive measures.

It should be noted that this additional analysis was included as part of a project modification directed toward a preliminary investigation of lane change and backing events. In addition to the analysis presented here, a large data set of over 500 lane changes and backing events has been submitted to researchers at the National Highway Traffic Safety Administration (NHTSA) for a more in-depth analysis.

5. Validation of Fatigue Factors

The results from the Phase I focus groups indicated that drivers believed that fatigue was one of the top five safety issues in L/SH operations. Also, drivers provided several reasons for fatigue being an issue. One goal of the present research was to determine the validity of these causal factors reported by the drivers. One might hypothesize that the results of objective data collected in the field will substantiate the claims made by the drivers with regard to (1) fatigue being a safety issue in L/SH operations and (2) the causal factors associated with fatigue in L/SH trucking. The analyses to determine if fatigue is an issue in L/SH trucking (as highlighted previously) provides an indication of whether or not fatigue was present during critical incidents. If fatigue is found in the data, the following research questions will be asked: (1) What components are generally involved? (2) What is the relative importance of each component? and (3) How does the relative importance of each component, as determined by the Phase II data, compare to the results of the Phase I research? The answers to these questions are used to validate the proposed model of L/SH driver fatigue and, on a larger scale, substantially add to the body of knowledge regarding fatigue in L/SH trucking.

A second way in which the claims made by drivers in the focus groups were validated was by asking drivers who participated in the field study, at the end of each work day, if their work was affected that day by Not Enough Sleep, Hard/Physical Workday, etc. One might expect to see a similar set of causal factors from the drivers in the field study as those discussed during the focus groups.

6. Guideline Development

As will be shown, the results of this research indicate that fatigue is an issue in L/SH operations and, as such, pragmatic guidelines that address fatigue and driving safety are presented. The development of these guidelines are based primarily on the analysis of the Phase II data collected in the field and, to a lesser extent, the data from the Phase I focus groups. The goal of these guidelines is to improve driving safety. In total, five guidelines are presented. Two of these are aimed at driver fatigue. The third is directed at driver age and experience. The fourth is focused on driver screening, while the fifth guideline recommends public monitoring of drivers. It is believed that by developing a set of pragmatic guidelines that can be used by L/SH drivers and management, the results of this research may have an important practical application; that is, the potential to improve safety for L/SH drivers and the general motoring public with which they interact.

RESEARCH METHODOLOGY

OVERVIEW

Phase II of this research consisted of conducting an on-road study where in-service L/SH trucks were instrumented with data collection equipment and driven by L/SH drivers. Both quantitative and qualitative data were collected and used to determine the extent that fatigue is an issue in L/SH trucking.

RESEARCH OBJECTIVES

The primary objective was to determine if fatigue is a safety issue in L/SH trucking. This question was answered by examining the level of driver fatigue present when drivers are involved in critical incidents. Multiple components of fatigue were considered, including components that can be determined through subjective measures (e.g., self-reported level of stress on the day of the incident), objective measures (e.g., percent of time that the driver's eyes are closed, or nearly closed, prior to the incident), and physiological measures (e.g., derived measures of sleep quality and quality via a wrist activity monitor).

DATA COLLECTION SYSTEM DEVELOPMENT AND INSTALLATION

Three "black box" data collection systems were developed for the on-road data collection effort. One such system is shown in figure 8. These systems provided the state-of-the-art in reliable and unobtrusive collection of driver alertness measures, driver attention and performance measures, and near-accidents/critical incidents. Though only a brief overview of the data collection systems is presented here, a more detailed description can be found in Hanowski, Wierwille, Dugger, and Dingus (1999).

The data collection systems were unobtrusive, compact, and reliable for long data collection intervals (24 hours) with no experimenter present. Small video cameras measuring 2.92 cm (1.15 in) square by 0.635 cm (0.25 in) deep with apertures measuring 0.0794 cm (0.03125 in) in diameter were used to collect the video information.

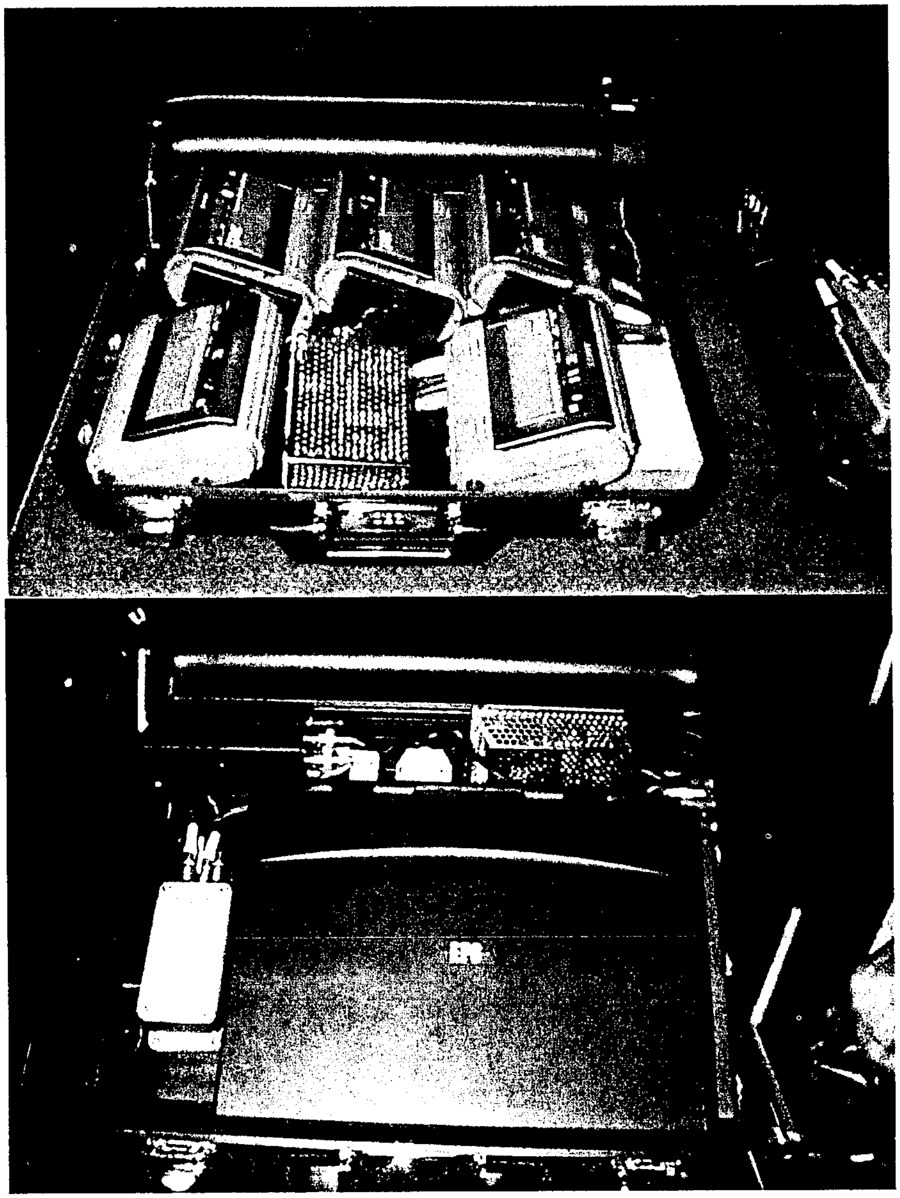

Figure 8. One of the black box data collection systems that were installed in L/SH trucks.

Video Camera Systems

As shown in figure 9, five video cameras were used in the system: (1) a forward looking camera that captured the forward roadway scene, traffic situation, and possible incidents; (2) a driver's face camera that was used to pick up facial expressions, eyelid closure, glance position, and head turns; (3) left-side and (4) right-side cameras that were mounted on the side mirrors and aimed toward the rear; and (5) a rear camera that was intended to capture the traffic situation behind the vehicle and to assist in incident capture.

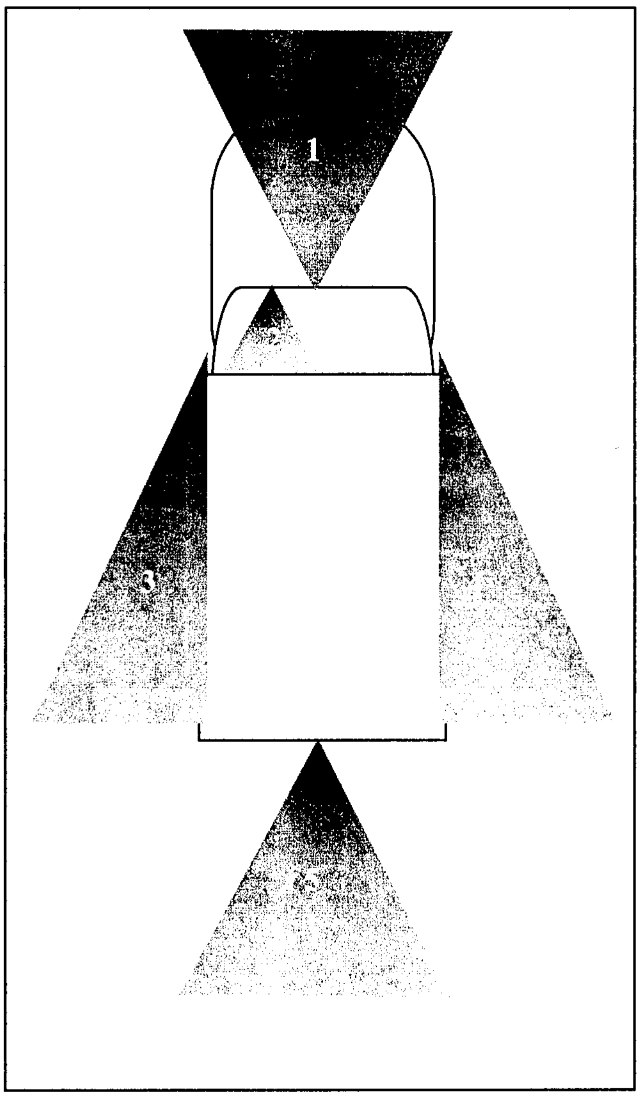

Figure 9. Camera directions and approximate fields of view.

The video camera arrangement shown in figure 9 had several advantages. First, it provided good coverage around the vehicle so that incidents could be captured as they developed. Second, the driver's facial expression, approximate glance direction, and approximate level of eye closure were also captured. And third, the arrangement provided appropriate views, whether moving forward or backward.

The five camera images were multiplexed into a single image as shown in figure 10. Note in particular that the two side cameras used a single quadrant in a split arrangement. This format was selected so that all five camera views could be included on a single image. A timestamp legend ("sync" number) was also included in the video frame.

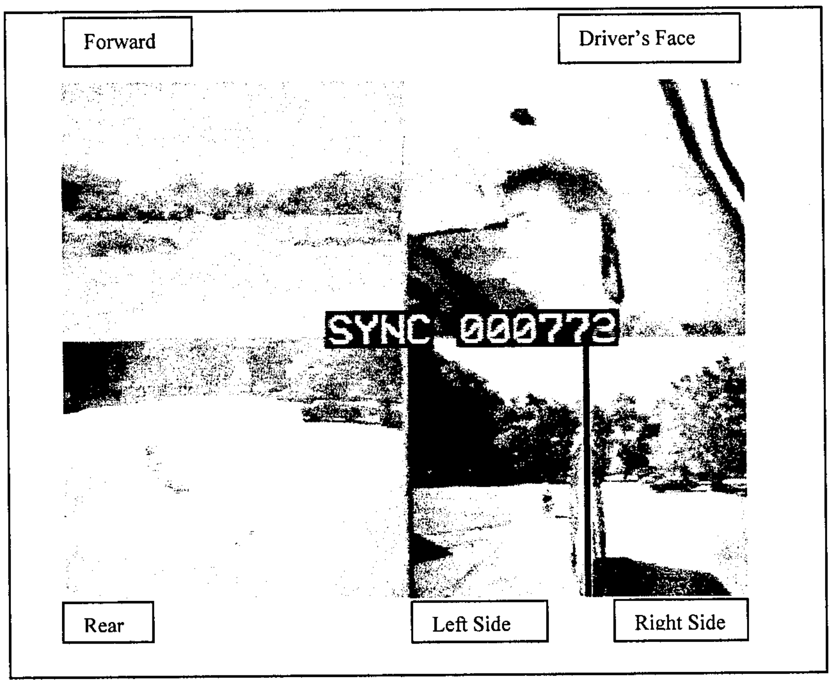

Figure 10. Split-screen presentation of the five camera views.

Usual Sensors

Eight usual sensors were installed on each truck. These are termed "usual" because they are typical of the types of sensors used in past field studies (e.g., Hanowski, Dingus, Gallagher, Kieliszewski, & Neale, 1999). These eight sensors collected data on the:

- accelerator - accelerator position sensor indicated the percentage of deflection,

- service brakes - brake-light was instrumented to indicate when the driver was/was not depressing the brake pedal,
- reverse gear - backup light was instrumented to indicate when the vehicle was/was not in reverse gear,
- steering - steering wheel sensor was used for recording steering wheel position and steering wheel velocity,
- directional signals - both the left and right directional (turn) signals were individually instrumented so that activation/deactivation could be determined,
- cab microphone - a microphone was mounted in the cab to pick up verbal utterances,
- incident push-button - an incident push-button labeled "INCIDENT" was mounted on the dash, and in a position that was readily accessible by the driver (described in more detail later),
- accelerometers - accelerometers instrumented in the vehicle were used to measure lateral and longitudinal accelerations.

Unusual Sensors

In addition to the usual sensors, a number of "unusual" sensors (i.e., sensors developed specifically for this project) were also instrumented on the trucks. These sensors consisted of a backing sensor system, driveshaft sensor system, and ambient illumination sensor. The backing sensor system was intended to determine the closing distance to any object as a function of time during backing maneuvers. The system provided a horizontal beam width that was roughly the width of the truck at a distance of 4.57 m (15 ft) from the rear bumper. The system operated from object distances of 0 to 7.62 m (25 ft) and provided very accurate distance measurement to objects at the rear. The driveshaft sensor system was instrumented with a non-contact distance and velocity measurement system. Multiple small magnets were strapped or wired into place at equally spaced intervals around the driveshaft. A dual Hall-effect sensor picked up the magnetic field variations and counted and timed them to determine distance and velocity. Finally, the ambient illumination system was calibrated to distinguish eight levels of illumination, with total darkness (black night running conditions) on one end and intense full sunlight on the other end. Scale levels were logarithmic, because of the great adaptation ability of the human eye. More detail on the "unusual" sensors can be found in Hanowski, Wierwille, Dugger, and Dingus (1999).

A calibration process was conducted to insure that the various sensors provided data that were accurate in both direction and magnitude. For the first several runs on each truck, the data were checked daily to insure all sensors were working properly or to eliminate data in cases were a sensor malfunction had occurred. After the data were downloaded from the on-board computers, a check of all data was made in the lab to, again, insure reliability.

SYSTEM ASPECTS

There were several features of the instrumentation system that are important to highlight. These features are described below.

System Booting/Powering

The system became active when the ignition system of the vehicle was on. System start up was delayed to allow for the computer to boot up, and occurred approximately 15 seconds after the ignition was turned on. To avoid the problem of double booting, the system remained active when the vehicle was in either the ignition-on position or the start position. In other words, the system was connected to a hot in-start and hot in-run line.

The system was fully automatic and did not require driver input except for the incident button (described below). In all but one situation, the system remained on as long as the ignition was on, and it was capable of orderly shut down when the ignition was shut down. In other words, the system gathered data as long as the ignition system was on and shut down in an orderly fashion when the ignition system was turned off. The one situation where this was not the case was when the velocity sensor did not detect vehicle movement for a two minute period. In this case, the entire system went into "suspend" mode. As soon as the velocity sensor detected movement, the system automatically re-engaged. The reason for including a suspend mode was to conserve video tape and hard drive space (i.e., so that when nothing was going on, no data were collected).

Video Recording Operation

Video recording was tied to the booting/powering system and it began to operate 15 seconds after the ignition was on. It also shut down in an orderly manner when the ignition was turned off. It was desired for the recording system to record for as long as possible without requiring technician/researcher attention. Therefore, multiple recorders designed to operate in sequence were used. The recording system operated for 18 hours of ignition-on time, without needing to have tapes exchanged. The video recorded continuously while the ignition was on. This allowed laboratory review and selection of the video without losses of any kind.

The videotaped episodes/incidents were selected and keyed to digitally recorded data. In some cases, the videotape timestamp was used to access the corresponding digital data. In other cases, the incident flags in the digital data were used to access the corresponding video. Therefore, there was a straightforward keying procedure to allow both kinds of access to take place efficiently.

Incident Flag

Though a more detailed definition is presented later, in general a critical incident involves an unexpected event resulting in a close call or requiring fast action on the part of a driver to avoid a crash. Incidents were detected by three methods: exceeding specified values in vehicle maneuvers, via an incident pushbutton used by the driver, and from analyst judgment. The "trigger criteria" for incidents are described later.

The incident flags were computed and detected on-line (as well as being stored), with the flag appearing in the video. Since the entire video recording was reviewed, the presence of flags indicated to the analyst the high likelihood of an incident occurrence.

Low-Light Recording

The L/SH operations studied in this research were performed primarily on a daytime (daylight hours) schedule. Nonetheless, the data collection systems were designed with the capability to collect video data in low light. Low light levels generally occurred at the beginning and end of the shifts.

Measures of Driver Performance and Behavior

In addition to the video data, a variety of driver performance, attention, and alertness variables were collected. The instrumented components (steering, accelerator, brake, velocity, lateral acceleration, and longitudinal acceleration) were digitized by a PC-based data acquisition system and recorded in real time at 10Hz by the data-recording computer. String potentiometers were used to measure the position of the steering wheel and accelerator. Tapping into the brake light signal provided an indication of braking. Accelerometers imbedded in the data collection hardware were used to measure the lateral and longitudinal acceleration. Hall-effect sensors, in conjunction with a magnetic element strapped to the drive shaft, were used to collect the vehicle velocity. The backup light signal was used to determine if the transmission was in reverse gear.

Trigger Criteria

Except for when the system was in suspend mode, as described previously, the data were gathered continuously as long as the engine of the vehicle was running. Since there were enormous quantities of data with the continuous approach, some form of flagging was needed to determine how and where incidents were taking place. Toward this end, a channel of the data gathering process was dedicated to flagging or triggering. During data analysis, time epochs around the trigger event were examined in detail, thereby making it possible to decide what to analyze.

The triggering criteria were "tweaked" for each of the four trucks (described later) depending on the characteristics of the truck. For example, steering angle rate was set differently for trucks that had substantial "play" in the steering wheel as compared to trucks with less play. Though minor variations in the criteria were used, the following provide the approximate trigger criteria that were used:

1. Longitudinal deceleration above 0.5g (intended to sense panic braking) OR
2. Longitudinal acceleration above 0.5g (intended to sense being hit in the rear) OR
3. Absolute lateral acceleration above 0.25g and longitudinal speed above 32.19 km/h (20 mph) (intended to pick up evasive maneuvers) OR

4. Absolute steering angle rate above 6.28 rad/sec and longitudinal speed above 32.19 km/h (20 mph) (intended to pick up panic steering) OR
5. Absolute lateral acceleration above 0.5g (intended to pick up side collisions) OR
6. Actuation of a critical incident pushbutton.
7. Turn signals were used as a means of determining passing events.
8. Reverse lights were used as a means of determining backing events.

It was hypothesized that the vehicle-related trigger criteria would lead to the flagging of many critical incidents. However, as one can imagine, situations existed where a critical incident occurred and no flag was triggered. To capture some of these potentially missed critical incidents, a driver critical incident pushbutton was installed (see 6. in the above list). This pushbutton worked as follows: When the driver believed that a critical incident had just occurred, he pushed the critical incident button. Note that the driver was trained to use the button *after* the incident had occurred and not during the incident. Despite the disadvantage of creating an artificial circumstance and reminding the driver of the presence of data collection instrumentation, the advantages appeared to outweigh the disadvantages. As part of the introduction of this technique, drivers were trained regarding pushbutton use, while attempting to minimize driver reluctance to have events recorded.

In addition to automatic flagging of potential incidents through vehicle sensors and the critical incident button, a third method of locating critical incidents was used. This third method entailed having an analyst manually review all of the tapes and watch for critical events. This third method was conducted in two stages. In the first stage, analysts, who were watching for lane change events, were also trained to keep vigilant for critical incidents. In the second stage, the first author of this document viewed all video tapes to identify critical incidents. This latter method (analyst review) proved very effective in locating any remaining incidents.

Power Requirements

A power inverter was used to supply the data collection equipment with power from the truck batteries. The total system required less than 150 watts of power and did not draw enough current from the truck to drain the batteries, even if the truck was shut off for a substantial period of time.

INSTRUMENTING THE DATA COLLECTION HARDWARE IN THE TRUCKS

In all, three data collection systems were developed and four L/SH trucks were instrumented. In the installation of the data collection hardware, it was important that the L/SH trucks were not damaged or permanently modified. Any modifications that were made to the trucks were repaired when the hardware was removed. A final check of the trucks once the hardware was removed was conducted to insure that the trucks were in the same, or better, condition as they were prior to installation.

Truck Types

The data that were collected for this effort came from four types of L/SH trucks: two panel vans of different lengths, a box truck, and a Class B straight truck. The trucks that were instrumented represent typical in-service trucks used at each company. The 15 ft panel van is shown in figure 11. It should be pointed out that it is the load-area, not including the driver's cab area, which measures approximately 15 ft. The 18 ft panel van is shown in figure 12. No special permit or drivers' license is required to operate a panel van. Note that the pictures have been modified to obscure the identifying markings.

Figure 11. 15' panel van used in the research.

Figure 12. 18' foot panel van used in the research.

A box truck was the third type of truck that was instrumented. As shown in figure 13, the cab area is separate from the load area. Access to the load is from the rear of the vehicle. This particular box truck had one "roll-door" in the back. This compares to other trucks that might have "swing doors." As with the panel vans, no special permit or drivers' license is required to operate a box truck.

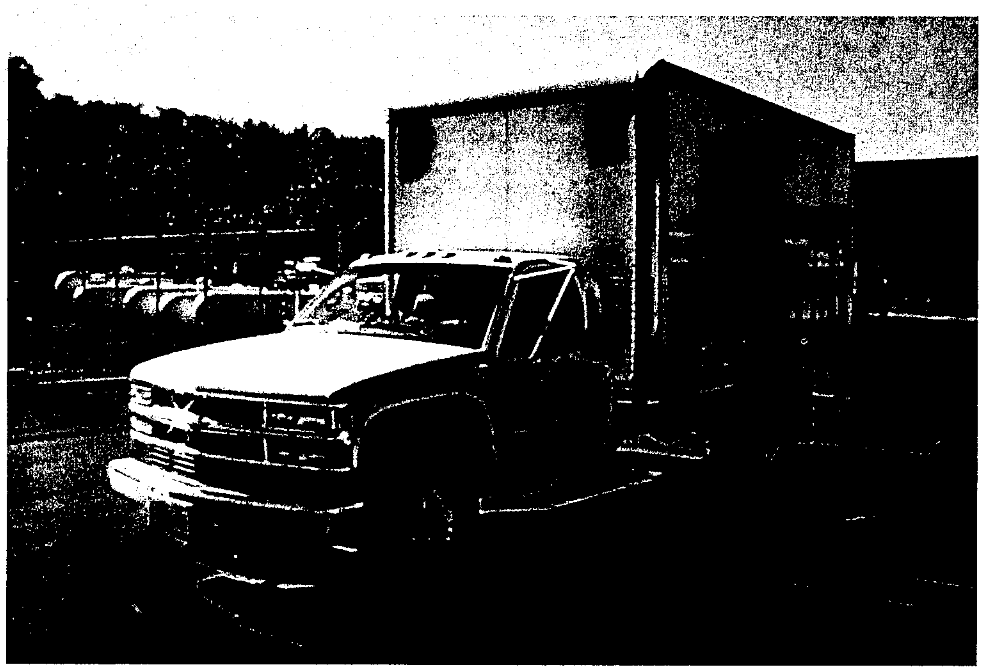

Figure 13. Box truck used in the research.

The fourth type of truck that was instrumented for this project was a Class B straight truck. This was the largest of the four trucks instrumented. Unlike the box truck, where entry was from the rear, entry to the load on this truck was from side roll-doors. Also, unlike the panel vans and the box truck, a Class B license is required to operate a Class B straight truck.

Figure 14. Class B straight truck used in the research.

DATA COLLECTION

TRUCKING COMPANIES

Two trucking companies participated in this research. One company hauls beverages while the other company hauls snack foods. Both trucking companies were paid for their participation. There were two types of payments made to the companies. The first payment was for use of the company trucks and garage facilities. Each company was paid a set amount for each truck they provided for instrumentation. The second payment to the companies was for allowing drivers to participate and for scheduling drivers on the instrumented trucks. For each driver that the company provided, a payment was made directly to the company. Billing was made on a monthly basis, whereby the companies would bill the Virginia Tech Transportation Institute for these services. As part of a contractual agreement made with each company, it was agreed that the companies would not coerce drivers to participate; rather driver participation was voluntary and drivers could withdraw at any time without censure or reprimand of any kind. Based on post-study driver debriefings, it is believed that neither trucking company coerced their drivers into participating. As described in the next section, the researchers also paid the drivers directly for their participation in the study.

DRIVER PARTICIPANTS

Forty-two male drivers participated in this research; 30 drivers from the beverage company and 12 drivers from the snack food company. (Note that the study was open to female drivers working at the companies; however, none of them chose to participate in this study.) Mean age of the drivers was 31 years. Each driver was expected to drive for two weeks. However, this estimate varied because of company scheduling, truck breakdowns, and other miscellaneous hindrances. In most cases, the schedule for drivers consisted of beginning their participation on a Monday and ending on the second Friday. That is, a driver typically worked Monday to Friday, and would have the weekend off. The driver would then work the following Monday to Friday. Though most drivers worked a Monday to Friday schedule, some drivers drove on Saturdays, while others began their workweek on Tuesdays. Still others worked four days per week, Tuesday through Friday.

All drivers were volunteers and were paid for participating. Each driver was paid a set amount for each day that he drove the instrumented truck and completed the required paperwork. In addition, drivers were paid for the weekend that occurred between their two weeks of driving. Payment for the weekend was based on the driver wearing the wrist activity monitor (described later) and completing the required paperwork. Finally, drivers received a small bonus if they completed the data gathering effort. The consent form that was signed by all participants is shown in appendix A, while the instructions that were presented to the drivers are shown in appendix B.

RESEARCH DESIGN

The research that was conducted can best be defined as a field study where data for a large number of variables were collected. The primary components of the research design are presented in the following sections.

Variables

To examine the impact of fatigue on L/SH operations, a number of variables were investigated. Perhaps the most logical way to present the variables of interest is to group them by the method in which they were collected. That is, variables were collected in one of three ways: (1) using "black box" data collection equipment instrumented on the trucks, (2) through questionnaires and paper-and-pencil forms completed by the drivers, and (3) via wrist activity monitors. Each method, along with the variables collected for that method, is described in turn.

Black Box Variables

The "black box" systems that were instrumented in the trucks collected a variety of driving performance data. A detailed description of the black box systems is presented in Wierwille, Hanowski, and Dingus (1998). Table 13 provides a description of the variables that were collected by the black boxes. Note that the data were collected either directly from the equipment, or by means of an analyst reviewing video tapes of the driver and the driving environment. A description of the analyst's data reduction process is presented later. Many of the variables, such as subject number, driver age, gender, etc., were recorded by one or both of the other methods (i.e., the paper-and-pencil forms and/or the wrist activity monitor).

Table 13. Variables collected by the black box systems, or derived by an analyst after reviewing the videotape of the incident.

Name	Description
Subject	Unique number assigned to each subject/driver.
EventNum	Unique identification number for each event.
CIType	Assessed cause of the incident where: Caused by the L/SH driver = 1; Caused by the driver of another vehicle = 2; Driver reporting an incident but not involved = 3; Driver reacting to a situation, but not caused by the driver of another vehicle (e.g., animal, debris in road) = 4.
CIButton	Who/what indicated the presence of an incident? Driver triggered = 1; Truck-sensor triggered = 2; Analyst triggered = 3.
Age	Age of the driver (years).
Gender	Gender of the driver (Female = 0; Male = 1).
Company	Company identification number (Beverage = 1; Snack = 2).
TruckTyp	L/SH truck type identification number (Class B Straight=1; Box Truck=2; 18' Panel=3; and 16' Panel=4).
TruckNum	Unique identification number for each truck within a company (First truck=1; Second truck=2). Note that two trucks were instrumented for each company.
DayWeek	Day of week (MON=1; TUES = 2; WED = 3; THUR = 4; FRI = 5; SAT = 6; & SUN = 7).
Shift	Normalized shift number where: First shift in driver's week = 1; Second shift = 2; etc.
TimeDay	Time of day (24 Hr. Clock).
ObsSync	Sync value that is approximately 3 minutes from event start point.
SyncBeg	Beginning sync value of the event (event start point).
TenBefor	Sync value approximately 10 seconds prior to event start point.
SyncEnd	Sync value at the end of the event (event end point).
Duration	Total time length of the event (event start point to event end point).
DurTen	Total time length of the event plus 10 seconds.
Illumin	Illumination outside vehicle (Dawn = 1; Daylight = 2; Dusk = 3; Night = 4; Other = 5). Later changed to Not Daylight=0; Daylight=1).
Visibil	Visibility outside of vehicle (Unlimited = 1; Rain = 2; Snow = 3; Fog = 4; Darkness = 5; Glare from Sun = 6; Glare from Headlights = 7; Twilight = 8; Other = 9). Later changed to Poor=0; Unlimited=1).
Weather	Weather conditions (Clear/Dry = 1; Drizzle = 2; Hard Rain = 3; Light Snow = 4; Hard Snow = 5; Sleet = 6; Other = 7; Cloudy = 8). Later changed to Not Poor=0; good=1).
Observ	Analyst's rating of driver drowsiness for the interval prior to the event start point (under ordinary conditions, this interval is three minutes). Drowsiness scale ranges from 0 (not drowsy) to 100 (extremely drowsy). Value outside of this range indicates that the assessment was not performed. Reasons for not performing an analysis includes not having enough videotape prior to the event to make an assessment and poor video quality.
PerClos	Time that eyes are closed or nearly closed divided by measurement interval prior to the event start point (under ordinary conditions, this interval is three minutes). Negative values indicate that the analysis was not performed.
EyeTrans	Number of eye transitions, from one major area to another, divided by the measurement interval prior to the event start point (under ordinary conditions, this interval is three minutes). Negative values indicate that the analysis was not performed.
EyesOff	Total time eyes were off the road divided by the measurement interval prior to the event start point (under ordinary conditions, this interval is three minutes). Negative values indicate that the analysis was not performed.
PropCFw	Proportion of time the driver looked center/forward from 10 seconds prior to the event start point until the end of the event.
PropLFw	Proportion of time the driver looked left/forward from 10 seconds prior to the event start point until the end of the event.
PropRFw	Proportion of time the driver looked right/forward from 10 seconds prior to the event start point until the end of the event.

PropLMir	Proportion of time the driver looked at the left (driver-side) mirror from 10 seconds prior to the event start point until the end of the event.
PropRMir	Proportion of time the driver looked at the right (passenger-side) mirror from 10 seconds prior to the event start point until the end of the event.
PropLWin	Proportion of time the driver looked out the left (driver-side) window (and not at the mirror) from 10 seconds prior to the event start point until the end of the event.
PropRWin	Proportion of time the driver looked out the right (driver-side) window (and not at the mirror) from 10 seconds prior to the event start point until the end of the event.
PropIP	Proportion of time the driver looked at the instrument panel from 10 seconds prior to the event start point until the end of the event.
PropOth	Proportion of time the driver looked at any other location from 10 seconds prior to the event start point until the end of the event.
PkLatAcl	Peak lateral acceleration (g) calculated over an interval beginning ten seconds before the beginning of the event to the end of the event.
PkLngAcl	Peak longitudinal acceleration (g) calculated over an interval beginning ten seconds before the beginning of the event to the end of the event.
MeanVel	Mean velocity (mph) calculated over an interval beginning ten seconds before the beginning of the event to the end of the event.
RoadType	Type of roadway (Parking Lot/Loading Area = 0; Alley Way = 1; One Way Road = 2; Rural Undivided = 3; Rural Divided by Median = 4; Rural Divided by Lane = 5; Urban Undivided = 6; Urban Divided by Median = 7; Urban Divided by Lane = 8; Other = 9).
RoadGeom	Geometry of the roadway (Straightaway = 0; Curve Left = 1; Curve Right = 2; S-Curve = 3; Intersection on Straightaway = 4; Intersection on Curve = 5; Loading Area/Parking Lot = 6; Merge Lane from Right = 7; Merge Lane from Left = 8; Other = 9).
RoadCond	Condition of roadway (Dry = 0; Wet = 1; Icy/Snow = 2; Gravel/Sand on Road = 3; Gravel Road = 4; Other = 5).
TraffDen	Density of surrounding traffic assessed in terms of level-of-service (LOS) (Not Applicable = 0; LOS A = 1; .LOS B = 2; LOS C = 3; LOS D = 4; LOS E = 5; LOS F = 6). For details about LOS, see the LOS definitions following the tables.
NumLanes	Number of lanes in roadway going in same direction as truck.
DrivLane	Lane that the driver was in at start of event (Not Applicable = 0; Right Lane = 1; Middle Lane = 2; Left Lane = 3; Shoulder = 4; Other = 5).

Paper-and-Pencil Variables

Data for a number of variables were collected using questionnaires and forms. Prior to beginning the study, and each day during the study, drivers completed paper-and-pencil questionnaires. Prior to the study, demographic information was collected. The demographic questionnaire that was administered to the drivers is shown in appendix C. Each day during the study, drivers complete three paper-and-pencil forms. The first daily form, presented in appendix D, was used to assess driver fatigue at the start of the driver's shift. The second form, presented in appendix E, was administered at the end of the shift and used to assess fatigue, workload, and activities performed during the shift. The third form, presented in appendix F, was a sleep log completed by drivers prior to sleeping and upon waking. Each question on the paper-and-pencil forms can be considered a variable that was, as appropriate, analyzed to determine the impact of fatigue on L/SH operations.

Activity Monitor Variables

In order to collect physiological fatigue-related data from drivers, activity monitoring was conducted. To this end, three Actiwatch units, developed by Mini Mitter Co, Inc., were used. As shown in figure 15, the Actiwatch units are small, wrist-worn devices. Monitoring is done using a piezoelectric accelerometer. As outlined in Mini-Mitter documentation, the Actiwatch monitors wrist movements at a rate of 32 times per second and integrates the degree and intensity of these movements. Data are downloaded from the watches using an Interface/Reader. Analyses were conducted using the Sleepwatch V. 2.53 software that was provided with the Interface/Reader.

Though a multitude of variables are available from the Actiwatch, the two that were of most interest for this effort were sleep quality and sleep quantity. Both of these sleep metrics were derived by the Sleepwatch software.

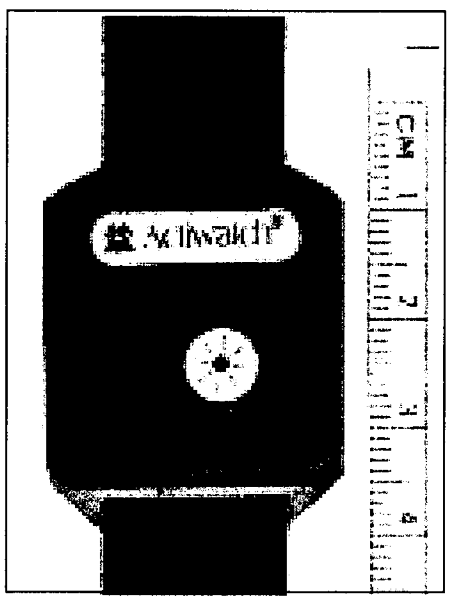

Figure 15. The Actiwatch wrist activity monitor by Mini Mitter. Picture downloaded from website: www.minimitter.com.

It must be pointed out that the research team had some difficulty with the Actiwatch units during this project. Specifically, the black plastic shell casing that enclosed the units broke down. After several weeks of use, wear-through holes were noticed on the corners of the casings (this occurred, at different times during the study, with all three units). When a hole was noticed, the unit was retrieved from the driver and a replacement watch was used. Unfortunately, holes in the casing resulted in complete data loss for that particular driver. As will be outlined later in the Results section, the loss of Actiwatch data was substantial during this study; there were 554 recordings from the driver's daily sleep log as compared to 414 Actiwatch recordings (i.e., a loss of 140 days of Actiwatch data).

DATA REDUCTION

OVERVIEW

Data reduction involved processing the raw data and putting the data in a form that was conducive to statistical analysis. The following sections outline this process.

THE PROCESS OF REDUCING AND ARCHIVING EACH EVENT

The process of reducing and archiving each critical incident (event) required the data reduction/archiving analyst (analyst) to complete six steps. The following sections provide a description of each step.

Step 1: Set Up Event

Setting up the event refers to locating an event on the videotape and preparing it for reduction/archiving. Before setting up the event, the analyst began by logging into the software program. Once logged into the program, the screen shown in figure 16 appeared.

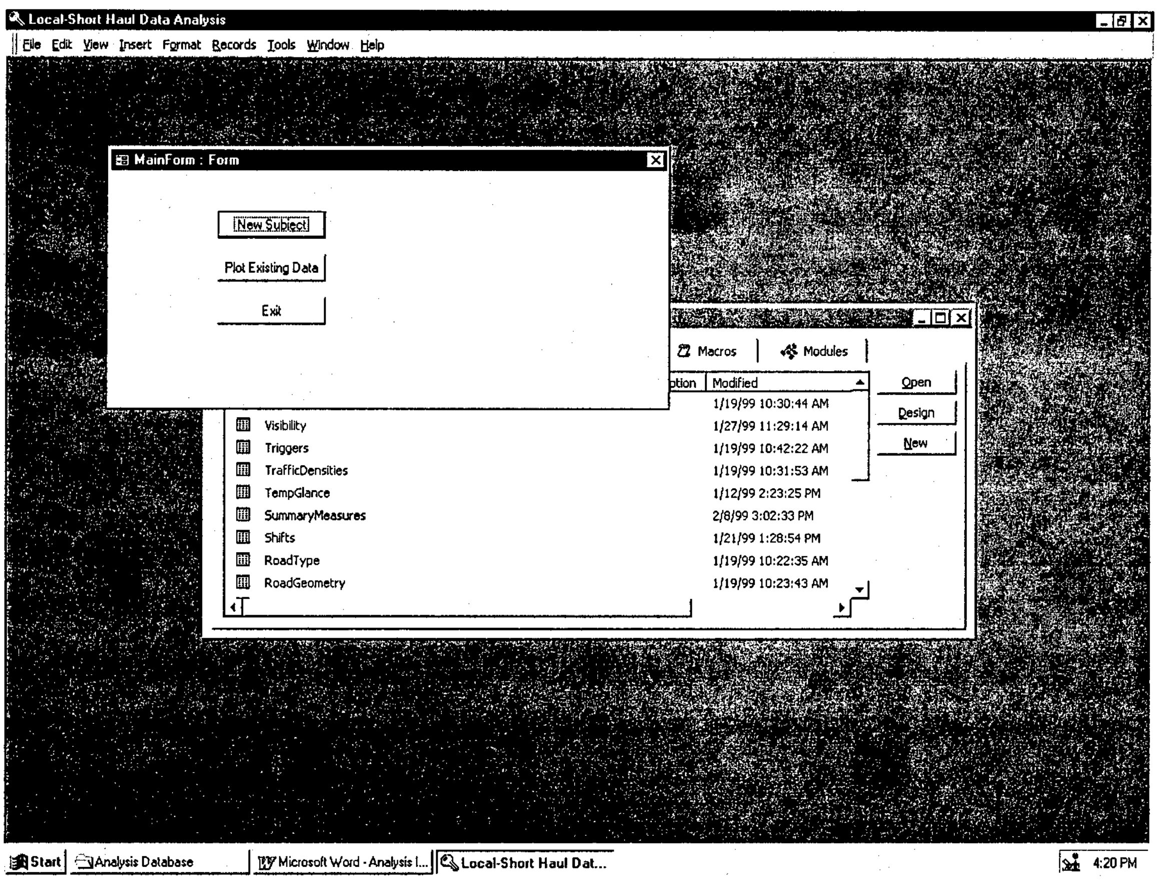

Figure 16. First screen of the program after logging into the system.

On the screen shown in figure 16, the analyst indicated the location of the data files to be analyzed (i.e., the directory in which the data files were stored). If the analyst was starting to reduce/archive a new subject (i.e., a subject number that had not been entered into the system), the analyst opened the New Subject form shown in figure 17.

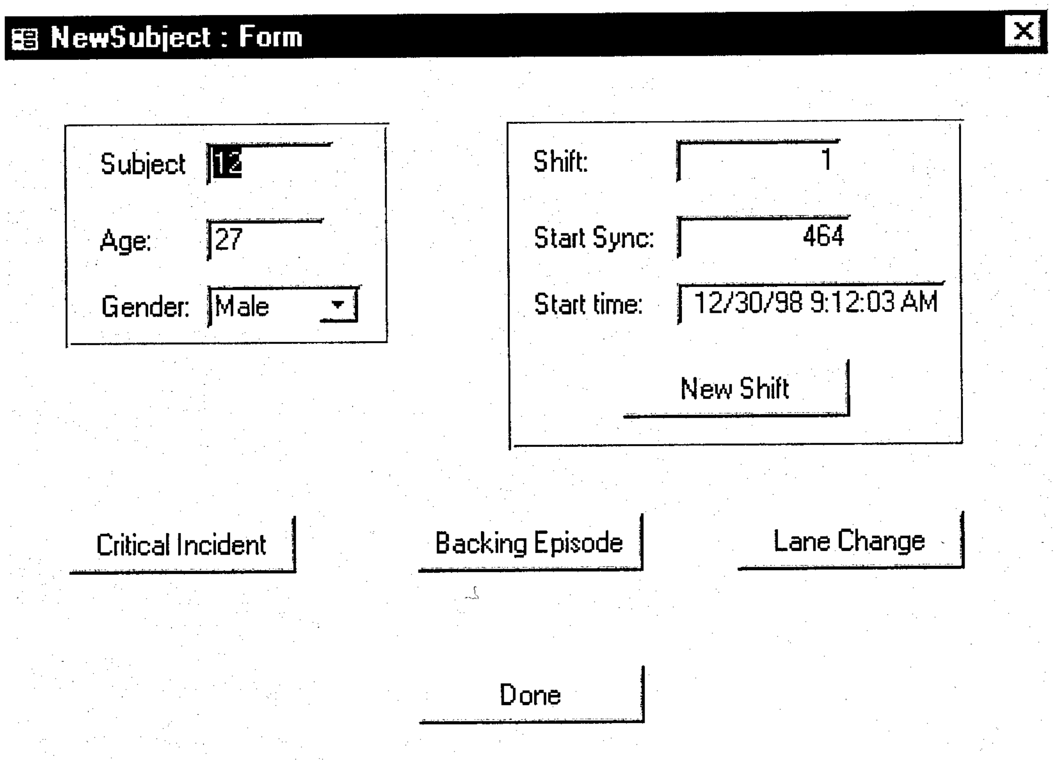

Figure 17. New Subject form.

Once reduction/archiving began on a new subject's data, the analyst entered the "sync" number (i.e., tagged video number) that corresponded to the beginning of that subject's work shift. Determining the start of the work shift was done for each new day of driving.

After the start of the shift had been determined, the analyst began to search for events. There were different types of events that were of interest: critical incidents, lane changes, and backing maneuvers.

When an event was located, the analyst filled-in the program fields shown in figure 18. Note that the fields in this form changed slightly depending on the type of event being analyzed. For example, the field and diagram in the lower right corner labeled "Lane Change" was only filled-in for lane change events. If a critical incident or backing event was being examined, this field was "grayed" (i.e., would not allow analyst input).

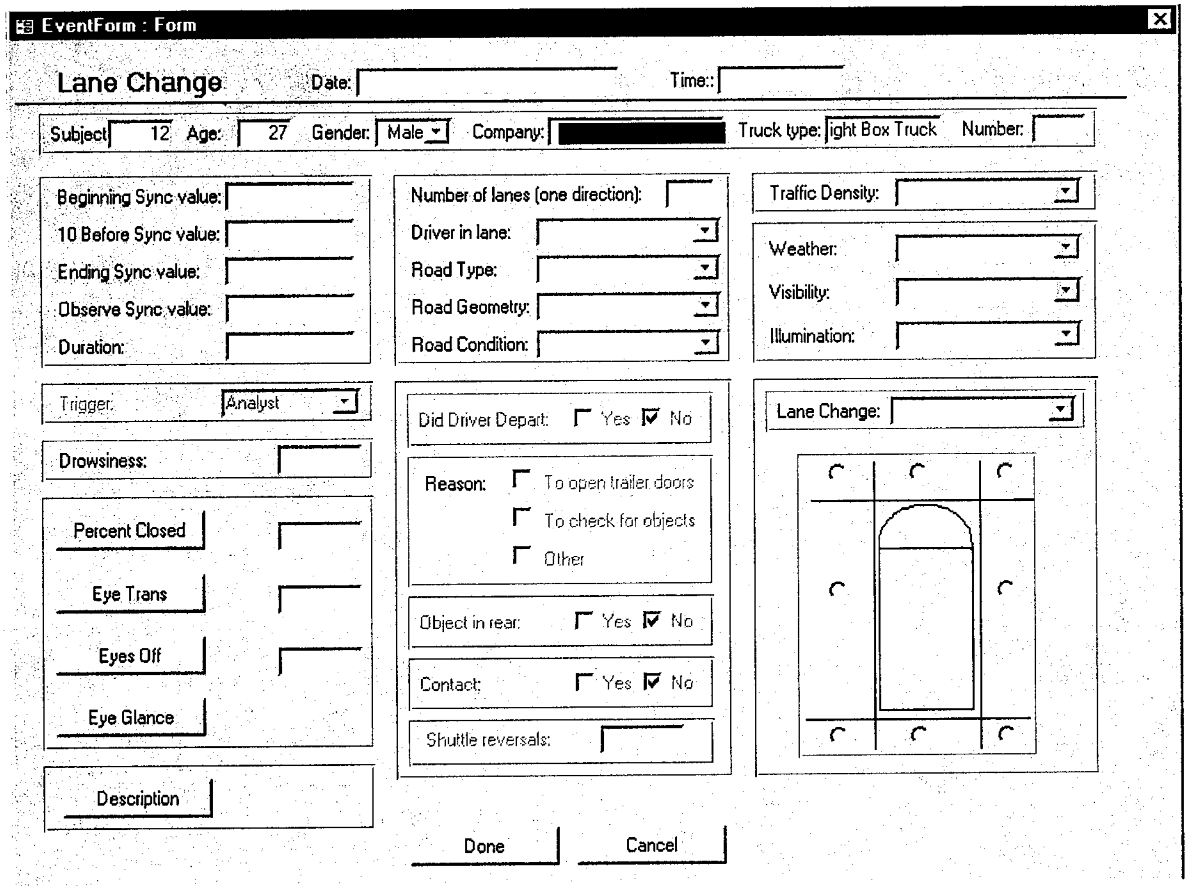

Figure 18. Event form used to enter information in the reduction/archiving process.

As can be seen in figure 18, the analyst entered a number of information items including: the truck number, the sync number that corresponds to the beginning of the event, the sync number that corresponds to 10 seconds prior to the beginning of the event (used for eye glance analyses), the end of event sync number, the sync number that corresponds to three minutes prior to the start of the event (used for drowsiness analyses), number of lanes, lane of travel, road type, road geometry, road condition, traffic density, weather, visibility, and illumination. In addition, for lane change events, the analyst determined the type of lane change that occurred (e.g., pass on left, merge right, etc.), and the location of any vehicles at the time the lane change began. For backing events, the analyst determined if the driver departed the vehicle prior to backing and, if so, the reason for the departure. The analyst also indicated if an object was present behind the truck at the time of backing, if contact with an object was made, and if "shuttles" were made.

Note that a "shuttle" is a shifting from reverse to forward and back to reverse. For both backing and critical incidents, the analyst specified what the event trigger was (i.e., truck trigger, critical incident button, or analyst's observation).

Step 2: Drowsiness Assessment

For all events, the analyst assessed the drowsiness level of the driver prior to the beginning of the event. The OBSERV measure was determined after the analyst reviewed the video for the three minute interval prior to the start of the event. Once this three minute segment was reviewed, the analyst used the drowsiness scale shown in figure 19 to make his/her assessment.

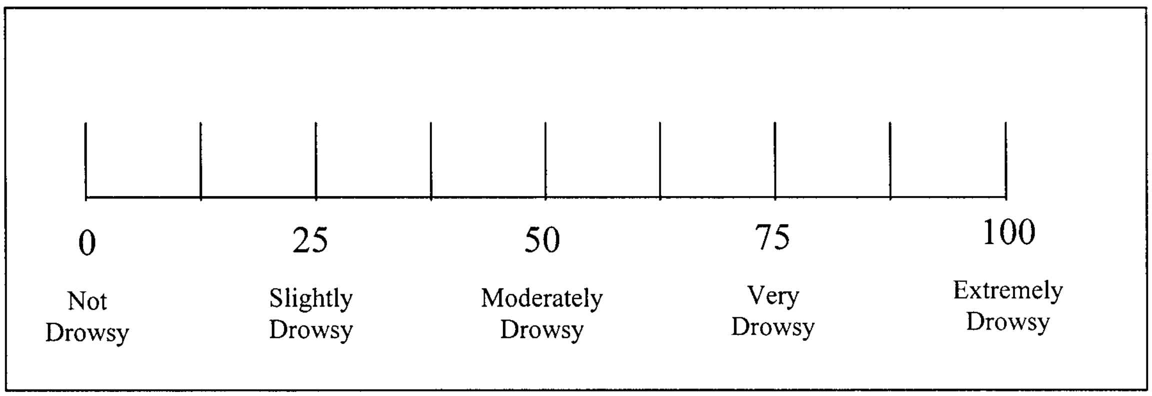

Figure 19. Drowsiness scale used by the analysts.

In addition to OBSERV, three other fatigue/inattention measures were determined: PERCLOS (fatigue), EYETRANS (inattention), and EYESOFF (inattention). Like OBSERV, each of these three measures was calculated for the three minute interval preceding the start of the event. Each of the three measures (i.e., PERCLOS, EYETRANS, and EYESOFF) was determined one at a time.

Though previous research have described the validity of PERCLOS (Wierwille, 1999) and OBSERV (Wierwille and Ellsworth, 1994), EYETRANS and EYESOFF are new measures that are being used for the first time in the present study. The assumed validity of these measures is based on the hypothesis that multiple short glances (i.e., scanning) with a high proportion of glances to the forward view (i.e., road) are likely to result in attentive and safe driving. Though these measures have not been validated, it seems reasonable to suggest that drivers who gather frequent small samples of the environment, and devote the largest proportion of time to the forward view, would appear to demonstrate a high level of attention to the driving task. It is also suggested that this higher level of attention would equate to safe driving.

The process of determining each measure was similar. Recall that previously, the analyst entered into the program the video sync number that corresponded to the beginning of the event. As in determining OBSERV, the analyst would rewind the video tape to three minutes prior to the start of the event. It was this time interval, from three minutes prior to the start of the event until the start of the event, which the analyst would use to determine OBSERV, PERCLOS, EYETRANS, and EYESOFF.

The program form shown in figure 20 was used to determine PERCLOS, the proportion of time during the interval that the driver's eyes were closed or nearly closed. As can be seen in the PERCLOS form, the analyst would type in the "Observe Sync" value, or the sync number corresponding to the point in the video that was three minutes prior to the beginning of the event. Based on the sync number for the beginning of the event (entered previously), the program automatically calculated the duration of the interval (i.e., approximately three minutes). Then, at the same time, the analyst would start the video and click the Start button on the PERCLOS form. Whenever the driver's eyes were closed, the analyst would press the "c" key on the keyboard. Whenever the driver's eyes were open, the analyst would release the "c" key. Whenever the analyst could not determine if the driver's eyes were open or closed, he/she would press the "x" key. The "x" key served to reduce the interval for the length of time that the "x" key was held down. At the end of the interval (i.e., when the sync number for the beginning of the event was reached), the program would automatically shut off and calculate PERCLOS by determining the total length of time that the "c" key was held down and dividing this value by total interval period. As shown in figure 20, the program would show the analyst the total time that the driver's eyes were closed, the derived percent closed, and the excluded time (i.e., time that the "x" key was pressed down). When the analyst was satisfied that PERCLOS was determined correctly, he/she clicked the "Done" key on the program form and the PERCLOS analysis was saved. (It should be noted that the program used the "proportion" definition of

PERCLOS internally, but multiplied the value by 100 to display it as a percentage, as shown in figure 20.)

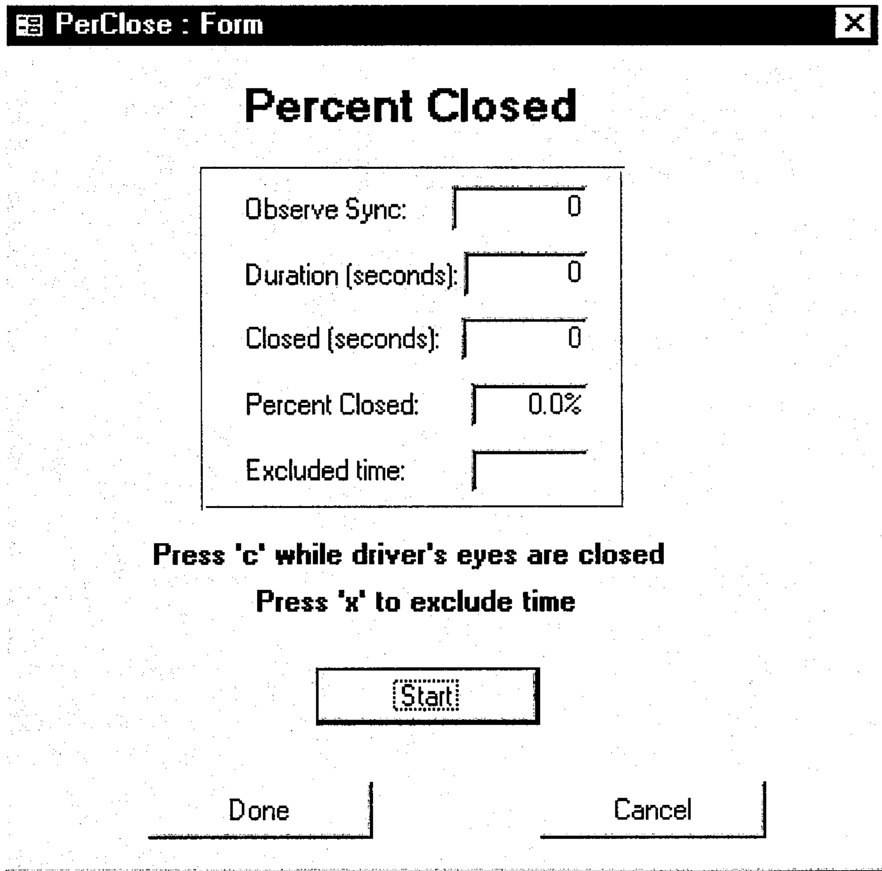

Figure 20. Program form for calculating PERCLOS.

EYETRANS, the number of eye transitions made by the driver over the three minute interval, was the third drowsiness/inattention measure determined by analyzing the video tape. The process for the analyst in determining EYETRANS was similar to that for determining PERCLOS. Figure 21 shows the EYETRANS form that was used. The analyst began by typing in the sync number corresponding to the point in the video that was approximately three minutes before the beginning of the event (i.e., Observe Sync). Using the Observe Sync number and the sync number corresponding to the beginning of the event, the program would calculate the time interval between the two sync numbers. Once this was done, the analyst would begin the video from the point three minutes prior to the start of the event, and click "Start" on the program form at the same time. Whenever the analyst would see the driver transition his eyes from one location to another, the analyst would press the "t" key on the keyboard. When the analyst could not determine what was occurring in the video, he/she would press the "x" key to exclude time in the interval. At the end of the interval, the program would calculate the total number of transitions (frequency count) and divide this number by the time interval to determine the eye transition rate, or EYETRANS. When the analyst was satisfied with the output, he/she would click "Done" and the EYETRANS analysis would be saved.

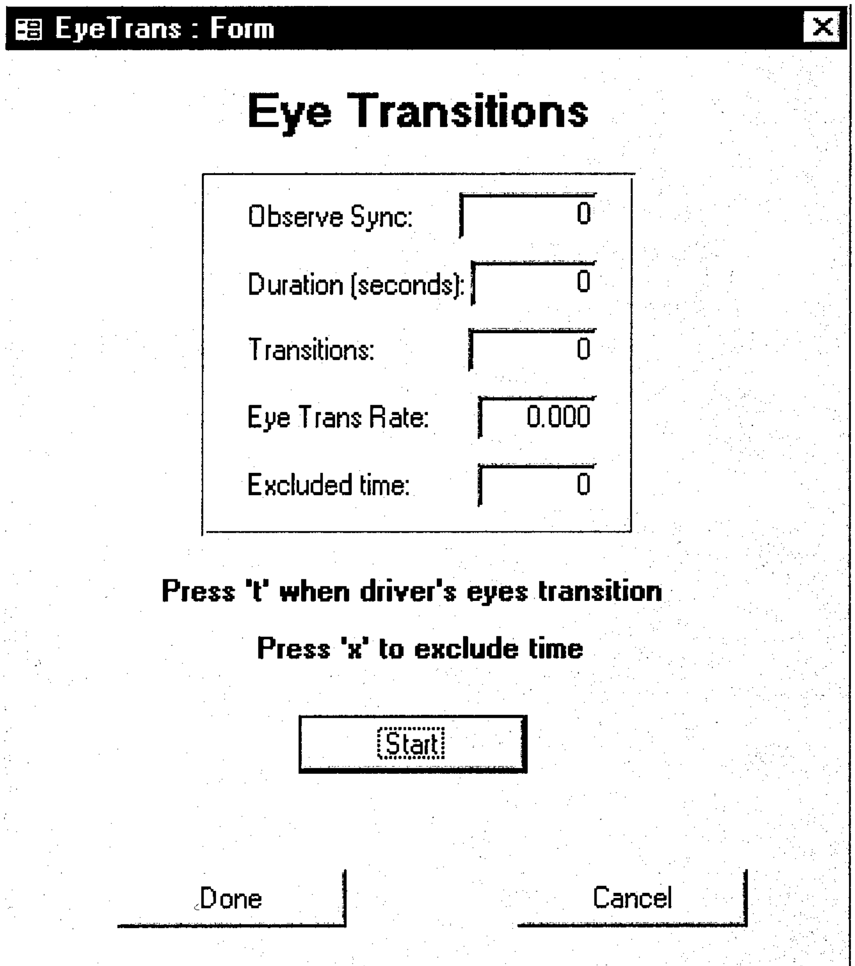

Figure 21. Program form for calculating EYETRANS.

EYESOFF, the proportion of time that the driver's eyes were off the road during the three minute interval, was the fourth drowsiness/inattention measure determined by the video analyst. Figure 22 shows the program screen that was used. The process to determine EYESOFF was similar to those of PERCLOS and EYETRANS. The only difference was that the analyst pressed the "o" key whenever the driver's eyes were off the road. Based on the interval duration, and the total time that the driver's eyes were off the road, the EYESOFF measure was determined. (Here also, the EYESOFF proportion was multiplied by 100 and displayed as a percentage in the form.)

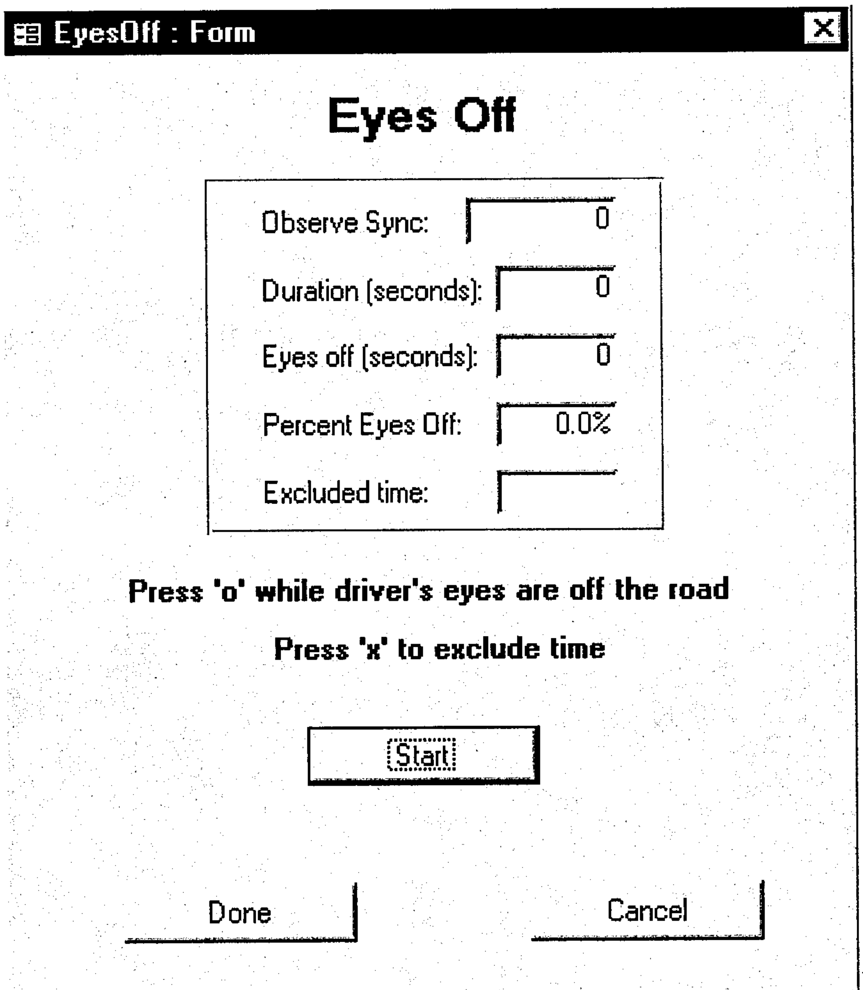

Figure 22. Program form for calculating EYESOFF.

Step 3: Eye Glance Reduction

The third step in the reduction/archiving process was to determine the eye glances of the driver *for the 10 second interval preceding the start of the event until the end of the event.* The Eye Glance form, shown in figure 23, was used for this process.

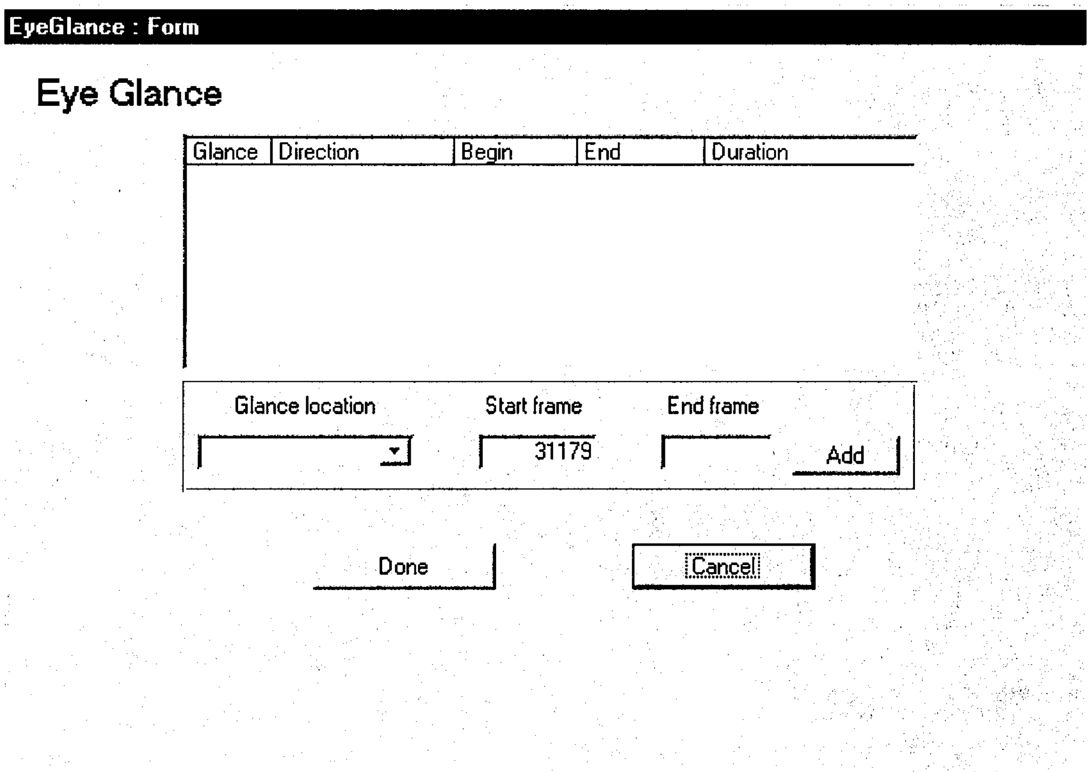

Figure 23. Program form for documenting eye glances.

As can be seen in the Eye Glance program form, a record was kept of the glance number, the glance direction/location, the sync number corresponding to the beginning of the glance, the sync number corresponding to the end of the glance, and the duration of the glance. The three fields in the middle of the form consist of: (1) Glance location, which is a pull-down menu of the different glance locations, (2) Start frame, which is the sync number for the start of the glance, and (3) End frame, which is the sync number for the end of the glance.

As noted, eye glances were determined for the interval that lasted from 10 seconds prior to the beginning of the event until the end of the event. The process of conducting the eye glance reduction occurred as follows, where the analyst would:

1. Find the point on the video that was 10 seconds prior to the start of the event.
2. Run the tape until the first eye glance, within the interval, was identified. Once the first glance was identified, the analyst would pause the video.
3. Identify this first glance location by using the pull-down menu that listed the various locations.
4. Type in the sync (frame) number for the start of this glance.
5. Un-pause the video and re-pause it when the glance location changed.
6. Type in the sync number corresponding to the end of the glance. This value also served as the beginning sync number for the next glance. In this manner, the transition time was included with the previous glance.
7. When the analyst was satisfied with the glance location and the start and end numbers, he/she would click the "Add" button and the glance information would be pasted to the columns in the form. This first glance would be labeled with a "1" in the glance number column and the location would be noted in the glance location column (note that the words "location" and "direction" are used synonymously). Begin, end, and duration values would also be noted for the glance.
8. This process of identifying eye glances would continue until the event was over.

Step 4: Written Description of Event

The written description was the fourth step in the data reduction/archiving process. The form in figure 24 shows the field where the analyst could type in information about the event. A sample description is also shown in the paragraph following figure 24.

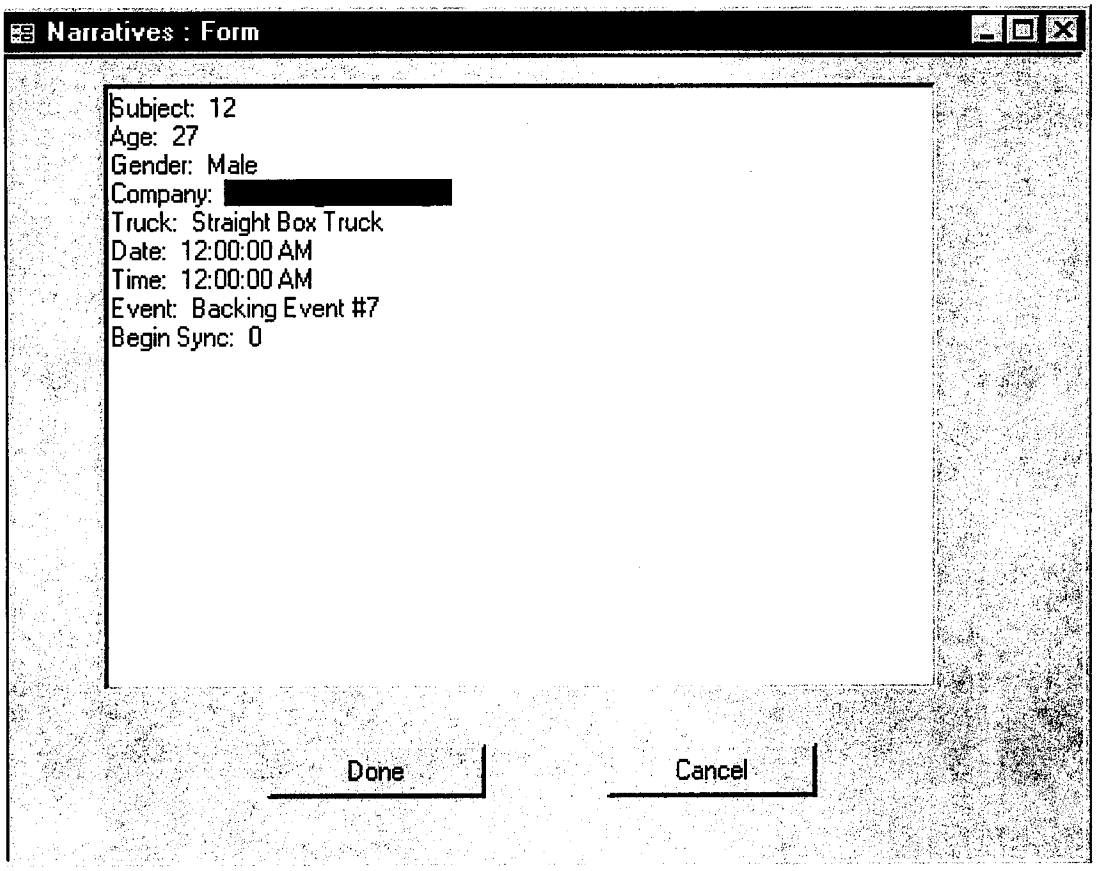

Figure 24. Form used to enter written description for the event.

<u>Sample Written Description</u>

The driver was returning back to the Distribution Center. He was driving east on I-81 and the traffic was moderately heavy ("C"). The driver was traveling in the middle lane and was approaching his exit. As he was about to turn off of the highway onto Exit 112, a Ford Escort cut the truck off, moving over from the far left lane, without signaling, forcing the truck driver to slam on the brakes. As the truck driver applied the brakes, he moved off the center of the lane to the right. He had one wheel in the right shoulder for approximately 5 seconds. There were no vehicles following the truck, so there was no chance of the truck being struck in the rear. The Escort sped away down the exit. The aggressive driving of the Escort's driver was the cause of the incident. The time of day was late afternoon and the sun was beginning to set. Visibility was good. The roads were clear and dry. The critical incident flag was initiated by the truck's sensors and *also by the driver who pushed the incident button. The driver described the incident by saying "he just cut me off," and pointing at the Escort.*

Step 5: Video Capture

The video capture process consisted of digitizing the event on the computer. In order to create the digital video files of the events, the program MiroVideo Capture was used. The resulting digitized video was saved in a bitmap format. The file was imported into AdobePremiere 5.0 and then formatted as a Quicktime movie. The final reduction/archiving data set includes digitized Quicktime files for all events. It should be noted that the digitized captured video was of lower resolution than the videotape image itself. The captured video was intended to provide an overview of the event while not overburdening system memory.

Step 6: Plotting of the Data

As a final step, the analyst indicated that the reduction/archiving was complete and pressed a "Done" button. At this time, the program automatically created a number of plots to characterize the events. The output for this step is fairly extensive, and an example is shown in appendix G. As can be seen in appendix G, the plots, along with the written description of the event, were collated into a single Excel file. Note that the plotted data differ somewhat depending on what type of event was reduced/archived (i.e., critical incident, backing, or lane change). For example, backing events have certain plots that lane change or critical incidents events do not have.

DATA FILES

Once the data reduction/analysis was complete, three data files were created. Of primary interest for the analysis of the critical incidents was the file called "Summary Measures." The purpose of the Summary Measures data set was to obtain a snap-shot of the measures associated with an event. Each row of this data set was one event (either critical incident, backing episode, or lane change maneuver). Columns of the data set represented the different variables, as described previously in table 12.

The second data file created from the reduction/archiving process was called "Performance." The Performance file provided a more in-depth set of data for each event, as compared to the Summary Measures file. In the Performance Measures file, a block of data, from 10 seconds prior to the start of the event to the end of the event, was stored for each event.

The third data file was the "Eye Glance" file. It was in this file that the data from the eye glance analysis were stored. Summary data from the Eye Glance file were also included in the Summary Measures file as proportions. That is, the proportion of time that a driver was looking at the instrument panel (for example, for the 10 second time interval preceding the event until the end of the event) was included as a measure of interest for each event.

RESULTS AND DISCUSSION

OVERVIEW

There are six outputs stemming from this research effort: (1) descriptive statistics on the drivers, (2) a description and categorization of critical incidents, (3) determining if fatigue is an issue in L/SH trucking, (4) an analysis focusing on critical incidents occurring while making lane changes and backing maneuvers, (5) the validation of the fatigue factors cited in Hanowski et al. (1998), and (6) guidelines to address fatigue in L/SH operations. The six major sections that follow detail each output.

DESCRIPTIVE STATISTICS ON THE DRIVERS

DRIVER WORKDAY

As outlined previously, compared to long-haul drivers, L/SH drivers perform a variety of tasks during their workday. At the end of each work day, drivers completed a questionnaire that queried them on the activities they performed during their work day. A breakdown of the drivers' tasks, as reported on the post-shift questionnaire, is shown in figure 25. Collectively, drivers spent about 28 percent of their day driving, 35 percent loading/unloading, 26 percent with other assignments (e.g., merchandising, checking in/out, vehicle inspection, etc.), 7 percent waiting to unload, 2 percent eating, 0.5 percent resting, and 1.5 percent on other activities.

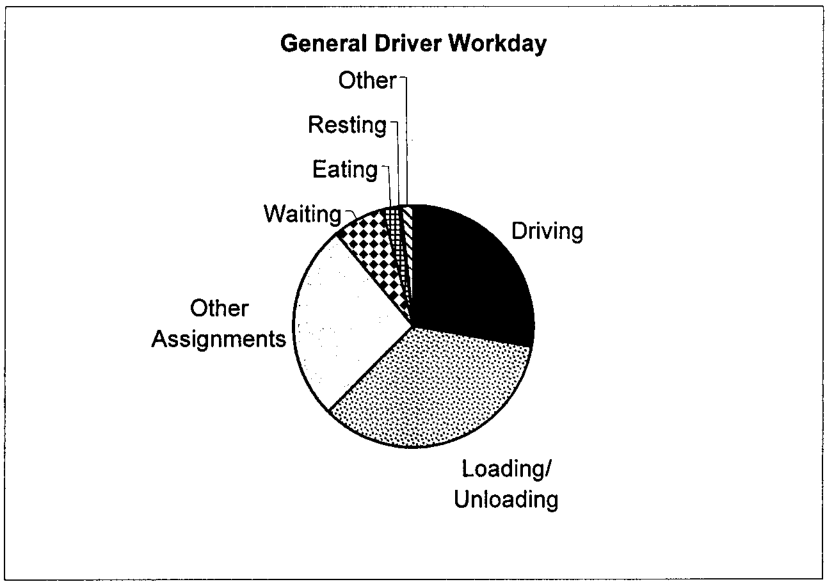

Figure 25. Percentage of workday spent on tasks; data summarized for all drivers.

Note that the data shown in figure 25 are means across all available data for all drivers. Substantial differences were seen in tasks across the two groups of drivers (i.e., beverage vs. snack). Figure 26 shows the workday breakdown for beverage drivers and figure 27 shows the breakdown for snack food drivers. As can be seen, the snack food drivers spent a greater percentage (nearly 40 percent) of their time on other assignments such as merchandising and stocking shelves (i.e., "other assignments"), while the beverage drivers spent about 20 percent of their day performing similar assignments. In addition, beverage drivers reported that driving constituted more than 30 percent of their day, while the snack food drivers noted driving for about 20 percent of their day.

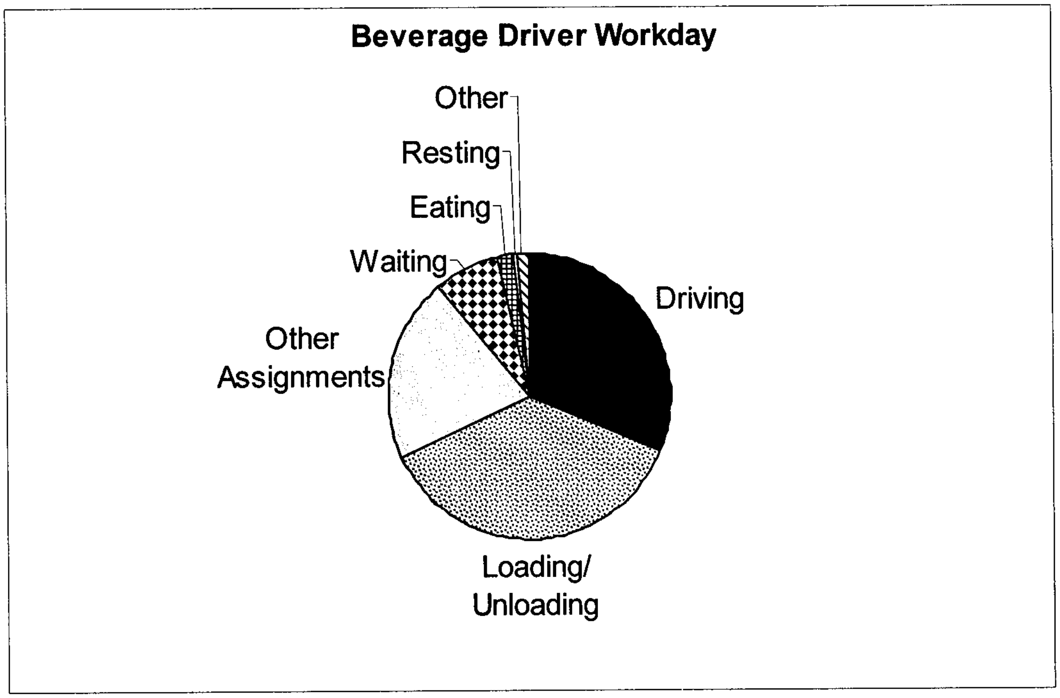

Figure 26. Percentage of time spent on tasks for beverage truck drivers.

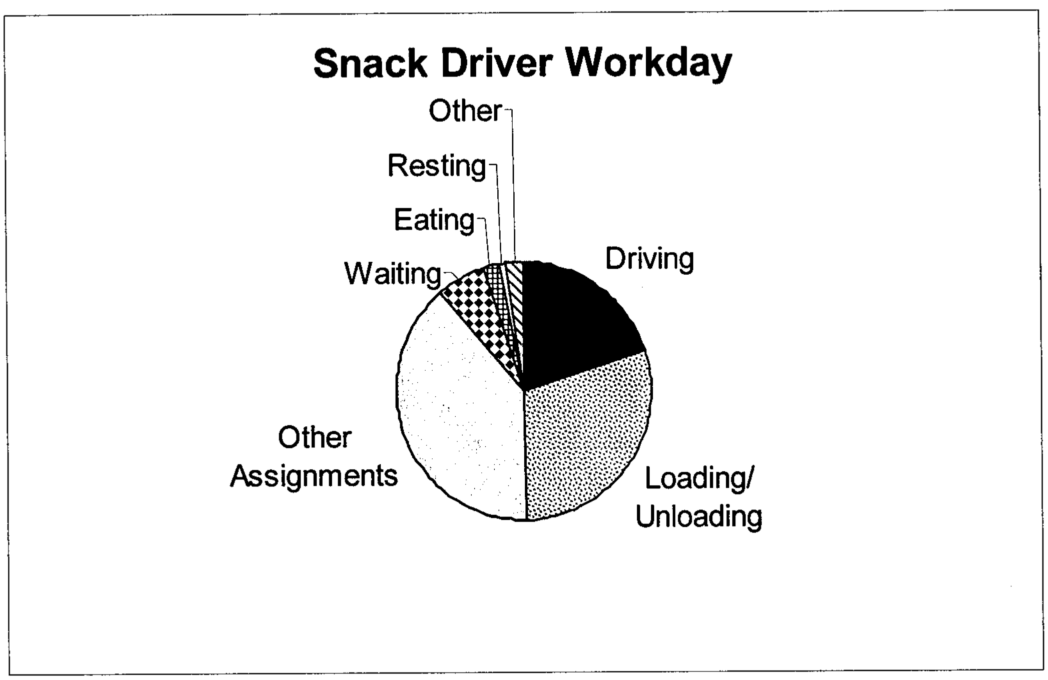

Figure 27. Percentage of time spent on tasks for snack food truck drivers.

DRIVER COMPARISONS

Table 14 outlines descriptive measures for the two groups of drivers for a variety of measures that were collected. (Note that all data in the table are presented on a per workday basis.) As can be seen, the two groups of drivers differed on a number of measures, including average miles driven per workday, number of deliveries made, the average load that was carried, and the length of the workday. The table shows that the beverage drivers drove more during the day than did the snack food drivers, a result that is consistent with the task breakdowns shown in figures 26 and 27. The beverage drivers also made more deliveries than did the snack food drivers. This result is also consistent with the data shown in the previous two figures. The start times for the drivers of the two companies were similar, though the snack food drivers worked approximately 1.5 hours per day more than the beverage drivers.

Table 14. Descriptive measures for each company/group of L/SH drivers.

Company/ Truck	Statistic	Miles	Deliveries	Load (lbs.)	Start Time (A.M.)	End Time (P.M.)	Shift Time (hrs.)
Beverage (N=30)	Mean	100.89	13.14	3037.23	5:54	16:32	10.50
	Std. Dev.	37.48	2.47	1867.52	0:26	0:51	1.17
Snack (N=12)	Mean	70.30	7.02	1138.31	5:35	18:05	11.87
	Std. Dev.	26.31	2.25	897.65	0:45	2:05	1.54
All Drivers (N=42)	Mean	92.15	11.39	2481.45	5:49	16:59	10.89
	Std. Dev.	37.08	3.67	1851.51	0:34	1:29	1.41

It must be noted that not only were there differences between drivers of each trucking company, but there were also differences between the types of trucks within each company. Table 15 presents the same measures shown in table 14, categorized according to truck type for each company. The data in table 15 show that the larger truck for the beverage company (i.e., Class B) drove fewer miles than the smaller box truck. However, the larger snack food truck drove more miles on average than did the smaller snack food truck. The total shift time shows that both groups of drivers from the beverage company typically worked 10 to 11 hours per workday, while the snack food drivers worked roughly 12 hours per workday. It should be noted that the majority of drivers, both beverage and snack food, typically worked five days per week. However, as outlined previously in the *Driver Participants* section, some drivers did work four days per week while a few drivers worked six. It should be pointed out that there were a total of 462 post-shift questionnaires that were completed (one questionnaire completed per day), and there were only two instances of drivers working fewer than eight hours on a Saturday (in these two instances, the total work day was approximately 7 hours). The start, end, and shift times shown are averages per day, regardless of the days or number of days worked.

Table 15. Descriptive measures for each truck type for each company.

Company/ Truck	Statistic	Miles	Deliveries	Load (lbs.)	Start Time (A.M.)	End Time (P.M.)	Shift Time (hrs.)
Beverage/ Class B (N=12)	Mean	85.48	11.28	4118.92	5:42	16:33	10.78
	Std. Dev.	34.96	1.29	2397.95	0:28	0:35	0.62
Beverage/ Box (N=18)	Mean	111.16	14.37	2376.20	6:03	16:32	10.31
	Std. Dev.	36.42	2.30	1068.70	0:23	1:01	1.41
Snack/ 18' (N=8)	Mean	81.11	6.24	1402.68	5:392	18:23	11.99
	Std. Dev.	25.68	2.21	983.69	0:41	2:30	1.40
Snack/ 16' (N=4)	Mean	48.68	8.6	609.58	5:28	17:29	11.63
	Std. Dev.	8.03	1.48	370.88	0:59	0:52	2.00

Sleep Statistics

Data on the drivers' sleep quantity and sleep quality were collected using two different methods. First, drivers made an entry into a sleep log each time they retired or awakened. In addition, drivers wore an Actiwatch activity monitor throughout their participation in the study. A summary of the sleep data is presented in table 16. The mean hours of sleep was 6.43 hours per night according to the sleep log and 5.31 hours based on the Actiwatch. Note that the Actiwatch software calculates sleep quantity by using the time that the drivers said they went to bed and awakened. As such, it is expected that the Actiwatch value would be smaller than that recorded on the sleep log. The sleep quality ratings were 2.51 from the sleep log and 81.37 from the Actiwatch. The Actiwatch scale for sleep quality was from 0 to 100, where a large value indicated high quality sleep. (Note, though the sleep quality scale was from 1 to 5 and in "reverse," where high quality sleep was rated as a low number, the ratings have been adjusted throughout this document to be directionally compatible with the Actiwatch data. As such, for both the sleep log sleep quality ratings and the Actiwatch sleep quality ratings, a high number represents high quality sleep.) The reader will notice that the sample sizes are different for the sleep log and Actiwatch ratings. As previously explained, the reason for this was a loss of data with the Actiwatch.

Table 16. Sleep-related mean values by day.

	Day of Week						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Sleep Log Hours (N=554)	6.15	6.15	6.22	5.84	7.51	8.27	6.13
Sleep Log Quality (N=554)	4.39	4.36	4.46	4.52	4.73	4.65	4.66
Actiwatch Hours (N=414)	5.12	5.09	5.11	4.66	6.28	6.62	5.35
Actiwatch Quality (N=414)	83.28	82.89	83.83	80.14	78.41	76.86	80.57

CATEGORIZATION AND DESCRIPTION OF CRITICAL INCIDENTS

CRITICAL INCIDENT CATEGORIES

A "critical incident" does not have a precise definition, but generally involves an unexpected event resulting in a close call or requiring fast action on the part of a driver to avoid a crash. Incidents often require emergency steering or braking, or both, by at least one of the drivers involved. Incidents are far more numerous than crashes, but they are believed to be related to crashes (Chapanis, 1959). One might think of a crash as an incident in which the drivers failed to avoid a collision through their emergency actions.

A thorough search was conducted of all of the videotapes that recorded the events as the drivers worked their delivery routes. From this search, a total of 249 critical incidents were identified. For all practical purposes, a critical incident was defined as an event that, in the opinion of an analyst (third party observer), either (1) was nearly a crash such that the driver of one or more of the vehicles involved was required to take immediate evasive action to avoid a crash or (2) put the driver of the vehicle, and perhaps nearby vehicles or pedestrians, in a dangerous situation that may have resulted in a crash. It should be evident that because a third party observer was the ultimate "filter" for determining if an event was a critical incident or not, the process of identifying critical incidents was subjective. However, careful review of the recorded video and audio left little doubt in most cases as to whether or not an event should be considered a critical incident. For example, the situation where the L/SH driver was cut-off by a car, and the driver pressed the critical incident button and made a verbal report that described the close-call, was common. There were also events where the L/SH driver was at fault, pressed the critical incident button, and reported that he had made an error in judgment. There were also situations where an event occurred that was considered a critical incident, but the driver did not push the critical incident button. In these cases, the video and the audio were the primary factors used in making the assessment.

The audio was often particularly helpful as certain drivers would, for example, curse after being involved in a critical incident (e.g., curse at the other driver). This behavior, and brief "verbal report," provided the analyst with information about the event that had occurred. The truck sensors were also used by the analyst to help determine if an event was a critical incident. For example, data flags would appear in the video if pre-set sensor parameters had been triggered. For example, if the driver depressed the brakes with sufficient force, and the vehicle braked suddenly (i.e., longitudinal deceleration above 0.5g), a flag would appear on the video image indicating to the analyst that the driver may have braked in a panic. Such flags would indicate to the analyst that he or she needed to pay particular attention to the events leading up to the flag.

As shown in figure 28, each critical incident event was classified into one of four categories. First, the driver may have been assessed by the researcher to be at fault. The determination of "driver-at-fault" was based primarily on violations of the law (e.g., running a red light, not having the right-of-way, etc.). Of the 249 critical incidents analyzed, 77 of these were judged to be the fault of the L/SH driver. Thirteen of these incidents (17 percent) involved the driver running a late-yellow or red light.

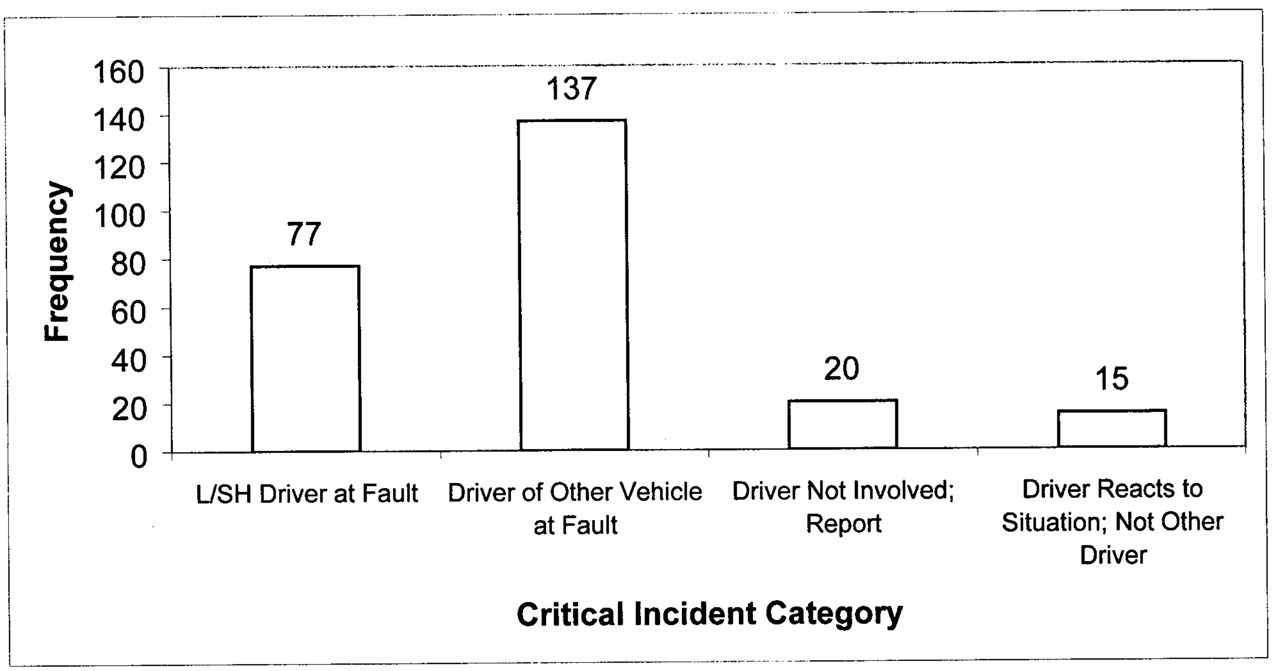

Figure 28. Frequency of the number of events included in the four critical incident categories.

The second critical incident category shown in figure 28 involved events that were judged to have been primarily the fault of the driver of another vehicle. As can be seen in the figure, this category contained the majority of events (n = 137). Typical events in this category involved other vehicles cutting-off the L/SH driver, an action which then required the L/SH driver to brake suddenly.

The third type of critical incident involved situations where the driver reported that he witnessed an event, but was not directly involved in it. For example, traffic accidents that occurred on the opposite side of the highway, that the L/SH driver witnessed, would be an example of this category of critical incident.

The fourth category of critical incident includes events where the driver reacted to a situation, but the situation did not involve another vehicle. For example, the driver having to swerve to miss an animal in the road would be included in this category. To better understand the nature of each type of critical incident, table 17 presents a sample narrative from each critical incident category.

It is important to note that many of the critical incidents were not data-flagged nor pushbutton-designated by the driver. In fact, more than half the incidents were detected by the analysts using the videotapes. As previously indicated, the videotapes were recorded continuously as long as the vehicle was operating. In data reduction, the tapes were carefully reviewed in real-time (as opposed to fast-time), and many incidents were detected solely by the analysts.

Table 17. Sample edited narratives from the four critical incident categories.

Critical Incident Category	Narrative
L/SH Driver at Fault	Subject: 19 Age: 19 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 4/1/99 Time: 6:35:38 PM Event: Critical Incident #8 Begin Sync: 827125 Our truck runs a red light at an intersection. Our truck is behind another truck. Just before the intersection, our driver is not looking at the road and as soon as he looks up ahead, the lead truck has passed through the intersection and the light is now red. It is too late for our truck to stop and he goes through the red light. The driver looks out of the windows to check for any oncoming vehicles. The driver is inattentive. It is late in the afternoon and hence it is a bit dark. It is cloudy and the roads are dry.
Other Driver at Fault	Subject: 4 Age: 35 Gender: Male Company: Beverage Truck: Straight Truck Date: 10/1/98 Time: 8:53:16 AM Event: Critical Incident #1 Begin Sync: 34237 A car coming from the opposite direction makes a left turn in front of our truck to go into a parking lot. Our truck is forced to slow down. The car cuts across the double yellow line. Our driver looks quite alert. He is wearing glasses and it is difficult to see his eyes clearly. The road condition is dry and the weather is clear.
Driver Report	Subject: 51 Age: 34 Gender: Male Company: Snack Truck: Panel Van Date: 8/10/99 Time: 1:32:19 PM Event: Critical Incident #2 Begin Sync: 528061 Our truck is not involved in this critical incident. Our driver reports seeing a log truck pulling in front of another vehicle and cutting it off. The road condition is clear and dry. The road geometry is curving right ahead. The visibility is unlimited. The driver does not appear to be drowsy. The footage lasts for less than 1.5 minute and no eye glance analysis was possible. The level of service on the road is A.
Driver Reacting to Situation; Not Other Driver	Subject: 22 Age: 26 Gender: Male Company: Snack Truck: Straight Box Truck Date: 5/13/99 Time: 6:05:31 AM Event: Critical Incident #14 Begin Sync: 891810 There is a dog sitting on the road which doesn't move even as our truck halts near it. Hence the driver moves into the oncoming lane to avoid the dog. There is one vehicle which slows down behind our truck while it passes the dog. The driver is alert. It is early in the morning. The weather is clear and the roads are dry.

Potential Causes of the Critical Incidents

Of particular interest to this research effort was the group of 77 critical incidents where the L/SH driver was at fault, because it is with this set of incidents that a determination of the impact of fatigue in L/SH trucking can be made. As a first step in determining if fatigue was involved in the critical incidents caused by the L/SH drivers, the videotapes and narratives of the events were carefully reviewed and a subjective judgment was made as to the *potential* cause or causes of the incident. The issues raised in the Phase I focus group effort, where drivers listed and ranked general safety issues, were used in making the current assessment of potential causes. That is, the issues specified in Phase I were considered when making the assessment of potential causes. Note that for each incident, one or more potential causes may have been assessed. For example, consider an incident where the driver proceeds through a red light. Potential causes of this incident may include, but may not be limited to, inattention (not paying attention to the traffic lights) and/or stress due to time pressure (in a rush to get to next delivery). The results of this subjective assessment are presented in figure 29, and operational definitions used to assess potential causes to each event are presented in table 18. It must be noted that the categories listed in table 18 are not necessarily mutually exclusive. For example, if a cellular phone was the assessed caused, driver inattention would also be considered an issue.

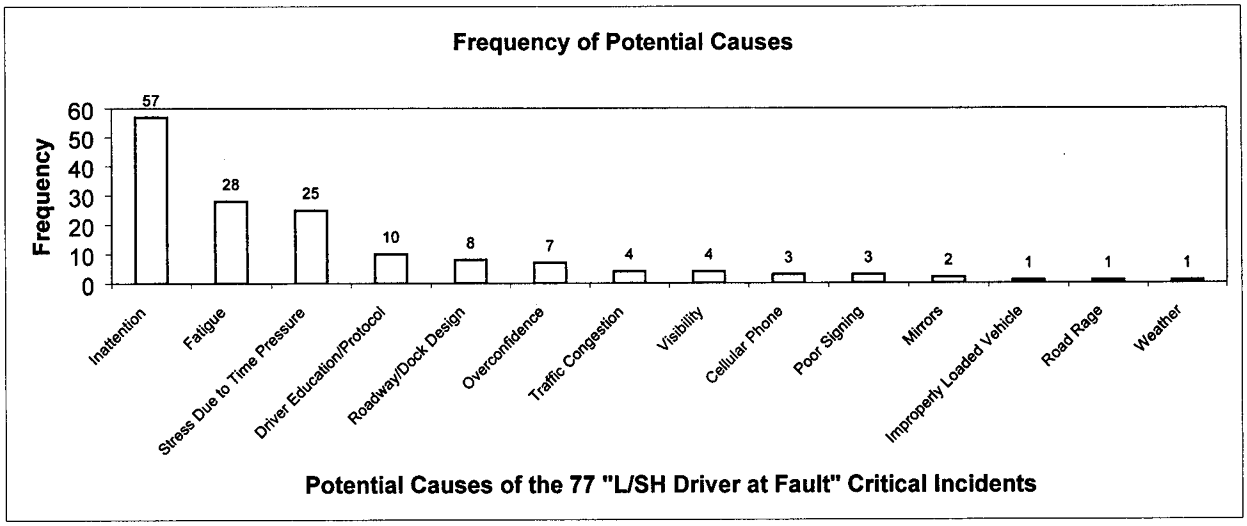

Figure 29. Frequency of the *potential* causes of the 77 critical incidents judged to have been caused by the L/SH driver.

Table 18. Operational definitions of potential causes and examples of incidents where they were assessed. Potential causes were observed for a period of time leading up to, and at the start of, the incident.

Potential Causal Factor	Definition Used in Subjective Assessment
Inattention	Driver not appearing attentive to his surroundings; consideration of EYESOFF and EYETRANS measures of attention. Example: driver running through red light, looking away from traffic lights while approaching intersection.
Fatigue	Observed driver drowsiness; consideration of PERCLOS and OBSERV measures of fatigue. Example: driver's eyes closed as driver runs off road onto shoulder.
Stress Due to Time Pressure	Apparent anxiousness to reach next destination (i.e., delivery or home base). Example: driver impatient while waiting to make left turn at busy intersection cuts-off oncoming vehicle.
Driver Education/ Protocol	Obvious lack of understanding of truck capabilities, rules of the road, and company protocols. Example: not checking area behind truck before backing up.
Roadway/Dock Design	Confusing roadway design and/or loading dock area. Example: short merge lanes on busy roadways.
Overconfidence	Overconfidence in driving abilities or truck capabilities. Example: driver taking a corner too fast, results in load shift.
Traffic Congestion	High volume of traffic resulting in reduced maneuverability. Example: truck merging onto busy highway must used shoulder to avoid crash from side.
Visibility	Degraded driver visibility. Example: fog or heavy rain.

Cellular Phone	Cellular phone used at start of incident. Example: cell phone used during right turn maneuver, driver drifts onto shoulder.
Poor Signing	No clearly posted roadside signing appears to lead to confusion. Example: "left turn only" sign posted too late for driver to maneuver to adjust lane position.
Mirrors	Neglecting to use rear-view mirrors. Example: driver not adequately checking mirrors, backs into pole.
Improperly Loaded Vehicle	Vehicle not loaded correctly causing load to shift. Example: driver reports not being able to stop truck at red light to do shifting of load.
Road Rage	Aggressive driving in reaction to other motorist. Example: driver intentionally slowing down on highway in response to tailgating car.
Weather	Inclement weather. Example: ice resulting in slick road conditions.

The results from the focus group effort described in Phase I of this research included an assessment of the L/SH driver's opinion of the general safety issues in L/SH trucking. Drivers listed and ranked, in order of importance, general safety issues in the L/SH industry. The potential causes found in Phase II (the current analysis) were rank ordered based on the frequency in which they occurred. A comparison was then made between the ranks from Phases I and II. This comparison is shown in table 19. In the table, the first entry on the right has been place there on the basis of the 137 critical incidents attributed to "other drivers." This seems justified because the number far outweighs any single category depicted in figure 29. As can be seen, the top issues ranked by the drivers in the focus groups and the assessed potential causes from the critical incidents captured on the videotape are very similar. A Spearman Rank-Order Correlation test was conducted on the rankings shown in table 19 (issues included in one phase but not in the other phase were ranked as a tie as per the method outlined in the focus group discussion on page 14). The results proved significant, $r_s = 0.498$, $p = 0.05$ (two-tailed), and indicate that the rankings from the two research phases are similar (i.e., there is association between the rankings). Though this was a subjective exercise, the agreement between the results from issues raised and ranked in Phase I and the potential causes assessed in Phase II provides support for the validity of these findings.

Table 19. Comparison of the potential causes of the critical incidents and the results from driver opinions as determined in the Phase I focus groups.

Rank	General Safety Issues from Phase I	Rank	Potential Causes from Phase II
1	Drivers of light vehicles- Other drivers	1	Other drivers
2	Stress due to time pressure	2	Inattention
3	Inattention	3	Fatigue
4	Roadway/dock design	4	Stress due to time pressure
5	Fatigue	5	Driver education/protocol
6	Carelessness	6	Roadway/dock design
7	Traffic congestion	7	Overconfidence
8.5	Weather	8.5	Traffic congestion
8.5	Vehicle design	8.5	Visibility
10	Overconfidence	10.5	Cellular phone
11	Poor signing	10.5	Poor signing
12	Mirrors	12	Mirrors
13.5	Road construction	14	Improperly loaded vehicle
13.5	Store location	14	Road Rage
15	Driver education	14	Weather

INCIDENT SEVERITY

As noted, Heinrich's triangle (Heinrich, Peterson, and Roos, 1980) is a method used to classify the severity of an accident/incident. Mollenhauer (1998) (also see, Dingus, Hetrick, and Mollenhauer, 1999) used Heinrich's triangle to classify critical incidents involving passenger vehicles, and then compared data within each classification category for several transportation field studies. A portion of the results of this comparison, along with data from the present effort, is shown in table 20. Mollenhauer included three sets of data in his comparison: TravTek data (Dingus et al., 1995), ADVANCE safety evaluation data (Mollenhauer, 1998), and ADVANCE baseline data (Mollenhauer, 1998). In his comparison, Mollenhauer looked at the frequency of injury accident events, non-injury accident events, near-miss accident (or near-accident) events, and driver error with a hazard present events. Because of the relatively small sample sizes in the data collection efforts, there were no injury accidents or non-injury accidents recorded. To remove any bias from the sample, Mollenhauer calculated the rate of the incident type (i.e., near-miss or driver error, hazard present) as a function of the number of miles traveled for the data collection interval. For example, as shown in the TravTek data in table 20, there were 30 near-miss events recorded over 2032 miles. Dividing the frequency of events by the vehicle miles traveled (vmt), and multiplying by 1 million, produces the number of incidents per million vehicle miles traveled (mvmt), which is a common metric used in reporting accident statistics. Converting the frequencies to the mvmt metric allows comparison between data collection efforts.

Table 20. Data points by level of interest by distribution.

			Near-Miss	Driver Error, Hazard Present
Previous Data	TravTek	freq	30	264
		vmt	2032	2032
		rate/mvmt	14763	129921
	ADVANCE, Safety Evaluation	freq	41	414
		vmt	2882	2882
		rate/mvmt	14226	143650
	ADVANCE, Baseline	freq	3	54
		vmt	487	487
		rate/mvmt	6160	110882
L/SH Data	L/SH Field Study	freq	15	199
		vmt	27924	27924
		rate/mvmt	537	7126

As can be seen from the near-miss column in table 20, a comparison of the TravTek and ADVANCE Safety Evaluation data sets shows that the TravTek data have a slightly larger near-miss rate (14763) than do the ADVANCE Safety Evaluation data (14226). For the driver error with hazard present column, the rates for the TravTek and ADVANCE Safety Evaluation data sets are, once again, similar. However, this time the rates for the ADVANCE study (143650) are slightly higher than that for the TravTek study (129921). There are several potential reasons why the near-miss rates were higher in the TravTek data set and the driver error with hazard present rates were higher in the ADVANCE Safety Evaluation data set. As Mollenhauer (1998) explains, the locations of the two studies and the equipment that was used were not the same and, as such, the results would likely differ. Another possible reason for the difference in rates is, perhaps, due to the subjective nature of classifying events into categories. That is, analyst opinion is required when classifying events, and differences in classification techniques may have accounted for some of the differences. Nonetheless, the rates between the two studies are very similar.

As can be seen by comparing the rates of the TravTek and ADVANCE Safety Evaluation data sets with the ADVANCE Baseline data set, drivers were involved in near-misses more than twice as often when they were interacting with an in-vehicle navigation system. Similarly, drivers committed more errors when there was a hazard present as they interacted with a navigation system. This, perhaps, is not surprising given the additional attentional demand that is required for operating and monitoring an in-vehicle navigation system.

As in the Mollenhauer (1998) effort, there were no instances of injury accidents or non-injury accidents in the L/SH data collection effort. To examine the relationship between the data collected and estimates of injury and non-injury accidents, Mollenhauer substituted data collected from other research efforts. His estimates were 2.17 rate/mvmt and 5.12 rate/mvmt for injury accidents and non-injury accidents, respectively (assumed to be police-reported accidents). Data from another source were also used to estimate that number of truck-involved injury and non-injury accidents. Data from the Department of Transportation, Federal Motor Carrier Safety Administration (2000), indicate that the accident rate/mvmt for trucks was 0.025 for fatal crashes, 0.45 for injury crashes, and 1.60 for non-injury (property damage only) crashes (again, assumed to be police-reported accidents.) To make the comparison with Mollenhauer's categories, the rates for fatal and injury crashes were added together. A comparison of the ADVANCE Baseline data from Mollenhauer and the L/SH data is shown in figure 30. Note that the axis showing "frequency" is a logarithmic scale. As expected, the category estimates are lower for the L/SH data. As can be seen for the near-miss and driver error data, the estimates are lower by about a factor of 10. This result shows the greater frequency with which car drivers are involved in critical incidents, and the associated critical incident categories (i.e., near-misses and driver errors), as compared to L/SH drivers.

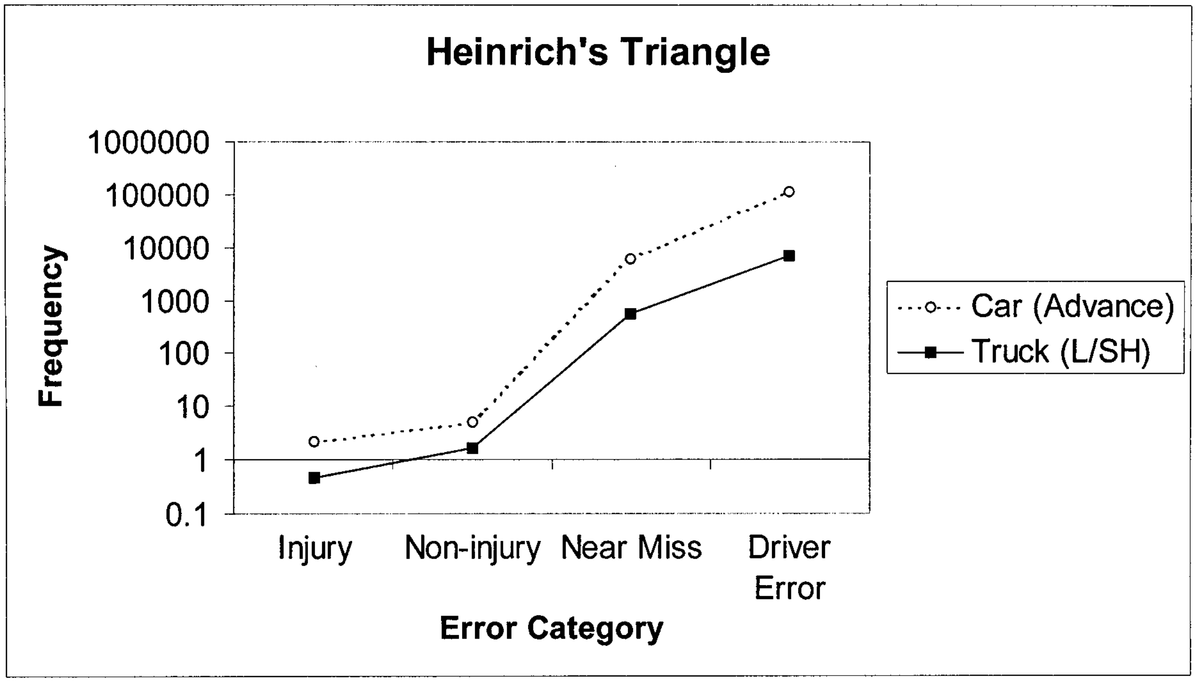

Figure 30. Comparison of car and L/SH data by Heinrich's Triangle categories.

As suggested in the figure, accidents are more rare of an event in trucks as compared to cars. There are several possible explanations for this. For example, it could be hypothesized that the average speed driven by L/SH drivers is lower than that of passenger vehicles that, in turn, may reduce the rate at which truck drivers incur critical incidents. A second explanation may be that, on average, professional L/SH drivers are more competent and/or less aggressive drivers than passenger vehicle drivers and, as such, are involved less often in critical incidents. A third possible explanation may related to driver visibility in that truck drivers' raised cab seating allows them to see better and avoid incidents. Finally, a fourth potential explanation relates to conspicuity such that the large size of trucks makes them more visible to other drivers on the roadway as compared to cars. Although all of these explanations may have merit, further research is needed. Insight into this area may lead to strategies that might decrease the critical incident rates of passenger vehicles and bring them more inline with truck rates.

To present a different view of the results shown in figure 30, the frequency data were normalized using Heinrich's triangle. Figure 31 shows the normalized frequency values for both the car and truck data where the "injury" category is set to a value of 1. As can be seen in the figure, normalizing the data results in shifting the car function (shown in figure 30) down and the truck function up.

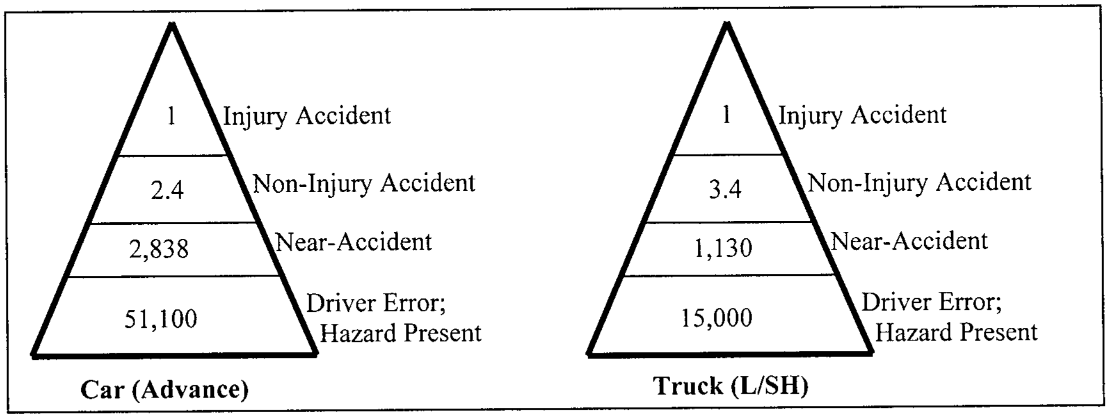

Figure 31. Normalized car and truck data using Heinrich's triangle.

Comparing the car and truck data in figure 31, notice that the ratio of non-injury accidents to injury accidents is 2.4:1 for cars, and 3.4:1 for trucks. This indicates that comparing any car accident (injury and non-injury) to any truck accident, there would be an approximately 40 percent greater likelihood that the car accident resulted in an injury as compared to the truck accident. One possible explanation for this finding is that the size and weight of trucks translates into greater occupant protection for the truck driver such that in the event of an accident, the truck driver is more protected than is the car driver. A second possible explanation, suggested previously, is that the speeds may be lower in truck crashes as compared to car crashes. Notice that this effect is then reversed when comparing non-accidents (near-accidents and driver errors) to injury accidents for cars and trucks. That is, there are substantially more near-accidents and driver errors for cars, relative to injury accidents, than there are for trucks. One possible explanation for this finding is that the maneuverability of trucks is much poorer than that for cars such that when a given driver commits an error, a car driver is more likely to safely recover from that error than is a truck driver. Once again, although this explanation may have merit, additional research is required to explore it further.

IS FATIGUE AN ISSUE IN L/SH TRUCKING?

OVERVIEW

The thrust of this research was an investigation of fatigue in L/SH operations. To answer the question, "is fatigue a safety issue in L/SH trucking?" a number of analyses were performed. Given the type of research that was conducted in this study (i.e., field study), it is difficult to determine cause-and-effect relationships between fatigue and L/SH operations. What can be accomplished is to look at the results of a variety of statistical analyses and assess whether a preponderance of the evidence suggests that drivers are (1) fatigued on the job and/or (2) driver fatigue is evident immediately prior to the occurrence of critical incidents caused by L/SH drivers.

To examine fatigue aspects, data analyses were conducted on four different data sets (i.e., data were parsed four different ways). The first data set was comprised of critical incidents where the driver was at fault and a control group of lane change (non-critical incident) events. The second data set was made up of critical incidents where the driver was at fault and a control group of critical incidents where the driver was not at fault. The third data set was comprised of critical incidents where the L/SH driver was at fault, and judged to be fatigued, as compared to a control group of critical incidents where the L/SH driver was at fault but no fatigue was apparent. Finally, the fourth data set was comprised of all critical incidents including those where the L/SH driver: (1) was at fault, (2) was not at fault but was reacting to another driver, (3) was not involved but merely reporting a witnessed incident, and (4) was not at fault but reacting to a situation which did not involve another driver. The remainder of this section describes the significant results from the analyses that were conducted on each of the four data sets. This is followed by a summary section that discusses these significant findings.

DATA SET: DRIVER AT FAULT VS. LANE CHANGE EVENTS (CONTROL)

The first set of analyses was conducted on a data set that comprised critical incident events where the L/SH driver had been judged to be at fault and non-critical incident lane change events that were used as a control or baseline (detail on the lane change events is provided later in the *Lane Change and Backing Analysis* section). The primary question being asked in the analyses with this data set was, "what measures are reliably different when comparing critical incidents where the driver is at fault to a control group of non-critical incident events?" The results from ANOVAs (conducted in SAS using the GLM procedure to account for unbalanced data) can be found in appendix H. It should be noted that given the statistical model used, where the means from two groups were compared, the one-way ANOVAs that were conducted are equivalent to t-tests where $t^2 = F$ (Winer, Brown, and Michels, 1991).

The reader will notice that the results presented in the appendices are highlighted if the p-value level was less than 0.10. For the most part, data that are discussed in the text of this document are limited to those that reached statistical significance at 0.05. However, given that the research topic considered here is related to "safety," results where the p-value was between 0.05 and 0.10 may also be considered noteworthy.

Figures 32 and 33 show that fatigue was evident in the critical incident group (N=77), but not in the lane change group (N=260). (Recall that the drowsiness measures were extracted for a three-minute interval prior to the event.) PERCLOS, or the proportion of time that the driver's eyes were closed or nearly closed, was substantially greater in those incidents judged to be caused by the L/SH driver ($M = 0.078$) as compared to control events ($M = 0.006$), $F\,(1, 314) = 53.63$, $p = 0.0001$. Similarly, as shown in figure 33, the analyst rating of driver drowsiness (i.e., OBSERV) was significantly higher in the critical incident group ($M = 23.75$) as compared to the control group ($M = 16.26$), $F\,(1, 325) = 11.78$, $p = 0.0007$.

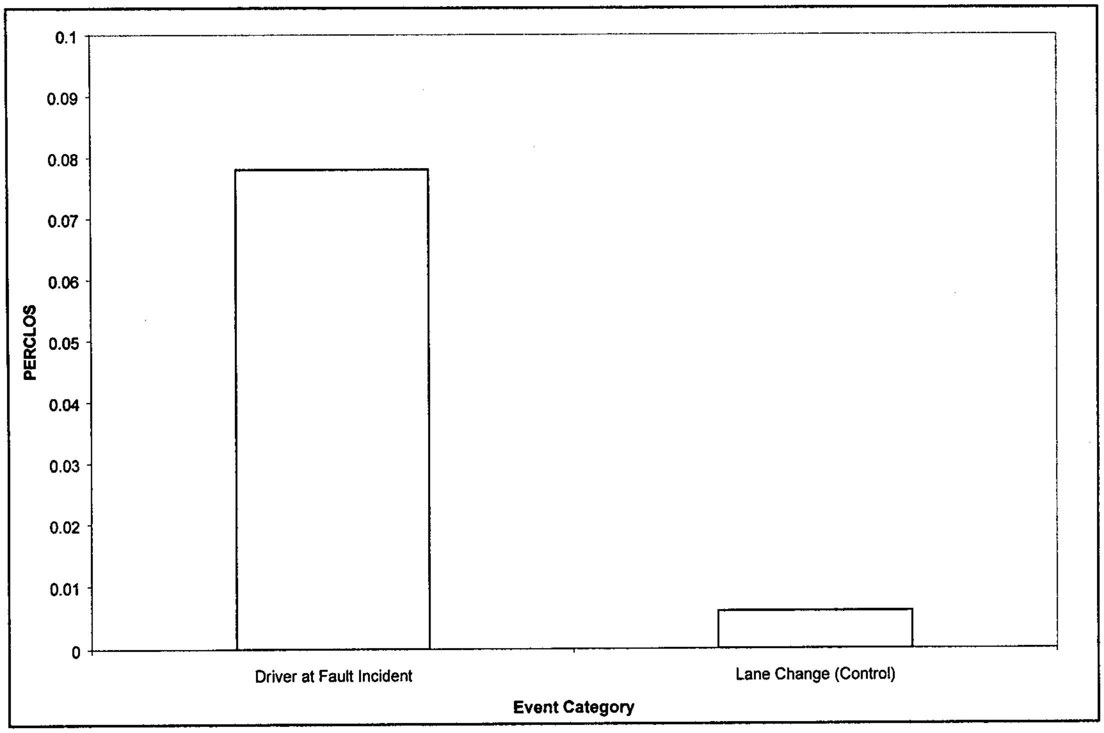

Figure 32. Assessed driver fatigue, using PERCLOS, as a function of event type.

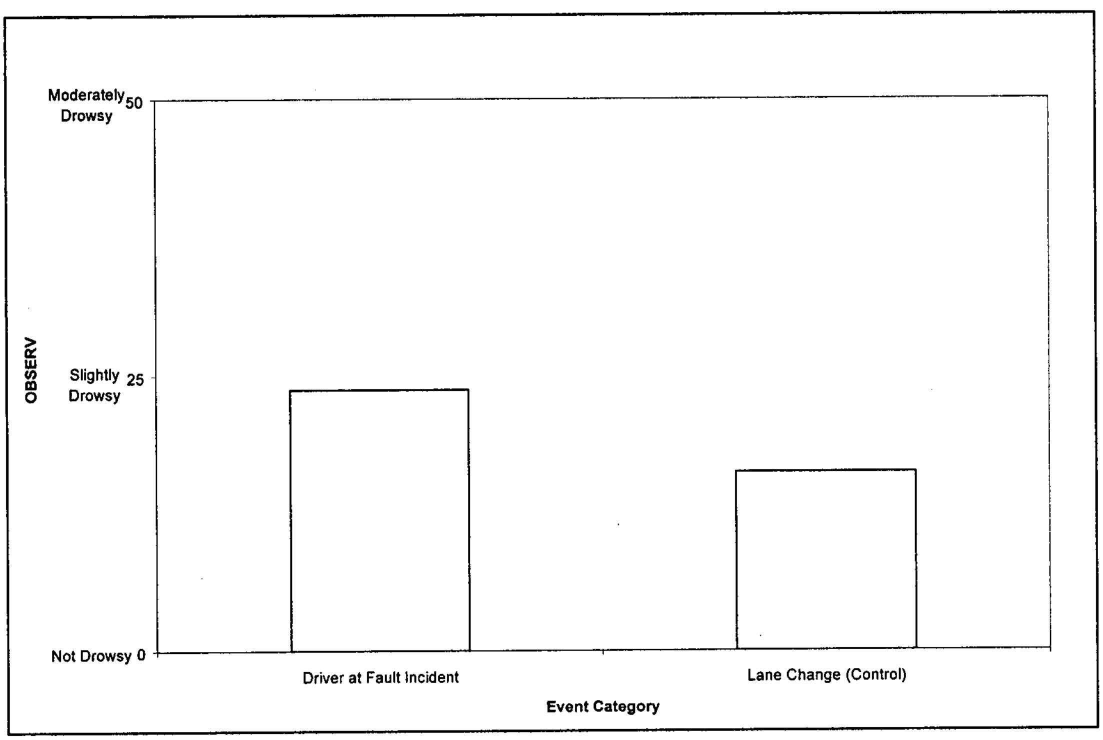

Figure 33. Assessed driver fatigue, using OBSERV, as a function of event type.

As shown in figure 34, younger drivers were over-represented in the critical incident group as compared to the control group, $F(1, 335) = 18.19, p = 0.0001$. As noted, the average age of the drivers who participated in the study was 31 years. As such, one would expect that the average age in the critical incident group and the control group would be approximately 31 years. This average age is representative for the control group; however, as can be seen, younger drivers were more prevalent in the group that was judged to have caused the critical incidents ($M = 25.52$).

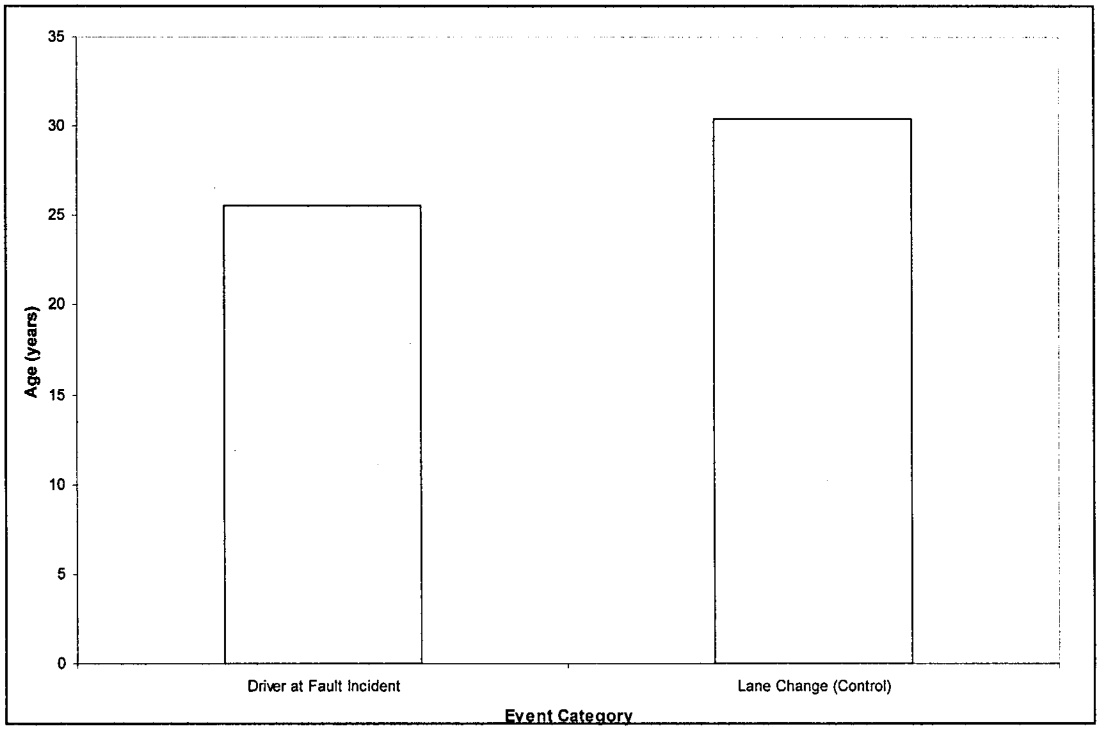

Figure 34. Driver age as a function of event type.

DATA SET: DRIVER AT FAULT VS. DRIVER NOT AT FAULT (CONTROL)

The second data set was comprised of two types of critical incident events: those where the L/SH driver was judged to be at fault and those where the L/SH driver was reacting to another driver (i.e., other driver at fault). Unlike the first data set, all the events in this data set were critical incidents. However, in this case, critical incidents where the L/SH driver was not at fault served as the control group. Once again, ANOVAs were conducted and the complete results are shown in appendix I. (The reader will notice that unlike the previous analysis using lane changes as control events, this and the remaining analyses use critical incidents as controls.)

Similar to the findings in the previous data set, drivers exhibited signs of fatigue more so in the driver-at-fault condition as compared to the control condition. Figure 35 shows that mean PERCLOS for the driver-at-fault condition was 0.078, while for the control condition it was 0.007. This difference was significant, $F(1, 156) = 21.19, p = 0.0001$. Similarly, figure 36 shows that a significant difference was found for the OBSERV measure, $F(1, 185) = 19.17, p = 0.0001$, where the means for the driver-at-fault condition and the control condition were 23.75 and 12.71, respectively.

One possible explanation for the significant finding for the PERCLOS and OBSERV fatigue measures is the significant effect of the self-reported quality of drivers' sleep for the night preceding the critical incident, $F(1, 178) = 3.97, p = 0.0479$. As shown in figure 37, the mean quality of drivers' sleep was 4.20 in the driver-at-fault condition as compared to 4.52 in the control condition.

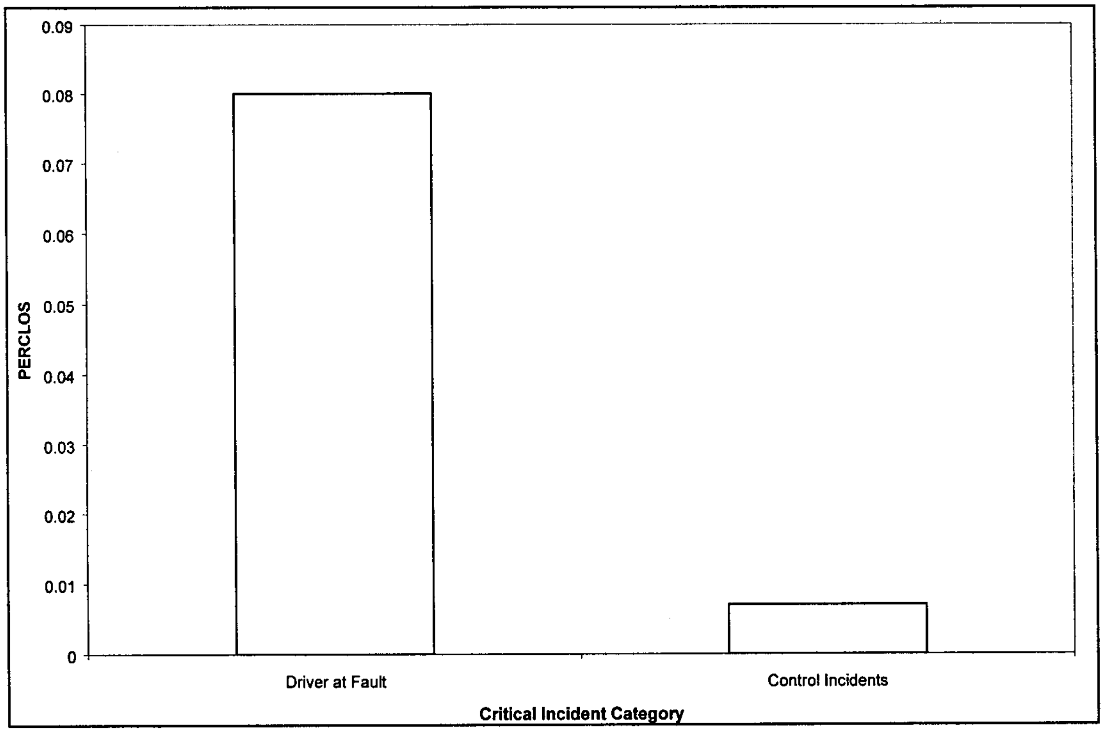

Figure 35. Assessed driver fatigue, using PERCLOS, as a function of critical incident category.

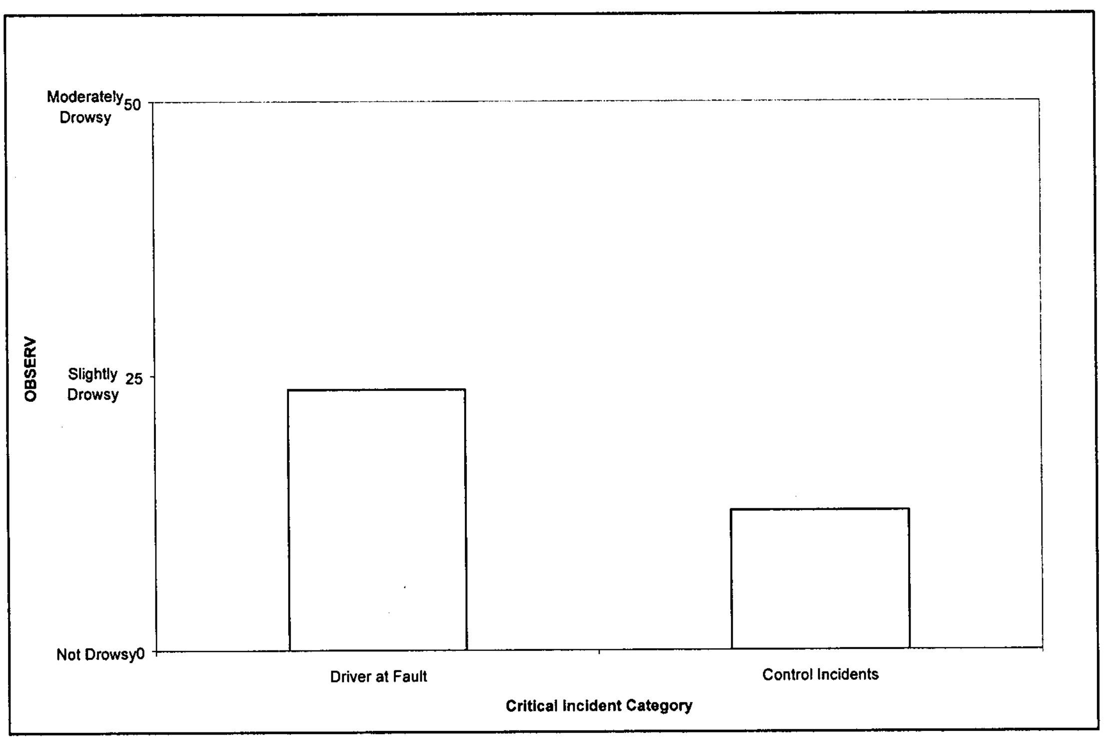

Figure 36. Assessed driver fatigue, using OBSERV, as a function of critical incident category.

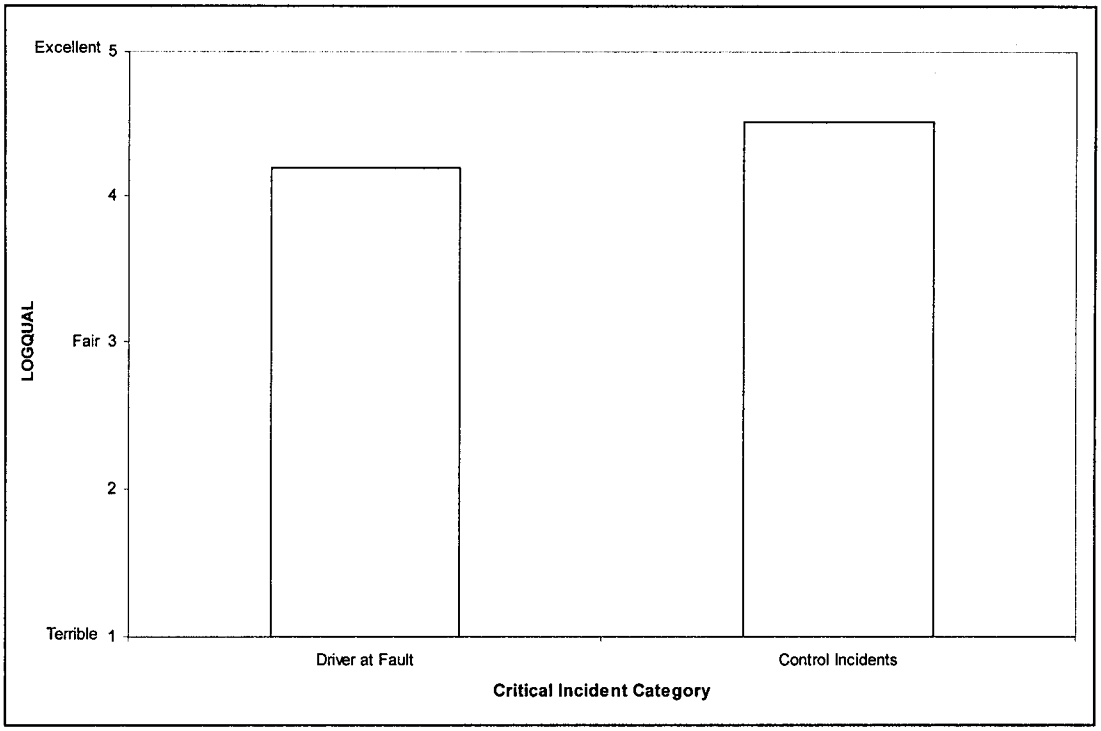

Figure 37. Driver's self-reported sleep quality as a function of critical incident category.

Figure 38 shows the frequency of incidents as a function of the time of day. As can be seen, the highest frequency of driver-at-fault incidents was between noon and 1 PM. This finding supports data from the U.S. Department of Transportation, Federal Motor Carrier Safety Administration (January, 2000) that indicates that the greatest number of truck crashes occur around midday. Potential explanations for this finding are that the L/SH drivers may be experiencing drowsiness after eating lunch, or that eating-while-driving, a common observance with the drivers in this study, may have drawn attention away from the driving task. It is also noteworthy that the driver-not-at-fault incidents spiked during the 7-8AM interval, the 1-2PM interval, and the 4-5PM interval. It is hypothesized that the increase in incidents during these time periods may have resulted from the greater number of vehicles on the road during these periods (i.e., morning, noon, and after-work rush-hours). Put another way, the increase in incidents during these periods may be attributed to increased exposure. These explanations are purely speculative, and no data were collected in this study that could validate them. To determine if the two distributions (i.e., driver-at-fault and driver-not-at-fault) were significantly different, a Kolmogorov-Smirnov test was conducted. The results of this test indicated that the distributions did not significantly differ, $p > 0.05$.

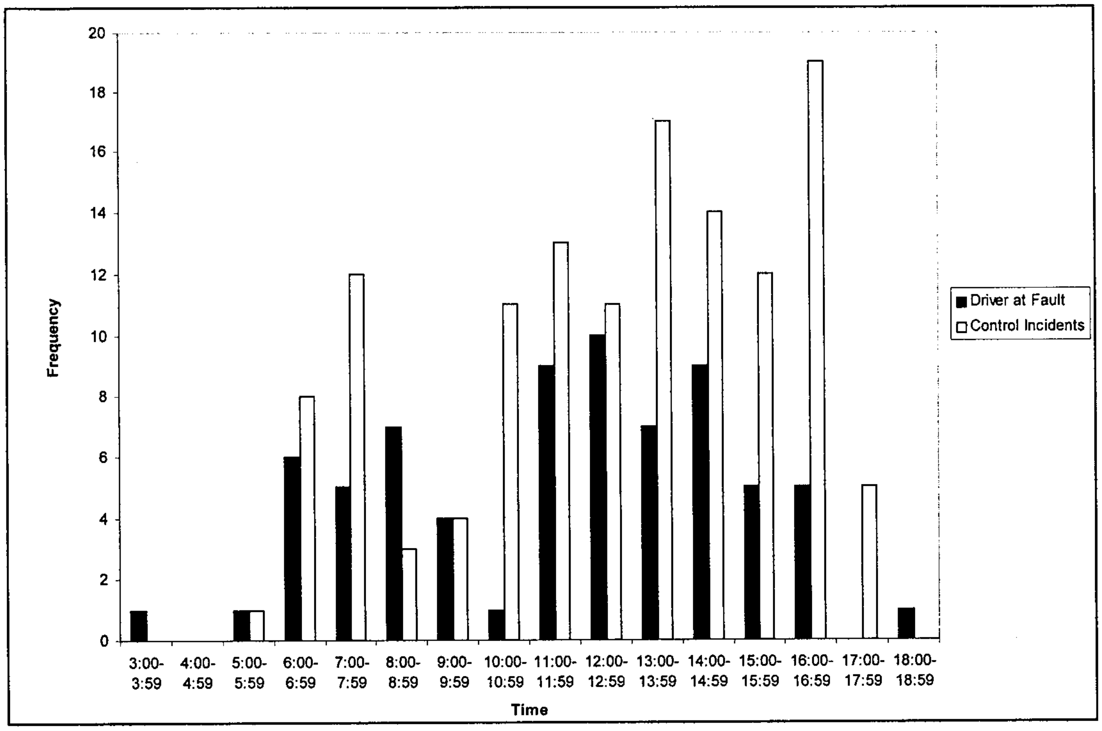

Figure 38. Frequency of critical incidents as a function of time of day and critical incident category.

Figure 39 shows that the mean hours driven during the workday were significantly higher for the driver-at-fault category of events ($M = 3.63$) as compared to the control events ($M = 3.00$), $F(1, 205) = 8.81, p = 0.0033$. Note that the hours of driving relates to the workday that the incident occurred. There are at least two plausible explanations for this finding. First, it is possible that drivers who are on the road and driving for longer periods of time have a greater exposure to critical incident involvement. A second explanation is that more hours driving is a fatiguing factor that, directly or indirectly, increases the prevalence of driver-at-fault critical incidents. The difficulty with this second explanation is, as shown in figure 38, most of the driver-at-fault incidents that were recorded occurred during midday (between 11 AM and 3 PM). As such, this second explanation would have more credibility if the bulk of driver-at-fault incidents occurred at the end of the day, but this was not the case.

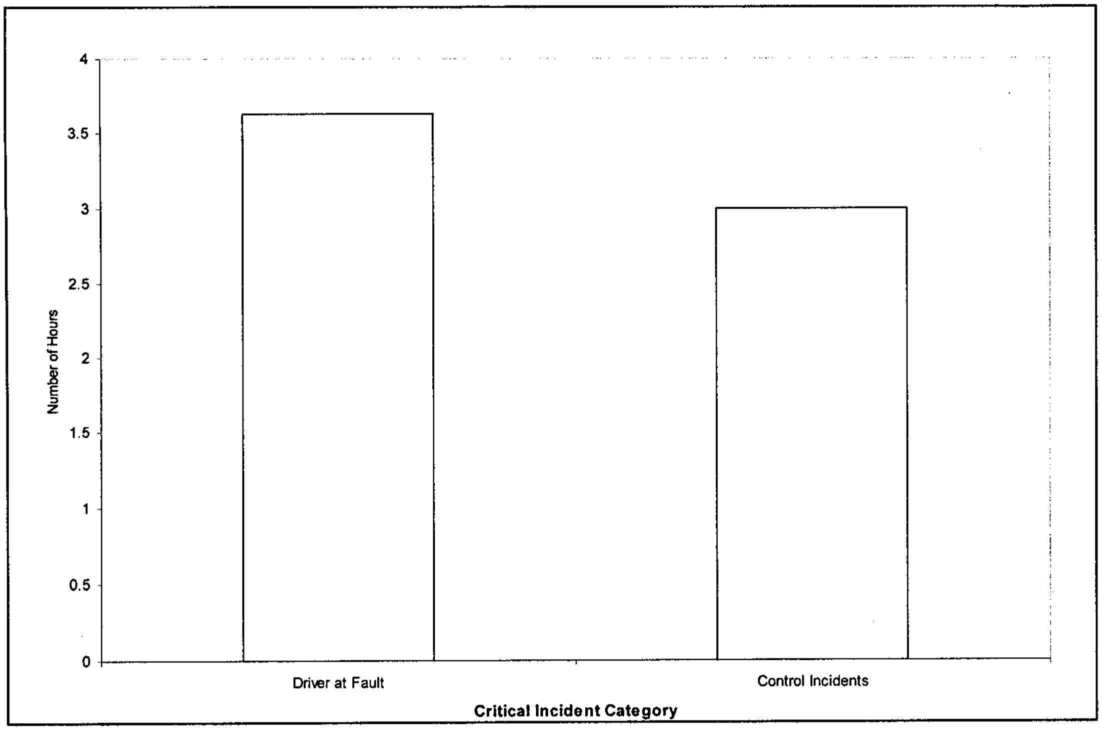

Figure 39. Number of hours driven as a function of critical incident category.

As shown in figure 40, the mean number of delivery stops for the driver-at-fault category of events was 13.03, and 11.44 for the control incidents. This difference proved reliable, F (1, 203) = 4.87, $p = 0.0285$. As in the previous finding, these data refer to delivery stops for the day that the critical incident occurred.

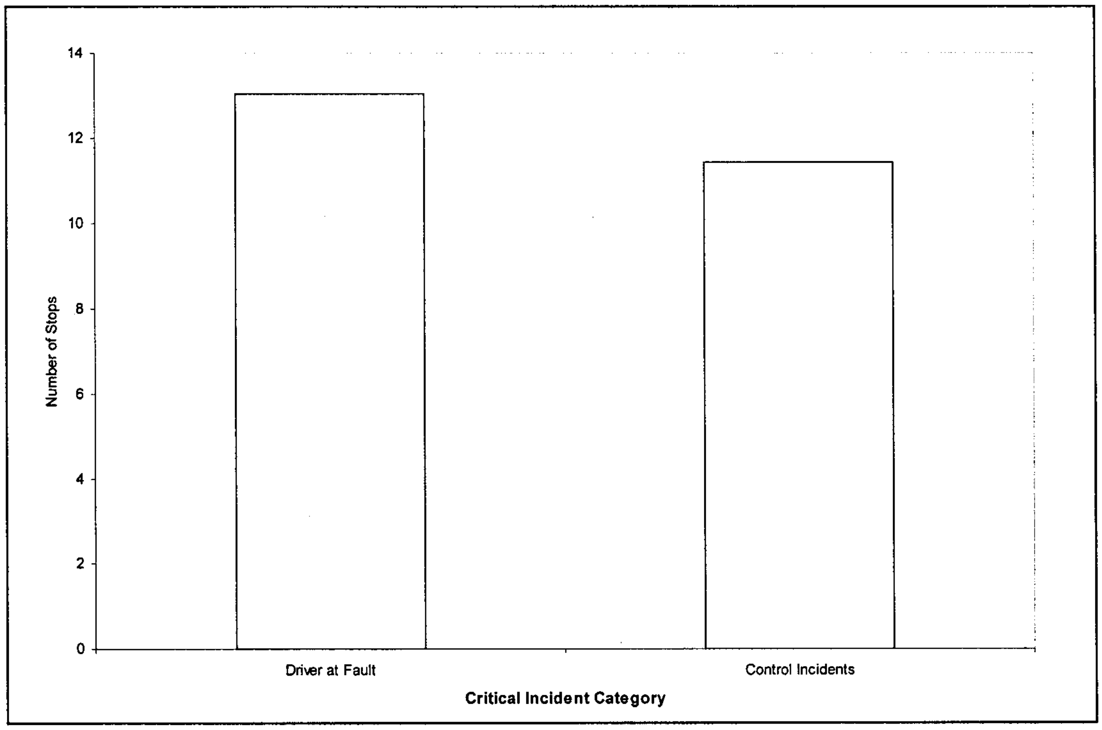

Figure 40. Number of delivery stops as a function of critical incident category.

As in the data set described previously with lane change events serving as the control, a significant age effect was found, $F(1, 212) = 22.50, p = 0.0001$. Figure 41 shows that the mean age for driver-at-fault events was ($M = 25.52$) while the mean age for the driver-not-at-fault events (control) was ($M = 31.19$).

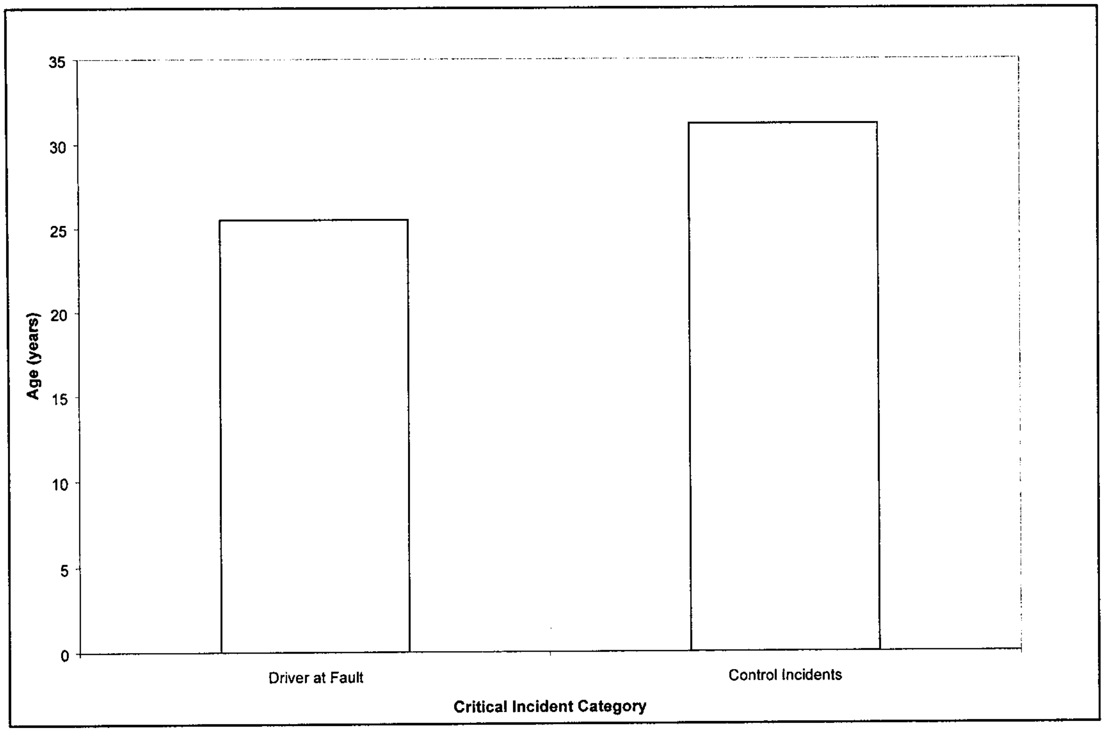

Figure 41. Driver age as a function of critical incident category.

To explore the importance of driver age more closely, the number of fatigue-related incidents was summed across different age groups. Confirming the results from figure 41, and as shown in figure 42, most fatigue-related critical incidents involved younger L/SH drivers. A chi-square test was performed on the frequencies shown in figure 42. (Because the expected counts of the older age groups were low, drivers aged 30 and over were combined into one group for this analysis.) The chi-square proved significant, $X^2(3, N = 77) = 8.17, p = 0.043$. As can be seen, for drivers 25 years or less, over 30 percent of their at-fault incidents were fatigue-related. For the 25 to 30 age group, the percentage of fatigue-related incidents was approximately 11 percent, while the 30 and over age group where not involved in any fatigue-related incidents. For reference, the total number of drivers who participated in the study within each age group, out of a total of 42, is shown in the figure as well.

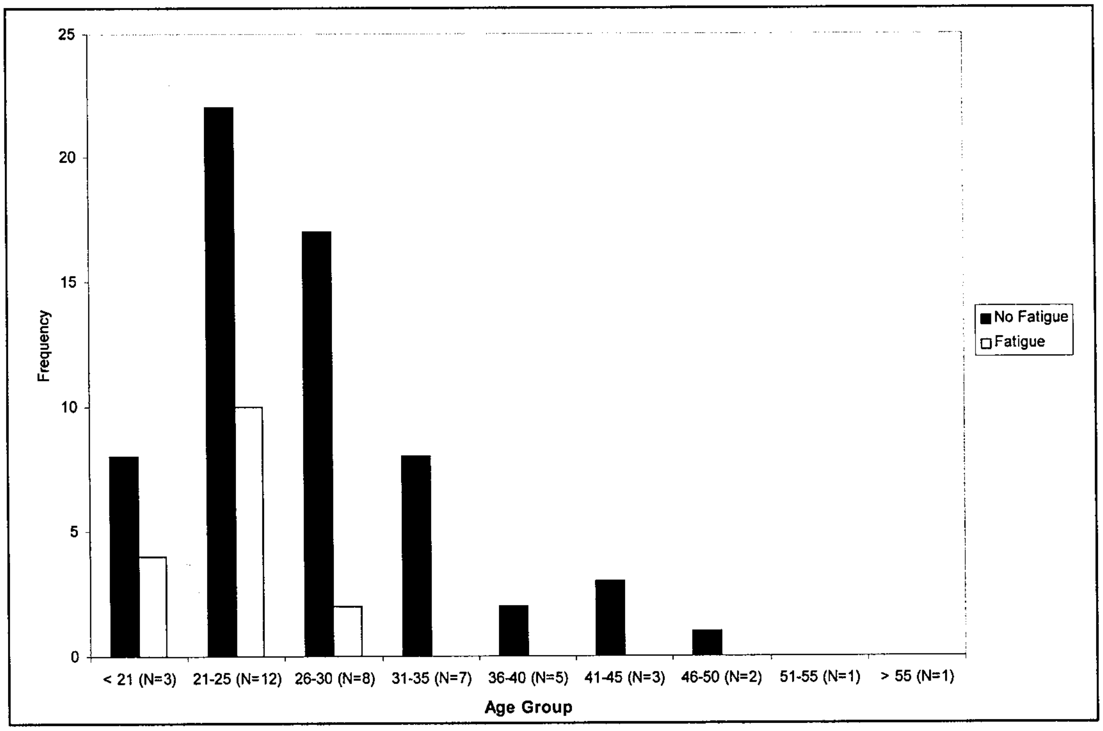

Figure 42. Driver age as a function of critical incident category.

Figure 43 shows that the various driving experience measures (including truck driving experience, L/SH experience, and years of general driving experience) were all found to be significant ($p < 0.05$). As with driver age, drivers with less experience were found to be over-represented in critical incidents where they were at fault.

A related significant finding was found with regard to driver training. Drivers were asked if they had any truck driver *training* prior to working as a truck driver. A chi-square test revealed that the difference in ratios between the frequency of trained vs. untrained drivers was greater in the driver-at-fault category as compared to the control category, $X^2(1, N = 214) = 5.24$, $p = 0.022$. This result is shown in figure 44.

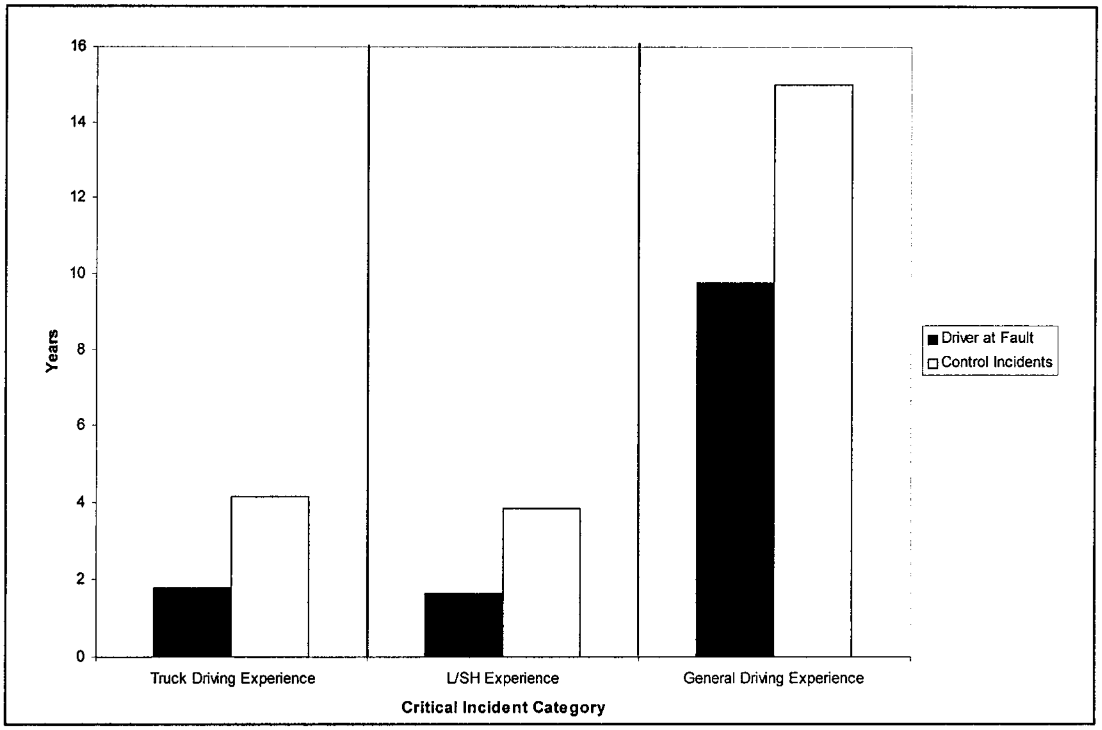

Figure 43. Experience as a function of critical incident category.

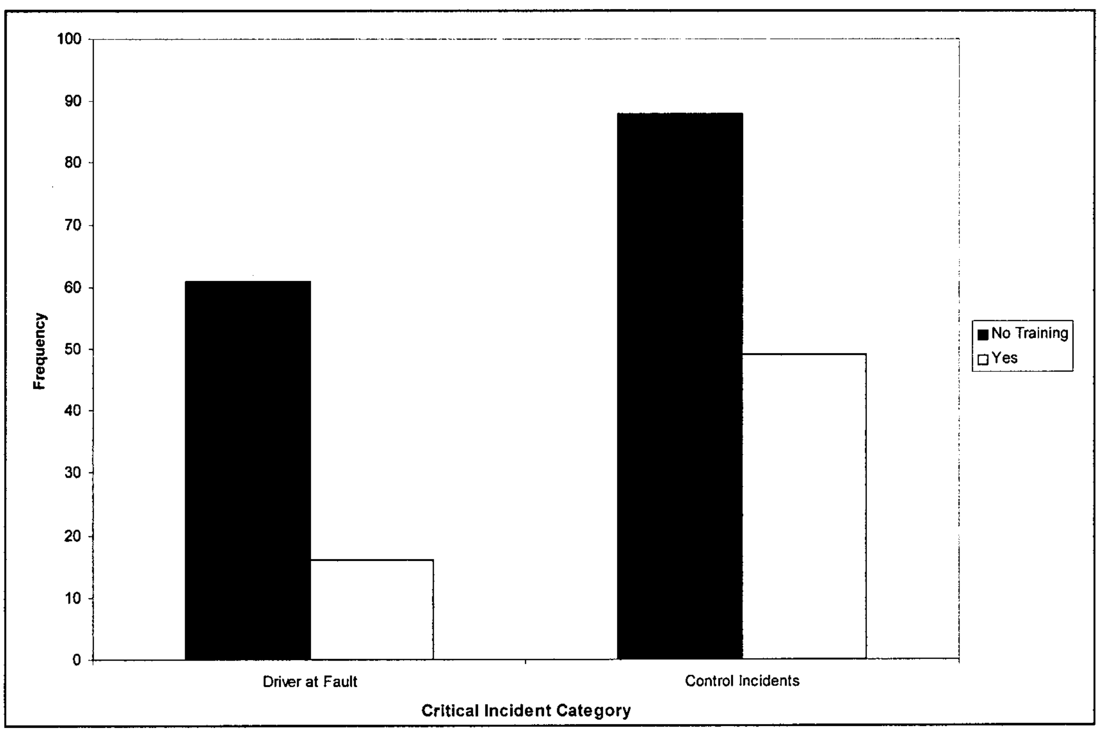

Figure 44. Frequency of critical incidents as a function of critical incident category and driver training.

In addition to conducting ANOVAs and chi-square tests, correlations, regressions, and discriminant analyses were also conducted on the data sets. Correlations were conducted to examine the data for multicollinearity (overlap of measures). The results from the correlations were used to eliminate common measures when conducting the regression and discriminant analyses.

For the present data set, there was one particularly interesting finding for a discriminant analyses that were conducted. Note that the purpose of a discriminant analysis is to identify a set of variables that best predicts group membership. For this particular data set, the analysis involved searching for a variable set that would best predict if any given incident was caused by the driver, or was a control incident (i.e., not caused by the driver). A stepwise discriminant analysis was used, and table 21 shows the optimal set of variables that were determined. As shown in table 22, applying these variables to the data set resulted in a 76 percent correct prediction rate for driver-at-fault incidents and a 75 percent correct prediction rate for control incidents. As can be seen, the optimal set of variables include several that were significant in the F-tests and chi-square tests. It is suggested that these complementary results can be seen as supporting the reliability of the findings.

Table 21. Optimal set of prediction variables determined in the discriminant analysis.

Number In	Variable	F Statistic	Prob > F
1	AGE (Driver age)	18.283	0.0001
2	OBSERV (Analyst rating of drowsiness)	12.486	0.0006
3	SHIFT (Workday within the week)	6.878	0.0098
4	HRSDRIV (Number of hours driven per day)	5.176	0.0245
5	TRAINING (Did the driver have truck driver training?)	3.574	0.0609
6	LOGQUAL (Self-reported sleep quality)	2.819	0.0956
7	PREFAT (Pre-shift fatigue measure)	3.304	0.0715
8	DEGSUCC (Driver response to how successful the day was)	2.688	0.1036
9	HRSLOAD (Number of hours spent loading/unloading)	2.828	0.0951
10	POSTSTRS (Post-shift stress questionnaire)	3.161	0.0778

Table 22. Number and percent of observations correctly classified by optimal variable set. 0 refers to control event and 1 is the at-fault event. Number correct is presented first.

		Observed 0	Observed 1	Total
Predicted	0	78	26	104
		75.00	25.00	100.00
	1	14	44	58
		24.14	75.86	100.00
	Total	92	70	162
		56.79	43.21	100.00

It is important to point out that not all variables were selected to be included in the stepwise discriminant analysis. For example, variables with substantial missing data were not included. The reason this approach was taken was that SAS eliminates an entire observation if that observation contains a variable with missing data. As such, variables with a substantial amount of missing data (e.g., sleep quantity as determined by the Actiwatch) were eliminated. To compensate for the variables that were eliminated, an effort was made to include correlated measures that did not have much missing data. For example, the PERCLOS measure was not included in the analysis because for many of the events, due to dark or degraded video footage, PERCLOS could not be determined. In its place, OBSERV was used (notice that OBSERV proved to be in the optimal variable set as indicated in table 21). It should be noted that the correlation between PERCLOS and OBSERV was $r^2=0.39$.

With regards to PERCLOS, it should also be pointed out that a stepwise discriminant analysis was conducted with a set of variables that included PERCLOS. The result was that PERCLOS was included in the optimal set of prediction variables with $p = 0.0008$ (i.e., proved to be highly significant and a very important variable in the optimal variable set). The prediction matrix with the variable set that included PERCLOS was 92.77 percent for the 0-0 cell, but only 52.38 percent for the 1-1 cell. It is hypothesized that the poor prediction for the 1-1 cell was due to a lack of data whereby 96 of the 214 observations where not included in the analysis due to missing data. The point of this discussion is that it appears that both OBSERV and PERCLOS are important variables to predict driver fatigue, and that conclusions should not be made based on variables that were *not* present in the optimal variable set (table 21).

DATA SET: DRIVER AT FAULT AND FATIGUED VS. DRIVER AT FAULT AND NOT FATIGUED (CONTROL)

All the critical incidents in the third data set were events where the L/SH driver was judged to be at fault. The data were divided into one of two groups: either fatigue was apparent for the L/SH driver or fatigue was not apparent. To classify incidents into one of these two groups, threshold values for PERCLOS and OBSERV were set such that fatigued drivers were defined as having PERCLOS greater than or equal to 0.08, or an OBSERV value greater than or equal to 40. If an event did not meet one of these criteria, then the driver was deemed to be "not fatigued." Threshold values were set based on two criteria: (1) observing natural breaks in the data (when it was plotted across PERCLOS and OBSERV) and (2) the opinion of Walter Wierwille, the developer of the PERCLOS and OBSERV assessment methodologies (Wierwille, 1999). Once the data had been classified into "fatigue" and "no-fatigue" groups, F-tests and chi-squares were conducted. The entire list of these results can be found in appendix J.

Applying these threshold values for PERCLOS and OBSERV resulted in 16 of the 77 driver-at-fault incidents being classified as fatigue-related. That is, using this approach, 20.8 percent of the critical incidents that were captured in this study were categorized as having L/SH driver fatigue as a contributing factor.

Recall that EYETRANS was a measure of driver inattention and measured the number of eye transitions, from one major area to another, divided by a three-minute interval period preceding the start of the critical incident. As shown in figure 45, drivers in the fatigue group had 16.90 transitions as compared to no-fatigue drivers who had 24.91. This difference proved reliable, $F(1, 58) = 5.91, p = 0.0181$. This finding indicates that fatigued drivers spent less time scanning their environment and, hypothetically, were less attentive.

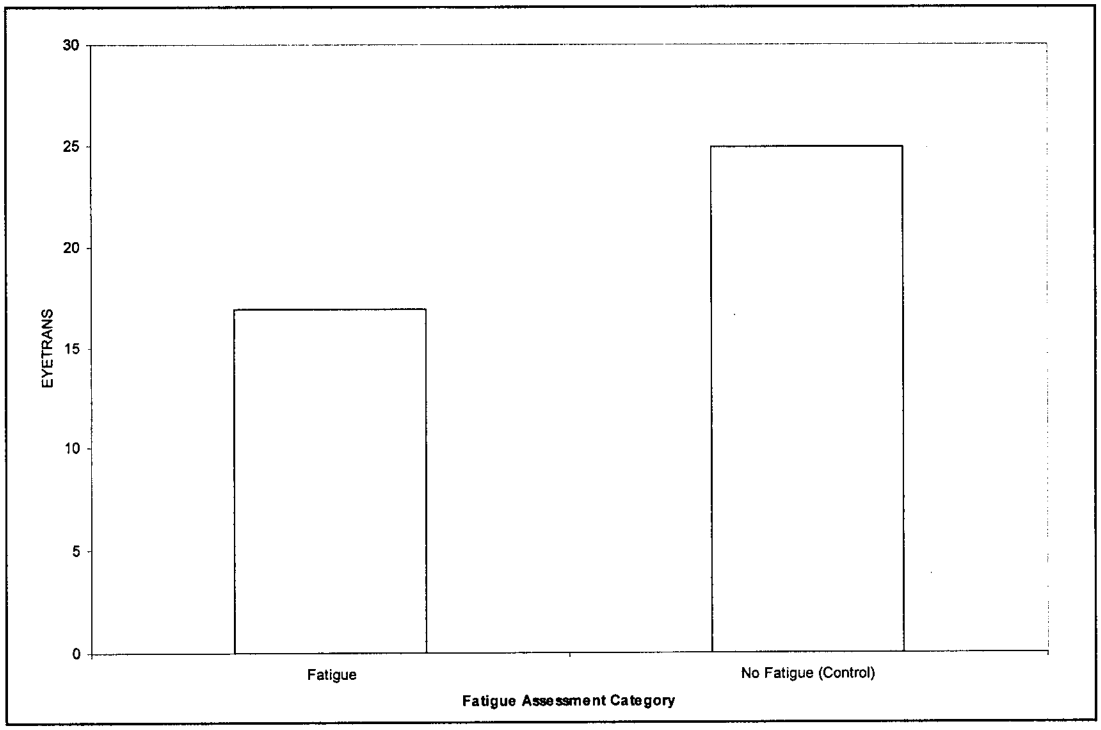

Figure 45. Driver inattention, as assessed by EYETRANS, as a function of critical incident category.

A second measure of driver inattention was EYESOFF, or the total time that the eyes were off the road divided by a three-minute interval preceding the event. As shown in figure 46, and consistent with the EYETRANS result, the mean time that the driver's eyes were off the road was 0.21 (proportion) for fatigued drivers compared to 0.13 for the no-fatigue group. This difference was statistically significant, $F\ (1, 59) = 4.84, p = 0.0317$. One interpretation of this finding is that fatigued drivers were less attentive and spent more time with their eyes off the road as compared to drivers who were not fatigued.

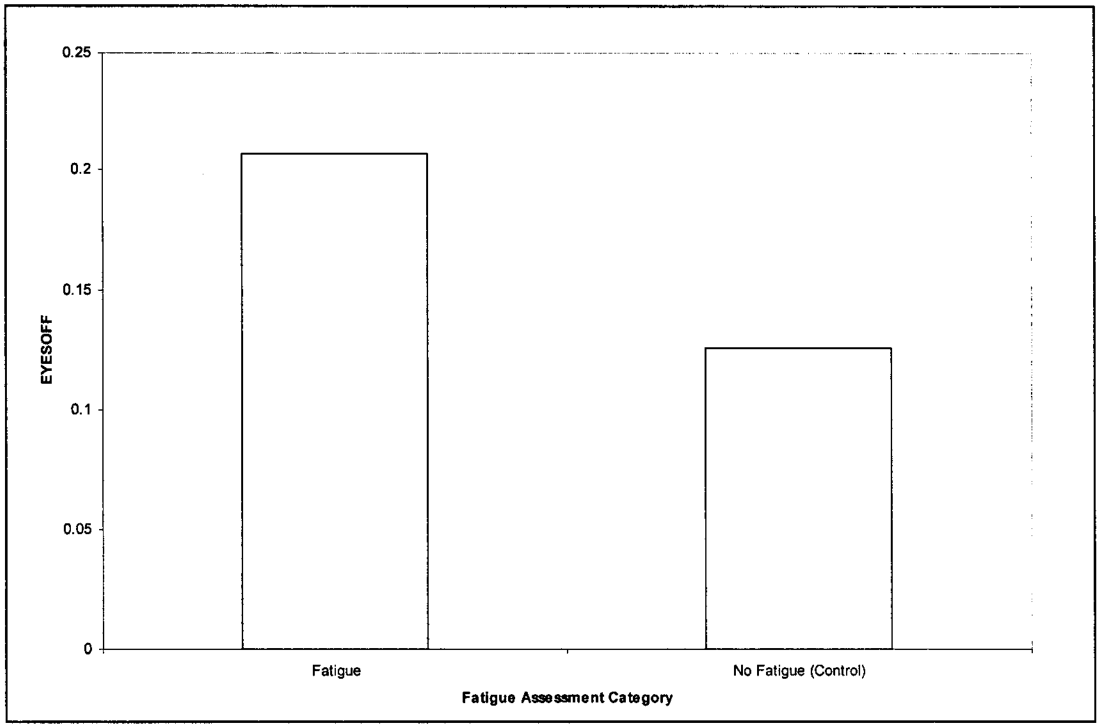

Figure 46. Driver inattention, as assessed by EYESOFF, as a function of critical incident category.

As shown in figures 47 and 48, both the self-reported amount of sleep and quality of sleep for the night before the incident were less when the driver was categorized as being fatigued. Drivers in the fatigue group had 5.33 hours of sleep compared to 6.13 hours in the no-fatigue group, $F\,(1, 66) = 4.51, p = 0.0374$. With regard to sleep quality, the mean quality rating for fatigued drivers was 3.46 as compared to 4.39 for the no-fatigue group; $F\,(1, 62) = 8.57, p = 0.0048$. It is noteworthy that the quantity and quality of sleep, as determined by the Actiwatch units, showed differences at the $p < 0.08$ level. As mentioned earlier, Actiwatch data were lost for several drivers because of malfunctions with the Actiwatches. This loss of data served to reduce the statistical power of the analysis. It is interesting to note that the Actiwatch-verified amounts of sleep for the fatigue and no-fatigue groups were 3.67 hours and 4.9 hours, respectively. The sleep quality ratings as determined by the Actiwatch were 68.28 for the fatigue group and 80.91 for the no-fatigue group.

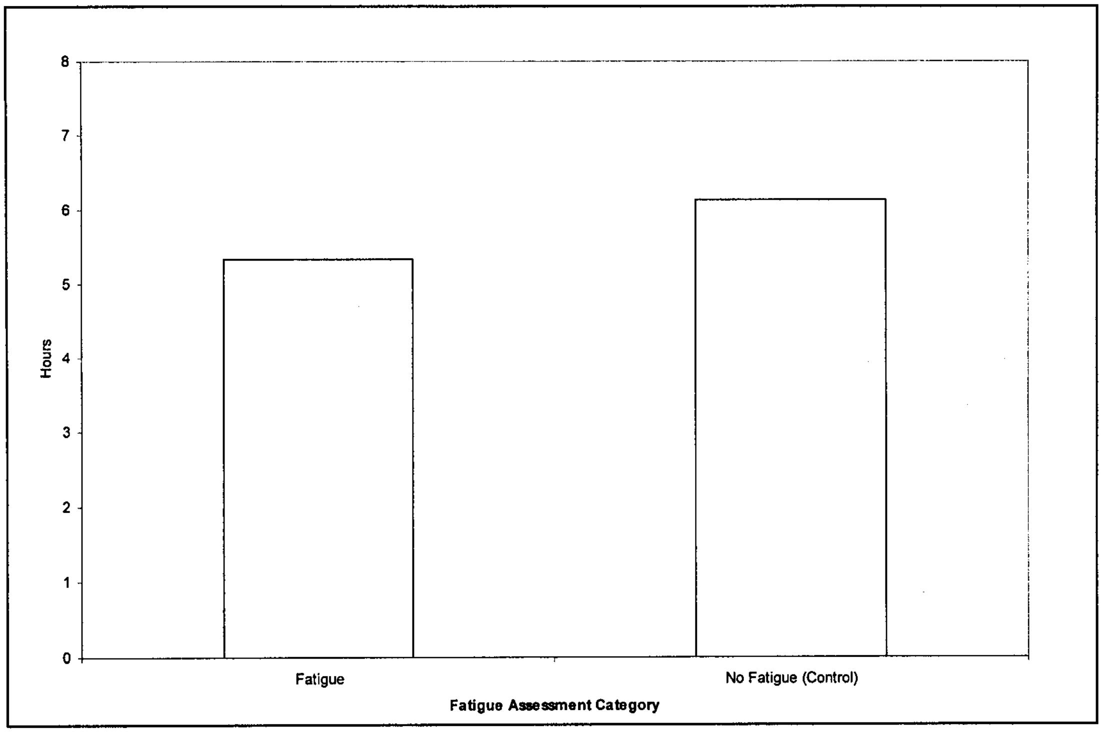

Figure 47. Driver sleep quantity as a function of critical incident category.

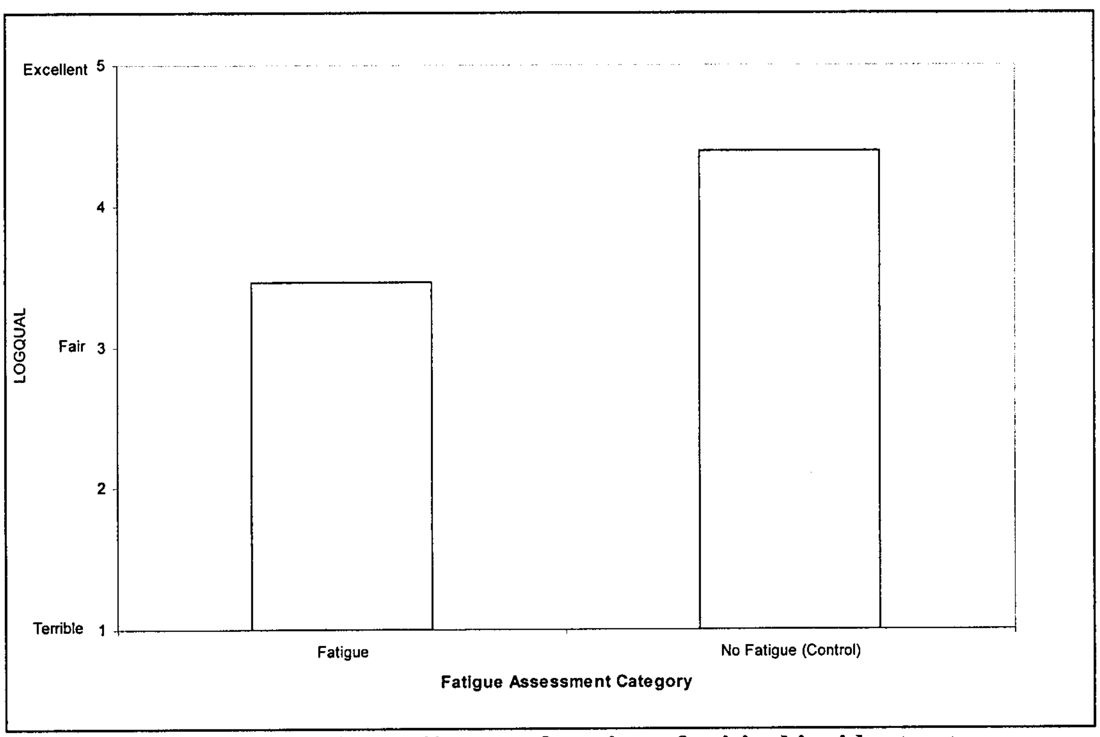

Figure 48. Driver sleep quality as a function of critical incident category.

Figure 49 shows that the drivers in the fatigue group spent more hours driving during the day of the critical incident ($M = 4.38$) as compared to drivers in the no-fatigue group ($M = 3.43$). This result proved to be statistically significant, $F(1, 73) = 4.07, p = 0.0474$. Note that hours driving refers to the driving day on which the critical incident occurred.

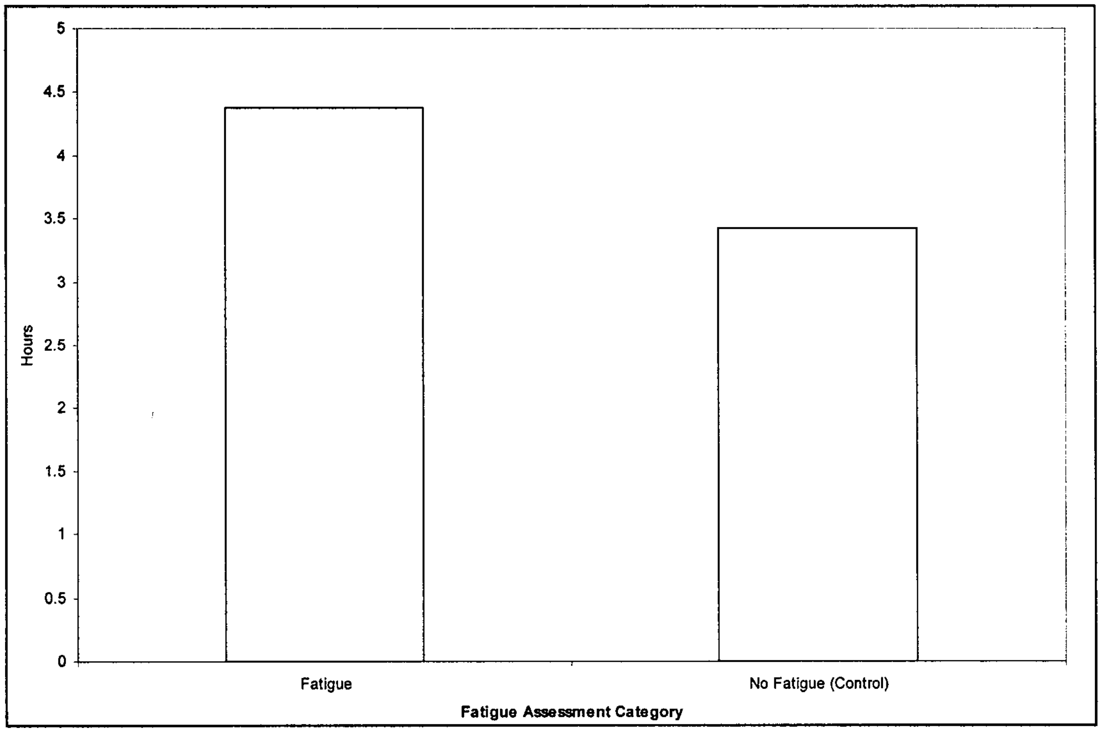

Figure 49. Number of hours driving as a function of critical incident category.

The number of hours the driver spent loading and unloading the vehicle was also found to be significantly different between the fatigue and no-fatigue groups, $F(1, 73) = 5.07, p = 0.0274$. As shown in figure 50, the drivers in the fatigued group spent, on average, 2.98 hours loading/unloading on the day of the critical incident as compared to drivers in the not-fatigued group who spend 4.03 hours on this task. Notice that the direction of this finding is in the opposite direction to number of hours driving per day. One possible explanation for this result is that the physical stimulation of loading/unloading helps drivers avoid fatigue. This explanation is consistent with the results from O'Neil, Kruefar, Hemel, and McGowan (1999) who found that a morning loading/unloading session improved drivers' performance in crash-likely circumstances. A second explanation is that drivers who spent less time loading/unloading were therefore spending more time driving, and driving for longer hours contributes to driver fatigue.

Note that there were no measures collected, or analyses that could be conducted, to investigate these explanations further.

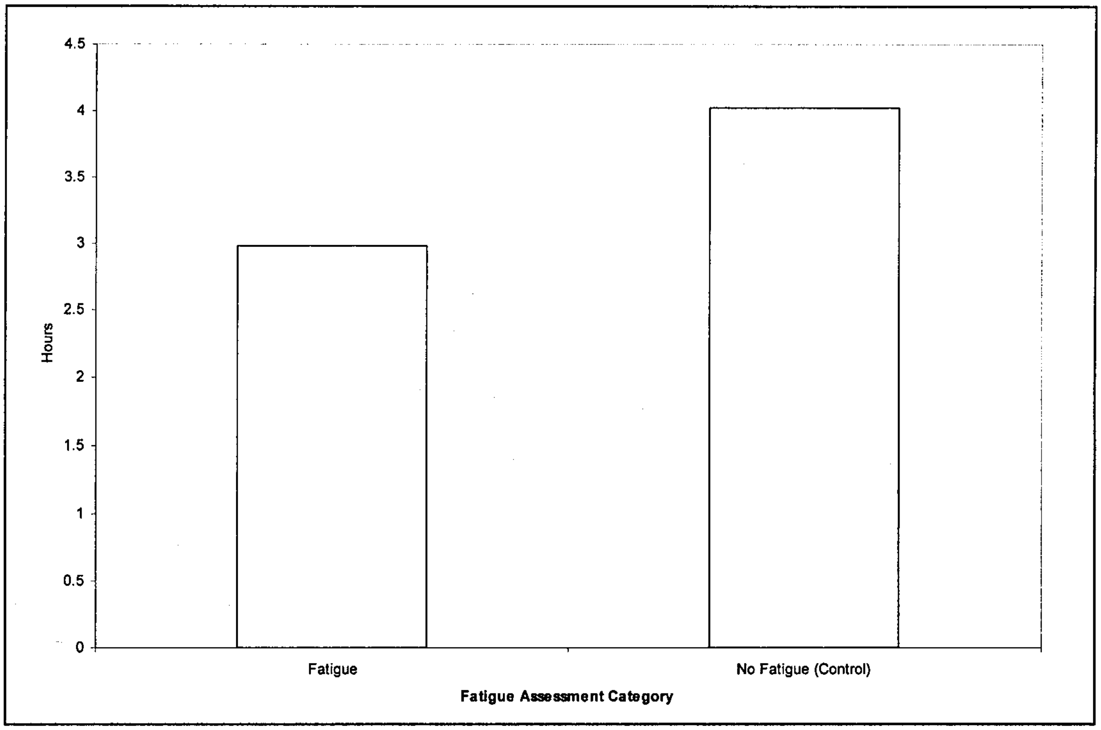

Figure 50. Number of hours loading/unloading as a function of critical incident category.

As shown in figure 51, like driver age, truck driving experience and L/SH driving experience significantly differed between the two groups of drivers. The mean truck driving experience for the drivers in the fatigue group was 0.285 years as compared to 2.19 years for the no-fatigue group, $F(1, 75) = 5.50, p = 0.0217$. Similarly, the mean L/SH experience for drivers in the fatigue group was 0.285 years as compared to 1.99 years for the no-fatigue group, $F(1, 75) = 5.25, p = 0.0248$. These findings show that it is the younger, inexperienced drivers who are most prevalent in the fatigue group.

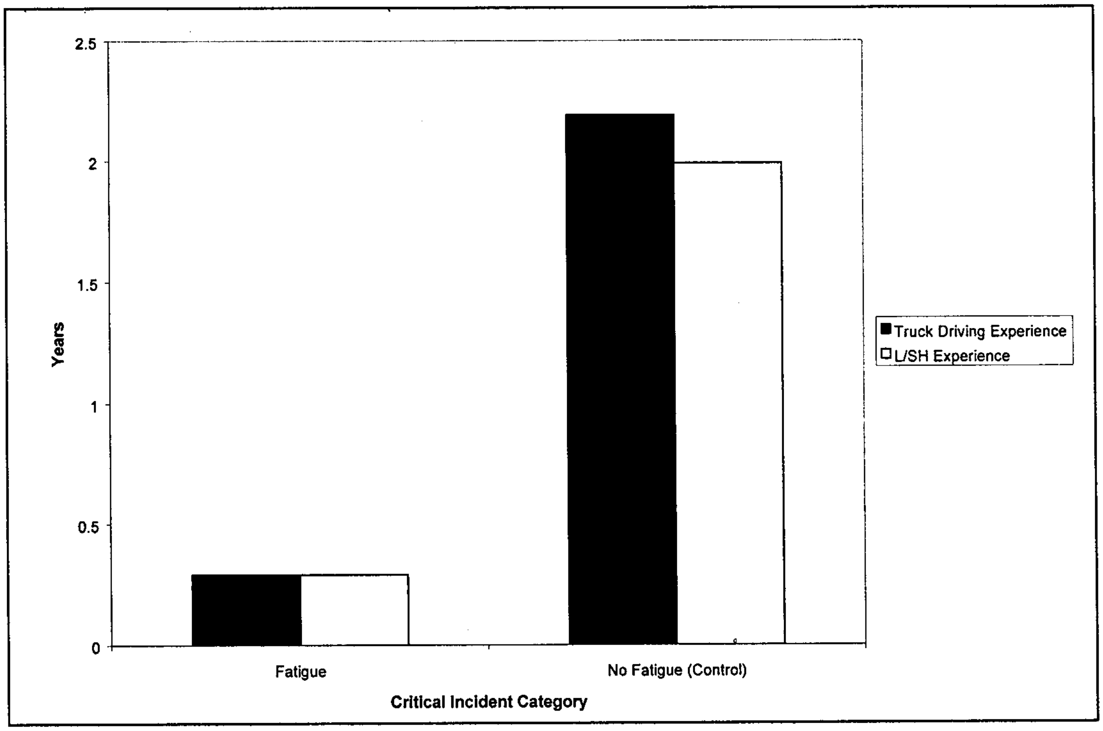

Figure 51. Driving experience as a function of critical incident category.

The final result that was significant was with respect to the shift, or workday, within the week that the drivers worked. Because drivers began and ended their workweeks on different days, a workday measure was created to "normalize" the workweek such that the first day was the driver's first working day, whether that was Monday or Tuesday. A chi-square test comparing the frequencies of critical incidents caused by the two groups of drivers proved significant, $X^2(4, N = 76) = 10.95, p = 0.027$. As shown in figure 52, critical incidents from the fatigue group were prominent early in the week, and non-existent on the fifth workday. For the no-fatigue group, the frequency of critical incidents was relatively stable throughout the week, though again tended to diminish late in the workweek. This result is somewhat surprising, as it might have been expected that the fatigue-related incidents would occur late in the week, perhaps as a result of increasing sleep debt (where drivers are more tired on Friday).

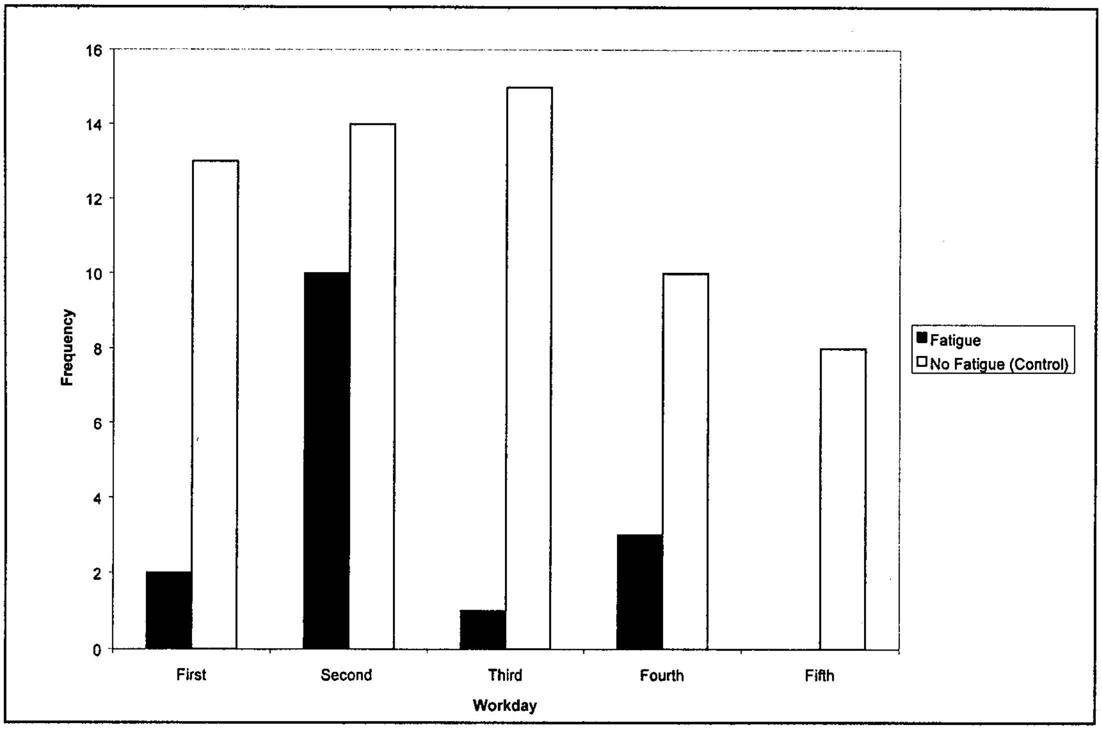

Figure 52. Frequency of incidents as a function of workday and driver fatigue.

As shown in figure 53, there was once again a significant effect for driver age, $F(1, 75) = 7.32$, $p = 0.0084$. The mean age for drivers in the fatigue group was 21.88 years, and 26.48 years for drivers in the no-fatigue group.

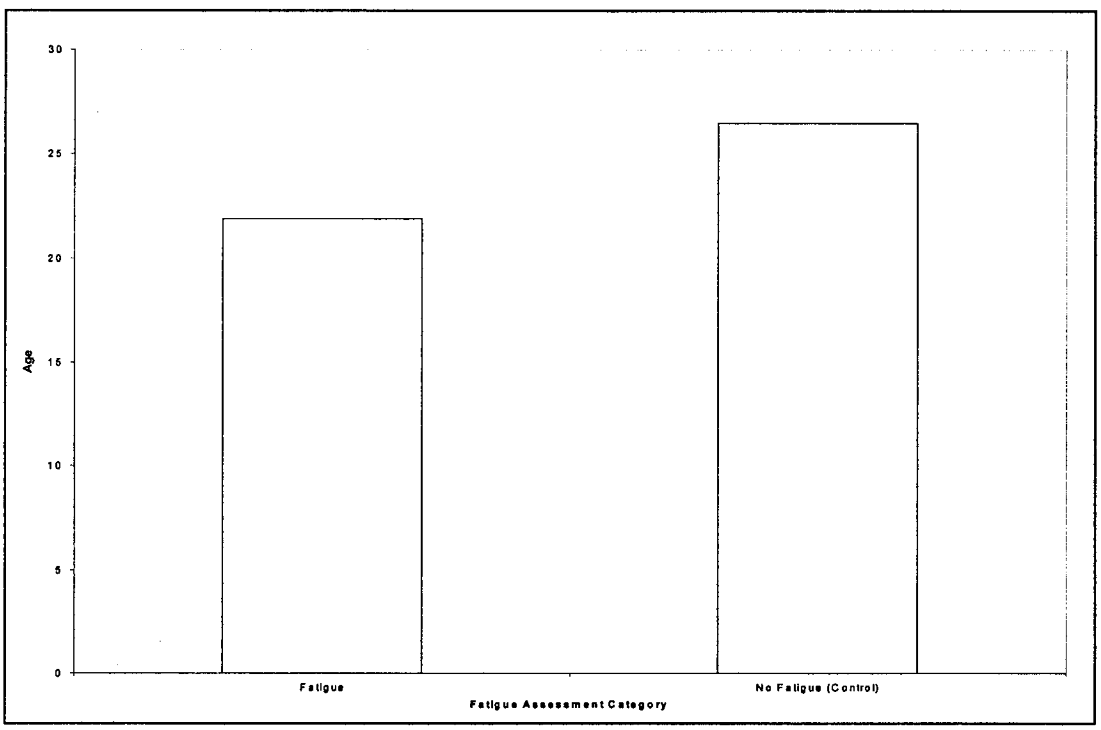

Figure 53. Driver age as a function of critical incident category.

A discriminant analysis conducted on the data set proved to be particularly successful. Table 23 indicates the variable set that was found to be optimal in predicting whether a given event belonged in the fatigue group or the no-fatigue group. Fatigue was again defined as having a PERCLOS value greater than or equal to 0.08 or an OBSERV value greater than or equal to 40. As in the discriminant analysis conducted with the previous data set, one can see that several of the variables that were significant in the ANOVAs were found to be important variables for group membership prediction. Notice that the variable set includes measures from each of the four groups of measures outlined previously (i.e., driver demographics, environmental, measures of apparent driver fatigue/inattention, and sleep hygiene/driver effort). The model that included the variable set outlined in table 24 was successful at predicting group membership in 100 percent of the cases. As will be discussed later in the Guideline Development section, this finding, in combination with the results from the ANOVAs and chi-square tests, suggests that recommendations targeting these particular measures may have the most significant impact in reducing critical incidents where fatigue is apparent.

Table 23. Optimal set of prediction variables determined in the discriminant analysis.

Number In	Variable	F Statistic	Prob > F
1	LOGQUAL (Self-reported sleep quality)	12.343	0.0011
2	TRAINING (Did the driver have truck driver training?)	5.752	0.0215
3	HRSLOAD (Number of hours spent loading/unloading)	5.427	0.0254
4	HRSDRIV (Number of hours driven per day)	5.574	0.0238
5	ILLUMIN (Outside illumination)	3.620	0.0653
6	SHIFT (Workday within the week)	3.787	0.0600
7	EYETRANS (Number of eye transitions)	2.306	0.1384
8	EYESOFF (Time eyes are off the roadway)	4.975	0.0329

Table 24. Number and percent of observations correctly classified by optimal variable set. 0 refers to control event and 1 is the at-fault event. Number correct is presented first.

		Observed		
		0	**1**	Total
Predicted	**0**	34	0	34
		100.00	0.00	100.00
	1	0	13	13
		0.00	100.00	100.00
	Total	34	13	
		72.34	27.66	

DATA SET: THE COMPLETE CRITICAL INCIDENT DATA SET

The fourth, and last, data set used the entire critical incident data set. This data set included critical incidents where the L/SH driver (1) was at fault, (2) was not at fault but was reacting to another driver, (3) was not involved but merely reporting a witnessed incident, and (4) was not at fault but reacting to a situation which did not involve another driver.

A multiple regression analysis was conducted on this data set with the goal of developing a regression equation to predict the frequency of critical incidents caused by a L/SH driver. Before this analysis could be conducted, the data were structured such that the daily frequency of critical incidents, that were judged to have been caused by the L/SH driver, were tallied. For drivers who were involved in multiple critical incidents where they were at fault, measures for the events were averaged. For example, if a driver had two critical incidents that he caused, the data from each incident was averaged, and a new variable, labeled "Critical Incident Frequency," was set to "2." All the data sets prior to this one treated each critical incident as an independent event. However, by averaging across incidents caused by a L/SH driver in a given day, measures for a particular driver who may have been involved in a disproportionate number of critical incidents, were not over-represented in the data set. For example, if a particular driver had a very poor night's sleep and was involved in multiple critical incidents in a given day, and each incident were treated as an independent observation, the criticism could be leveled that the data set is biased because of this driver (outlier). To address this potential limitation, multiple observations (critical incidents) from a given driver, within a given day, were combined.

As noted, regression was the data analysis method that seemed most appropriate to conduct on this data set. A stepwise regression equation was computed and the resulting equation, which predicts the frequency of incidents (per day), is shown below. An explanation of each variable is presented after the equation. Note that the R^2 for the model was 0.53. Table 25 shows a partial output for the regression analysis including the *F*- and *p*-values for each variable. It should be noted that the SAS default for a variable being removed from the model is $p > 0.15$.

Frequency of Critical Incidents Caused by the L/SH Driver = 1.5628 + (-0.0447 X AGE) + (-0.3548 X ILLUM) + (0.3325 X LOGQUAL) + (0.0134 X OBSERV) + (-0.0813 X POSTFAT) + (0.0105 X THINKING) + (-0.0106 x PHYSDEM) + (-0.0093 x TIMEPRES) + (0.0060 x FRUSTRAT)

Where:

- AGE is the age of the L/SH driver in years.
- ILLUM is the illumination outside the vehicle (0 = dark and 1 = light).
- LOGQUAL is the self-reported quality of sleep for the night preceding the critical incident.
- OBSERV is the analyst rating of driver drowsiness on a scale of 0 (not drowsy) to 100 (extremely drowsy).
- POSTFAT is the Stanford Sleepiness scale ranging from 1 (wide awake) to 7 (losing struggle to remain awake).
- THINKING is component of the NASA TLX scale that assesses level of thinking (i.e., mental workload) required of the driver that day and ranges from 0 (very low) to 100 (very high).
- PHYSDEM is also a component of the NASA TLX scale that assesses physical demand and how much physical activity was required that day. The scale ranges from 0 (very low) to 100 (very high).
- TIMEPRES is another component of the NASA TLX scale that assesses the amount of time pressure felt by the driver that day. The scale ranges from 0 (very low) to 100 (very high).
- FRUSTRAT is yet another NASA TLX scale component and assesses the frustration level of the driver for the day. The scale ranges from 0 (very low) to 100 (very high).

Table 25. Regression equation to predict frequency of critical incidents.

Variable	Parameter Estimate	F	Prob>F
Intercept	1.5628	11.69	0.0011
AGE	-0.0447	24.33	0.0001
ILLUM	-0.3548	3.14	0.0812
LOGQUAL	0.3325	16.18	0.0002
OBSERV	0.0134	9.01	0.0038
POSTFAT	-0.0813	3.97	0.0505
THINKING	0.0105	6.57	0.0127
PHYSDEM	-0.0106	5.82	0.0187
TIMEPRES	-0.0093	4.77	0.0327
FRUSTRAT	0.0060	2.22	0.1414

In looking at the regression equation, it can be seen that an increase in the frequency of critical incidents is associated with (1) younger drivers, (2) darkness outside the vehicle, (3) poor sleep quality, (4) an analyst's assessment that the driver appears drowsy, (5) an after-work self-report from the driver that he is *not* drowsy (note this is counter-intuitive)[1], (6) a self-report that indicates that the workday required a high level of thinking, (7) a self-report that indicates that the workday was not physically demanding, (8) a self-report that indicates that the driver did *not* feel very much time pressure (again, counter intuitive), and (9) a self-report that indicates that the driver's day was frustrating.

Table 26 shows example data for each variable. Substituting these values into the regression equation results in an estimate of 1.56 critical incidents per day for the given driver.

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[1] In multiple regression, it is possible for an independent variable to be weighted negatively (or counter intuitively) to obtain the best fit to the data. This is a result of one independent variable being used to offset another in the optimization process.

Note that changing the LOGQUAL[2] value from 3 ("Fair") to 1 ("Excellent"), and the OBSERV value from 40 (a rating between "Slightly Drowsy" and "Moderately Drowsy") to 0 ("Not Drowsy") changes the regression output to 0.36 critical incidents per day.

A strong caution must be given when interpreting the results for this analysis. Specifically, when the data were set up, the frequency of critical incidents that were judged to have been caused by a driver in a given day ranged from 0 (N = 109) to 1 (N = 45), to 2 (N = 11), to 3 (N = 2), to 4 (N = 1). Because the sample sizes at the high end of this distribution are very small (i.e., N = 2 and N = 1), the ability to make accurate predictions at the high end is limited. Nonetheless, cases where the independent variables are within the experimental ranges and the resulting predicted number of incidents is 2.0 or less are likely to produce representative results.

Table 26. Regression equation variables and sample data.

Variable	Sample Data
AGE	25
ILLUM	0
LOGQUAL	3
OBSERV	40
POSTFAT	3
THINKING	50
PHYSDEM	50
TIMEPRES	50
FRUSTRAT	50

MISCELLANEOUS FINDINGS

Recall that 77 of the 214 critical incidents that were captured were judged to be the fault of the L/SH driver. Of these 77 incidents, 2 drivers (4.8 percent of the driver participants) accounted for 25.97 percent of the incidents, and 8 drivers (19.05 percent of the driver participants) accounted for 59.74 percent of the incidents. In addition, there were no recorded critical incidents that were judged to have been caused by the L/SH driver for 33.33 percent of the drivers, and 61.90 percent of the drivers were judged to be responsible for one incident or

[2] Data were not inverted to match the directional compatibility of the Actiwatch sleep quality data. That is, the raw values were used where a low value indicates high quality sleep and a high value indicates low quality sleep.

less. In considering the events where the driver demonstrated signs of fatigue and was judged to have caused a critical incident (N = 16), only 5 drivers (11.90 percent of the driver participants) were involved, and 3 of these drivers (7.14 percent of the driver participants) had multiple (i.e., two or more) incidents. Finally, for multiple incidents that were judged to have been caused by the L/SH driver, only 7 drivers (16.67 percent) were involved in two or more critical incidents. The conclusion that can be drawn from these results is that the majority of critical incidents that were recorded can be attributed to a fairly small group of the L/SH driver participants.

SUMMARY OF CRITICAL INCIDENT ANALYSIS

As suggested previously, because of the limitations of field-study data collection, it is difficult to make cause-and-effect links between independent and dependent measures. For example, it cannot be said that driver inexperience causes critical incidents. Rather, the best that can be done is to identify variables that appear to be related to certain grouping measures. In the data analyses presented here, the data that were collected during the field study were grouped in several different ways and multiple analyses were conducted. In considering all of the results that were presented, a number of strong relationships have become apparent. As previously indicated, in addition to the "Critical Incident" variable, which specified the event of interest and the control events, four variable categories were identified. A summary of the research findings is presented in the following sections for each of the four variable categories.

Driver Demographics Measures

Across all data sets, regardless of how the data were parsed, it was apparent that younger, less experienced drivers were more apt to be involved in critical incidents, cause critical incidents, and be fatigued prior to causing critical incidents. It is perhaps not too speculative to propose that the skills of L/SH drivers likely improve with experience and, as such, the frequency with which more experienced (and older) drivers are involved in critical incidents is lower than their younger, less experienced counterparts. In addition, more experienced drivers may have learned to obtain adequate rest.

Environmental Measures

There did not appear to be a strong trend with regard to the "environmental" measures that were collected. In one analysis, time of day was significant and may suggest that L/SH drivers should be particularly cautious during the latter part of the day when actions of "other drivers" seem especially troublesome. The results also indicate that L/SH drivers may be particularly prone to causing incidents during the midday hours. This result, coupled with significant PERCLOS and OBSERV measures (detailed later), suggest that L/SH drivers may suffer from an "after-lunch" period of drowsiness that could impact there driving safety. In addition, incidents caused by L/SH drivers, and where drivers seemed fatigued, were most prevalent on the second workday. It is difficult to determine the meaning of this result. However, as will be discussed in the Sleep Hygiene/Driver Effort section, sleep quantity and sleep quality were also significantly less on the nights before such incidents. One might surmise that, for one reason or another, drivers were less likely to be well-rested on mornings early in the workweek.

Measures of Apparent Driver Fatigue/Inattention

From the multiple analyses that were conducted, using various data sets and control events, it is apparent that driver fatigue significantly increased the likelihood of driver involvement in an at-fault critical incident. Both PERCLOS and OBSERV measures were significantly different from baseline measures when the baseline selected was either non-critical incident lane change events or critical incidents that were not caused by L/SH drivers. When the data analysis was directed at critical incidents caused by L/SH drivers, where the driver showed signs of fatigue, measures of driver inattention also proved to be significant. This result suggests that fatigued drivers are probably not paying as much attention to the driving task as they should. Though the claim cannot be made that driver fatigue and inattention lead to L/SH drivers causing critical incidents, it can be stated that when a critical incident occurs, that has been judged to be the fault of the L/SH driver, the L/SH driver often demonstrates symptoms of fatigue. And, when the driver seems fatigued, the driver also appears to be inattentive to the driving environment. Finally, using threshold values for PERCLOS and OBSERV to classify incidents as fatigue-related or not, it was found that fatigue was a contributing factor in 20.8 percent of the incidents where the L/SH driver was judged to be at fault.

Sleep Hygiene/Driver Effort Measures

With regard to drivers' sleep hygiene, poor sleep quality and less sleep quantity were found to be more prevalent when drivers demonstrated characteristics of fatigue during the workday. Poor sleep quality was also found for drivers who had been judged to have caused a critical incident. One might make a common sense hypothesis and say that drivers who are well-rested are less likely to suffer the next day from the effects of fatigue, which may include degraded performance and judgment. In the present study, degraded performance and judgment may be thought of as being represented by involvement in at-fault critical incidents.

In terms of driver effort, one result that proved significant in multiple analyses involved the impact of driving hours on causing critical incidents. That is, longer driving hours were associated with critical incidents caused by L/SH drivers, in comparison to critical incidents that L/SH drivers were involved in that they did not cause. Associated with this result, though not reported previously, the total mileage driven by drivers deemed to be at fault in a critical incident was 102.81 miles as compared to 90.63 miles for drivers not at fault. Though this failed to reach statistical significance at $p < 0.05$, there was a trend for significance, $F(1, 181) = 3.55$, $p = 0.0613$. These measures of driver effort suggest that drivers who drove more were more likely to be involved in an at-fault critical incident. A potentially related finding involved number of hours loading/unloading during the workday. Recall, that drivers who were judged to be at-fault but *not* fatigued, spent over one hour more loading/unloading as compared to drivers who were at-fault and fatigued. This finding may suggest that the physical stimulation of loading/unloading helps alleviate fatigue (a finding supported by the focus group results, and by O'Neil, Kruefar, Hemel, and McGowan, 1999).

LANE CHANGE AND BACKING ANALYSIS

OVERVIEW

One of the goals of the research effort was to collect both critical incident data and non-critical incident data (i.e., "normative" data) for lane change and backing events. Before describing the results from the analyses, it is helpful to outline how the lane change and backing event data sets that were used in the analyses were structured. Figure 54 illustrates how the lane change and backing event data were classified. As can be seen, there were a total of 274 lane change events that were analyzed, 260 normative events, and 14 with critical incidents. In the analysis conducted on the critical incidents, the 260 normative events served as the control (baseline). For the backing data set, there were 268 backing events, 260 of these were normative events (control) and 8 of which involved critical incidents.

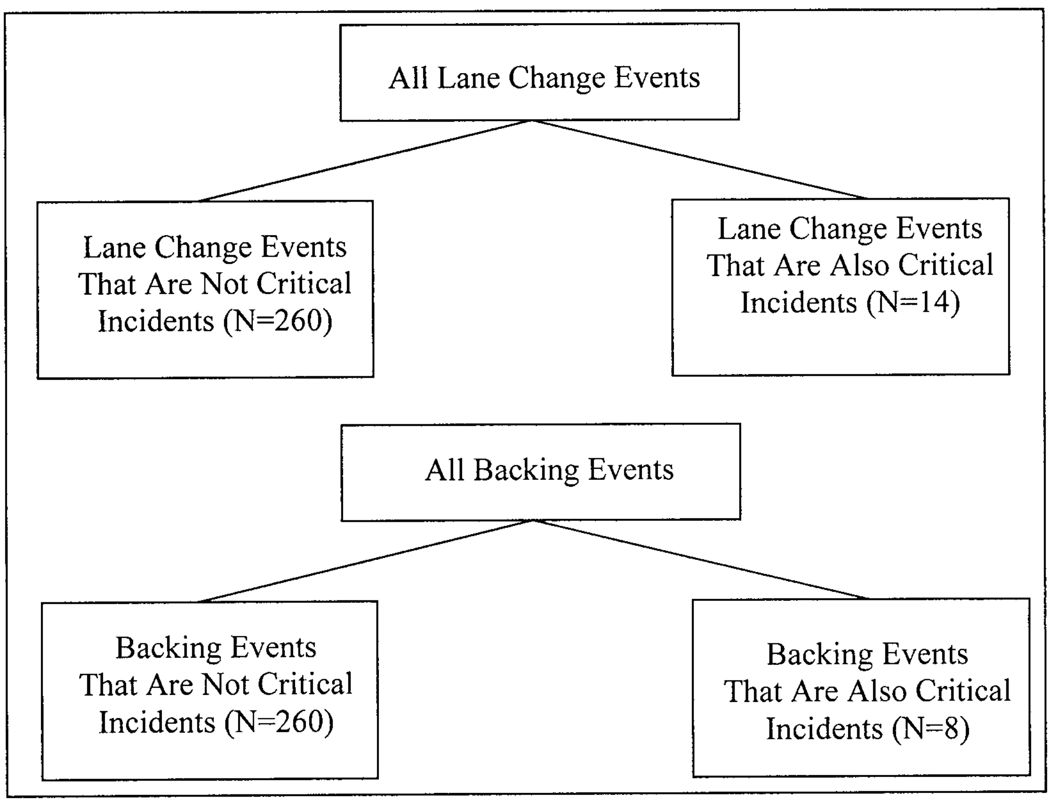


Figure 54. Data set structure for analyzing lane change events and backing events.

With regard to the normative analyses, a simple taxonomy was used to structure the data. Descriptive measures were then calculated using this taxonomy. For the critical incident data, a 2 x 2 (Critical Incident x Drowsiness) Analysis of Variance (ANOVA) was conducted on both the lane change and backing data sets. With regard to the extent that fatigue is an issue in critical incidents that occurred while making lane change and backing maneuvers, the lane change and backing data sets were divided into one of two fatigue-related groups: either fatigue was apparent for the L/SH driver or fatigue was not apparent. To classify incidents into one of these two groups, threshold values for PERCLOS and OBSERV were again set such that fatigued drivers were defined as having PERCLOS greater than or equal to 0.08, *or* an OBSERV value greater than or equal to 40. (Recall that the OBSERV scale was from 0, "not drowsy," to 100, "extremely drowsy." OBSERV anchor points were 25 for "minimally drowsy" and 50 for "moderately drowsy.") If an event did not meet at least one of these two criteria, then the driver was deemed to be "not fatigued." Once the threshold values were set and the events (lane change and backing) classified, the result was a data set that had two classification variables of interest: Critical Incident (yes or no) and Fatigue (yes or no), where Fatigue was assessed by either PERCLOS or OBSERV. ANOVAs on each of the dependent measures were then conducted using the General Linear Model (GLM) procedure to account for unbalanced data.

LANE CHANGE ANALYSIS RESULTS AND DISCUSSION

The results of the lane change analysis are divided into two sections. The first section outlines an analysis conducted to examine general lane change performance using the normative data. The second section describes the results of the ANOVAs that were performed on the critical incident data.

Normative (Non-Incident) Lane Change Events

A taxonomy was developed to classify the types of lane changes. Table 27 outlines the taxonomy that was used and the number of lane change events that were classified for each category. Results are presented in frequency-of-occurrence order. As previously indicated, the total number of normative lane change events was 260. Note that all 260 events were classified into one of the categories. Also, it should be noted that the categories were developed as the data were being analyzed and, as such, the categories listed in table 27 do not necessarily represent the entire spectrum of lane change types.

Table 27. Taxonomy categories and the frequency with which each lane change type occurred (shown in descending order).

Lane Change Type	Frequency
Pass on Left	62
Arbitrary	48
Move to Exit Right	46
Move to Exit Left	31
Merge Left	26
Move Right	16
Pass on Right	15
Merge Right	14
Move to Shoulder	2

Using the categories outlined in the taxonomy, descriptive statistics were calculated for each category. Table 28 shows the mean and standard deviations for a sample of the measures that were collected. For convenience, abbreviated definitions for the dependent measures are shown in table 29.

Table 28. Descriptive statistics for the lane change taxonomy categories. Upper value in each row is mean (M) and lower value is the standard deviation (S).

Measures	Taxonomy Categories								
	Pass on Left	Arbitrary	Move to Exit Right	Move to Exit Left	Merge Left	Move Right	Pass on Right	Merge Right	Move to Shoulder
Duration	M=4.66	M=4.71	M=3.98	M=4.96	M=4.52	M=3.96	M=4.81	M=4.47	M=5.10
	S=2.20	S=1.39	S=1.44	S=1.59	S=1.41	S=1.47	S=1.88	S=1.92	S=1.20
Eyetrans	M=26.7	M=24.7	M=22.3	M=24.0	M=26.4	M=24.1	M=30.5	M=24.8	M=21.5
	S=11.2	S=9.77	S=11.5	S=7.41	S=11.5	S=11.3	S=13.5	S=8.46	S=7.78
PropCFw	M=0.66	M=0.68	M=0.74	M=0.77	M=0.56	M=0.68	M=0.67	M=0.71	M=0.60
	S=0.18	S=0.18	S=0.21	S=0.17	S=0.19	S=0.11	S=0.17	S=0.16	S=0.16
PropLFw	M=0.05	M=0.03	M=0.04	M=0.05	M=0.12	M=0.03	M=0.03	M=0.03	M=0.03
	S=0.13	S=0.06	S=0.09	S=0.08	S=0.19	S=0.08	S=0.05	S=0.04	S=0.00
PropRFw	M=0.03	M=0.02	M=0.07	M=0.03	M=0.06	M=0.04	M=0.07	M=0.02	M=0.03
	S=0.04	S=0.05	S=0.12	S=0.05	S=0.09	S=0.07	S=0.10	S=0.04	S=0.05
PropLMir	M=0.14	M=0.08	M=0.05	M=0.08	M=0.15	M=0.05	M=0.02	M=0.04	M=0.17
	S=0.10	S=0.14	S=0.08	S=0.11	S=0.12	S=0.07	S=0.04	S=0.04	S=0.04
PropRMir	M=0.04	M=0.11	M=0.03	M=0.02	M=0.01	M=0.14	M=0.12	M=0.11	M=0.04
	S=0.09	S=0.13	S=0.04	S=0.04	S=0.04	S=0.09	S=0.09	S=0.14	S=0.02
PropLWin	M=0.01	M=0.02	M=0.02	M=0.03	M=0.03	M=0.00	M=0.01	M=0.04	M=0.02
	S=0.04	S=0.06	S=0.04	S=0.06	S=0.06	S=0.01	S=0.05	S=0.09	S=0.03
PropRWin	M=0.00	M=0.00	M=0.00	M=0.00	M=0.00	M=0.01	M=0.01	M=0.02	M=0.04
	S=0.02	S=0.01	S=0.01	S=0.02	S=0.02	S=0.02	S=0.02	S=0.04	S=0.06
PropIP	M=0.02	M=0.01	M=0.01	M=0.01	M=0.03	M=0.01	M=0.04	M=0.02	M=0.01
	S=0.04	S=0.02	S=0.04	S=0.03	S=0.05	S=0.03	S=0.06	S=0.03	S=0.01
PropOther	M=0.03	M=0.03	M=0.03	M=0.00	M=0.04	M=0.03	M=0.00	M=0.02	M=0.06
	S=0.09	S=0.07	S=0.08	S=0.02	S=0.07	S=0.10	S=0.01	S=0.06	S=0.00
PlLatAcl	M=-0.07	M=-0.05	M=-0.02	M=-0.04	M=-0.01	M=0.00	M=-0.02	M=-0.01	M=-0.11
	S=0.09	S=0.12	S=0.10	S=0.09	S=0.13	S=0.10	S=0.10	S=0.09	S=0.02

Table 29. Description of the measures presented in table 26.

Abbreviation	Description
Duration	Event duration.
Eyetrans	EYETRANS value.
PropCFw	Proportion of time looking center forward.
PropLFw	Proportion of time looking left forward.
PropRFw	Proportion of time looking right forward.
PropLMir	Proportion of time looking left mirror.
PropRMir	Proportion of time looking right mirror.
PropLWin	Proportion of time looking left window.
PropRWin	Proportion of time looking right window.
PropIP	Proportion of time looking at the instrument panel.
PropOther	Proportion of time looking at another location.
PkLatAcl	Mean peak lateral acceleration.

Lane Change Critical Incidents

Before presenting the results from the ANOVA conducted on the lane change data, it is worthwhile to examine the lane change events that were also identified as critical incidents. Table 30 presents the analyst's description of these 14 events. It should be noted that the purpose of the narratives was for the analyst to provide a brief written description of the event. As there were multiple analysts, the narratives differ somewhat as to the writing style and the amount of detail provided.

Table 30. Narratives from the 14 lane change events also classified as critical incidents.

Event Number	Narrative
1	Subject: 14 Age: 21 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 1/19/99 Time: 1:55:07 PM Event: Critical Incident #3 Begin Sync: 260570 Driver was in the left-hand lane of a divided, urban, three-lane road. A van braked and signaled to get into a left turn lane, but was still partly in the driver's lane (left lane). The driver of the truck checked his right mirror, waited for a vehicle to pass and then swerved to the right around the van, partly entering the middle lane. It was clear, daylight, and light traffic.
2	Subject: 14 Age: 21 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 1/19/99 Time: 12:55:39 PM Event: Critical Incident #5 Begin Sync: 237092 Driver was preparing to enter the highway from a right hand merge lane. Visibility was good and the weather was clear. As he was entering the highway, another truck in the right lane of the highway was continuing along the right lane of the highway. The driver had to slow down and drive on the shoulder to avoid the truck.
3	Subject: 19 Age: 19 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 3/26/99 Time: 6:26:11 AM Event: Critical Incident #3 Begin Sync: 413531 The driver is looking down at something placed beside him and in the process drifts from right lane into left lane. It is early in the morning and there is not much traffic around, hence nobody is affected. The driver is eating and drinking all the while he is driving and most of the time his eyes are off the road. The driver is inattentive and this may be due to fatigue. It is dark but the weather is clear and the road condition is dry.

4	Subject: 21 Age: 26 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 4/23/99 Time: 3:30:09 PM Event: Critical Incident #6 Begin Sync: 671890 The driver drifts into the oncoming lane due to lack of attention on the road. The driver is looking out of the right window when he drifts onto the oncoming lane. There are no vehicles nearby and hence no one is affected. The driver does not seem alert and seems to be a bit drowsy. The driver is wearing glasses and hence it is difficult to observe his eyes clearly. The weather is clear and the roads are dry.
5	Subject: 22 Age: 26 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 5/5/99 Time: 8:32:22 AM Event: Critical Incident #3 Begin Sync: 227409 The driver is merging onto a freeway from the left side. While he is trying to merge there is traffic behind him as well as a slow-moving vehicle ahead of him. He merges before the slower moving vehicle in front does (i.e., passes the slower moving vehicle). The road is dry and the weather is clear. The driver seems alert. He is eating, drinking soda, and smoking during the interval preceding the event.
6	Subject: 22 Age: 26 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 5/5/99 Time: 12:00:26 PM Event: Critical Incident #8 Begin Sync: 274102 The driver is not paying attention and drifts into the left lane from the right lane on a road which is curving left. The driver is in the left lane for a considerable time after which he moves back into the right lane. There is not much traffic and the road is dry. The weather is clear.
7	Subject: 22 Age: 26 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 5/7/99 Time: 1:17:54 PM Event: Critical Incident #12 Begin Sync: 575243 The driver is reading something placed on the steering wheel, possibly a map. He strays into the oncoming lane. He still is not concerned and reads the map even while he is taking the corrective action. There are no other vehicles in sight. The weather is clear and the road condition is dry.
8	Subject: 25 Age: 20 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 6/18/99 Time: 6:01:42 AM Event: Critical Incident #1 Begin Sync: 318678 The driver drifts in to the next lane. There are two lanes in one direction, and the driver is in the right lane. He drifts into the next lane and it's a while before he takes the corrective action. There is no traffic behind him and hence there was no serious consequence of his mistake. It is early in the morning (6:30) and the driver is very drowsy and often closes his eyes (lasting about 400-600 ms). He is struggling to keep awake and reduces the speed of his truck. He is wearing glasses and hence it is difficult to observe his eyes. The weather is clear and visibility is unlimited. The roads are dry.

9	Subject: 25 Age: 20 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 6/25/99 Time: 8:59:38 AM Event: Critical Incident #6 Begin Sync: 751107 The driver approaches an intersection and proceeds towards the right turn lane. But, before he completely enters that lane he moves across the middle lane into the left turn lane. In the process of completing the lane change he crosses the stop bar and has to back up considerably. The driver is alert but seems confused and indecisive. There is no traffic coming behind him while he is backing, with the exception of a car proceeding towards the right turn lane. The driver is wearing glasses and hence it is difficult to clearly see his eyes. The weather is clear and there is unlimited visibility. The roads are dry.
10	Subject: 27 Age: 19 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 7/21/99 Time: 12:24:51 PM Event: Critical Incident #1 Begin Sync: 216599 The driver was on a two-lane road. His chance to pass is about 200 feet away when he crosses the double yellow line. He had completely crossed the line and was in the other lane while the line was still a double yellow. When he made the final move back into his lane the line had changed to a passing line. This move was illegal, which is why it was deemed a critical incident.
11	Subject: 27 Age: 19 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 7/28/99 Time: 2:41:32 PM Event: Critical Incident #5 Begin Sync: 692962 Our driver is on cell phone and is trying to change lanes. An SUV is trying to pass him and our driver cuts the SUV off in the process of changing lanes. The SUV has to slow down. The driver seems to be engrossed in conversation and doesn't notice his mistake. The weather is clear and the roads are dry.
12	Subject: 29 Age: 42 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 8/25/99 Time: 2:44:05 PM Event: Critical Incident #3 Begin Sync: 485721 The driver is on a one-way, two-lane highway. There is a truck behind our truck and one directly beside him. The truck beside him speeds up and gets in our driver's lane. The truck behind him decides to switch lanes too into the lane beside our driver. Our driver begins to change lanes at the same moment as the other two vehicles. Our driver very obviously cuts off the driver behind him.
13	Subject: 45 Age: 23 Gender: Male Company: Snack Truck: Panel Van Date: 6/8/99 Time: 2:23:31 PM Event: Critical Incident #1 Begin Sync: 72442 The driver was driving down a two-lane road. He appeared to be very drowsy. His eyes never left the road and they never close. He crossed a double yellow line and drove completely in the other lane for about nine seconds before returning to his lane. There was a car a long distance behind him, but no vehicles in front of him.

14	Subject: 45 Age: 23 Gender: Male Company: Snack Truck: Panel Van Date: 6/18/99 Time: 3:20:12 AM Event: Critical Incident #3 Begin Sync: 663505 The snack truck driver passes a slower moving heavy vehicle and in the process passes over a solid line. He says (paraphrased) that he does not have the time to wait for this truck. The truck is on an urban road divided by a median. Visibility is limited because it is dark. The drivers face cannot be seen and no eye glance analysis could be done. The road condition appears to be dry, clear and is straight ahead. The level of service is A.

Recall that in setting up the data for the 2 x 2 (Critical Incident x Drowsiness) ANOVA, events classified as "drowsy" had the following criteria: PERCLOS of 0.08 or greater, or OBSERV value of 40 or greater. For one of the 14 lane change critical incidents, the driver's face could not be seen because it was too dark. As such, only 13 lane change incidents were available for analysis. Using the drowsiness classification procedure, two of the 13 lane change critical incidents were judged to have involved a drowsy driver. Put another way, 15.4 percent of the lane change critical incidents had drowsiness as a contributing factor. This compares to 18 of the 260 non-incident lane changes, or 6.9 percent, that involved a drowsy L/SH driver. An ANOVA was conducted on Critical Incident vs. No Critical Incident events, with PERCLOS and OBSERV as dependent measures. The results of this analysis indicated that drivers involved in a lane change incident were significantly more drowsy than drivers not involved in an incident, $F(1, 271) = 13.05$, $p=0.0004$. This finding is shown in figure 55. The ANOVA with OBSERV was not statistically significant, $p>0.05$. To determine the extent that inattention was a factor in the lane change critical incidents, ANOVAs were conducted with the dependent variables EYETRANS and EYESOFF. No statistically significant findings were determined in either analysis, $p>0.05$. The results of all of these analyses are detailed in appendix K.

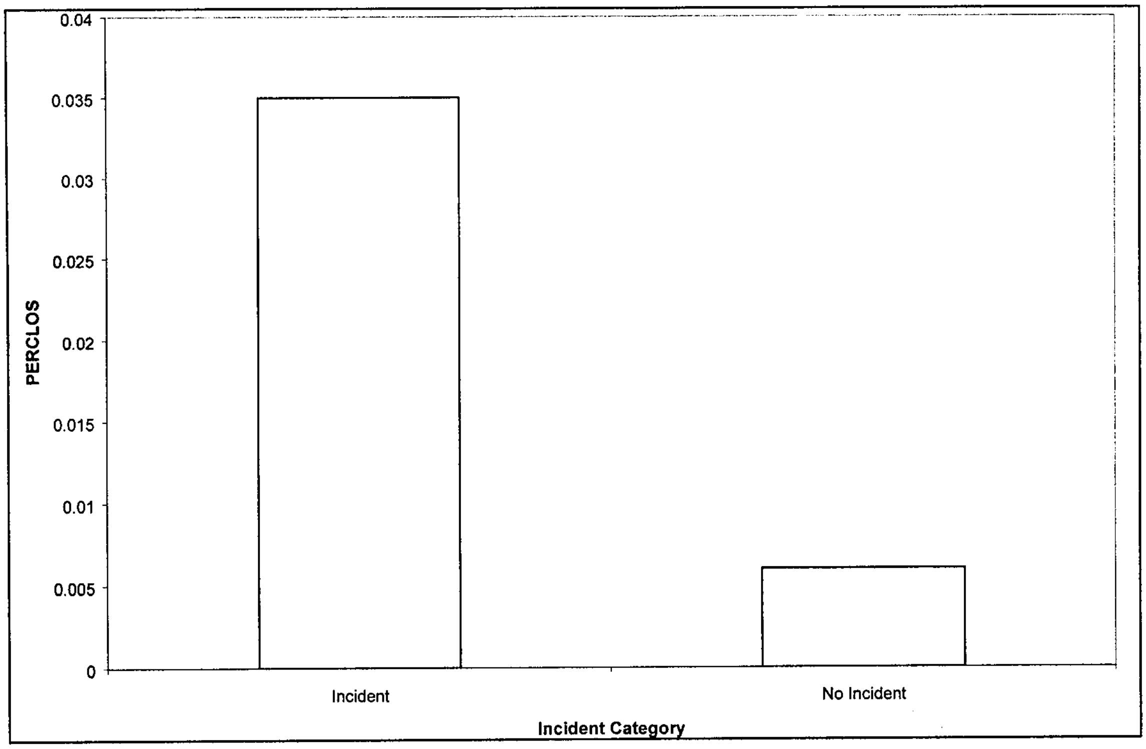


Figure 55. PERCLOS as a function of lane change critical incident involvement.

A 2 x 2 (Critical Incident x Drowsiness) ANOVA was conducted on the lane change/critical incident data set and the results are presented in appendix K. Although the results shown in the appendix have *p*-values less than 0.10 bolded, the text focuses on those results that have a significance level of $p < 0.05$. Once again, the reason for highlighting results with larger *p*-values than is traditionally presented (i.e., 0.05) is because the topic being discussed is related to safety.

Figure 56 shows that it took significantly less time to complete lane change events that were also critical incidents ($M = 4.52$ seconds) as compared to lane change events that were not critical incidents ($M = 4.79$ seconds), $F(1, 270) = 12.49, p = 0.0005$. There is no single satisfying explanation for this finding. However, it could be hypothesized that the faster maneuver contributed to the critical incident or that it was a result of the critical incident, in that it included an evasive-maneuver component.

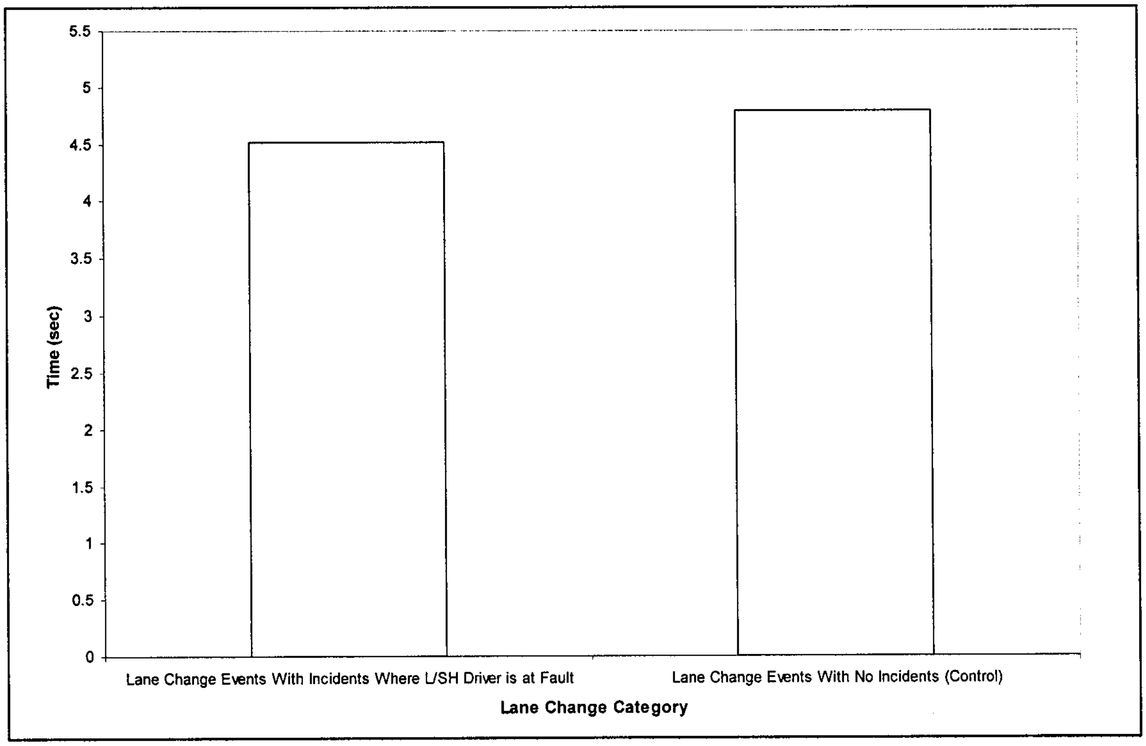


Figure 56. Duration of lane changes as a function of lane change category.

Figure 57 shows that drivers who were assessed to be fatigued during the lane change event, using the PERCLOS measure, also spent less time to complete a lane change. For fatigued drivers, the mean time to complete a lane change was 3.73 seconds, as compared to no-fatigue drivers' time of 4.79 seconds. This result proved to be significant, $F(1, 270) = 5.64, p = 0.0183$. Once again, there does not seem to be a fully satisfactory explanation for this finding. One possible, though speculative, reason for the shorter lane change times is that drowsy drivers waited longer to start a lane change and then had to hurry it.

Figure 58 shows that drivers who were assessed to be fatigued, using the OBSERV measure, spent significantly more of their time looking at the center-forward location as compared to the no-fatigue group, $F(1, 270) = 3.95, p = 0.0478$. The time proportions for the fatigue and no-fatigue drivers were 0.79 and 0.68, respectively. One possible explanation for this finding is that fatigued drivers spend less time scanning their environment and more time focused on the forward location. The next result that is presented supports this explanation.

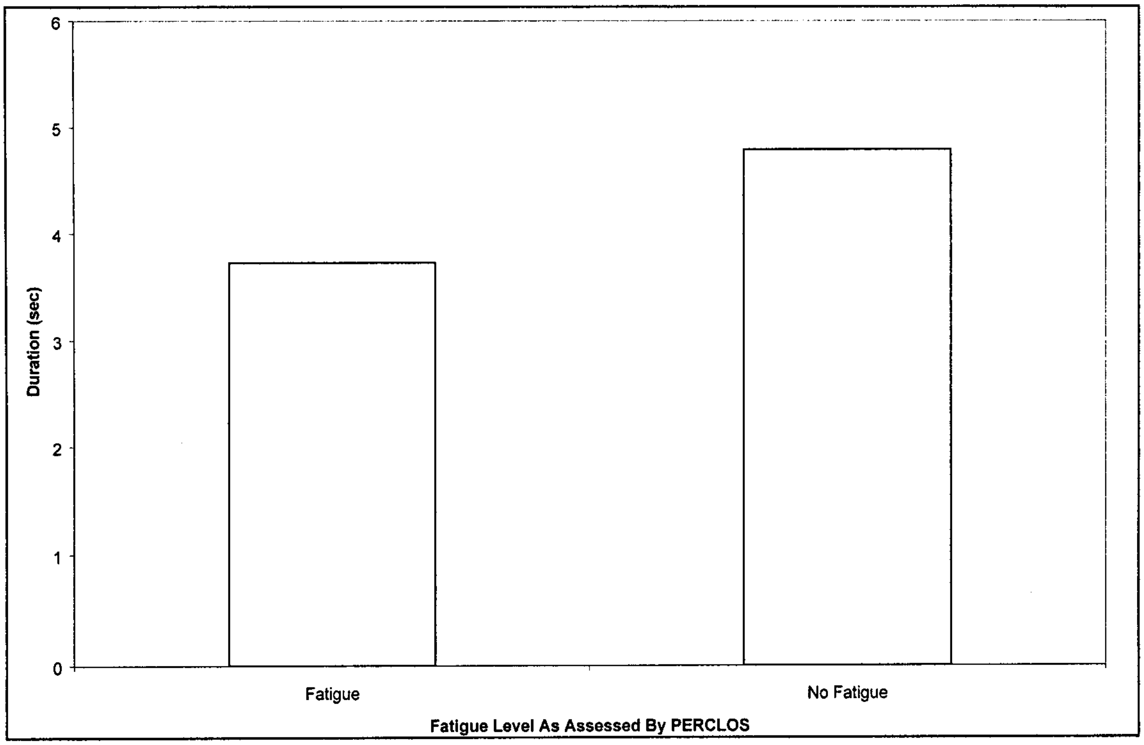


Figure 57. Lane change duration as a function of assessed driver fatigue using PERCLOS.

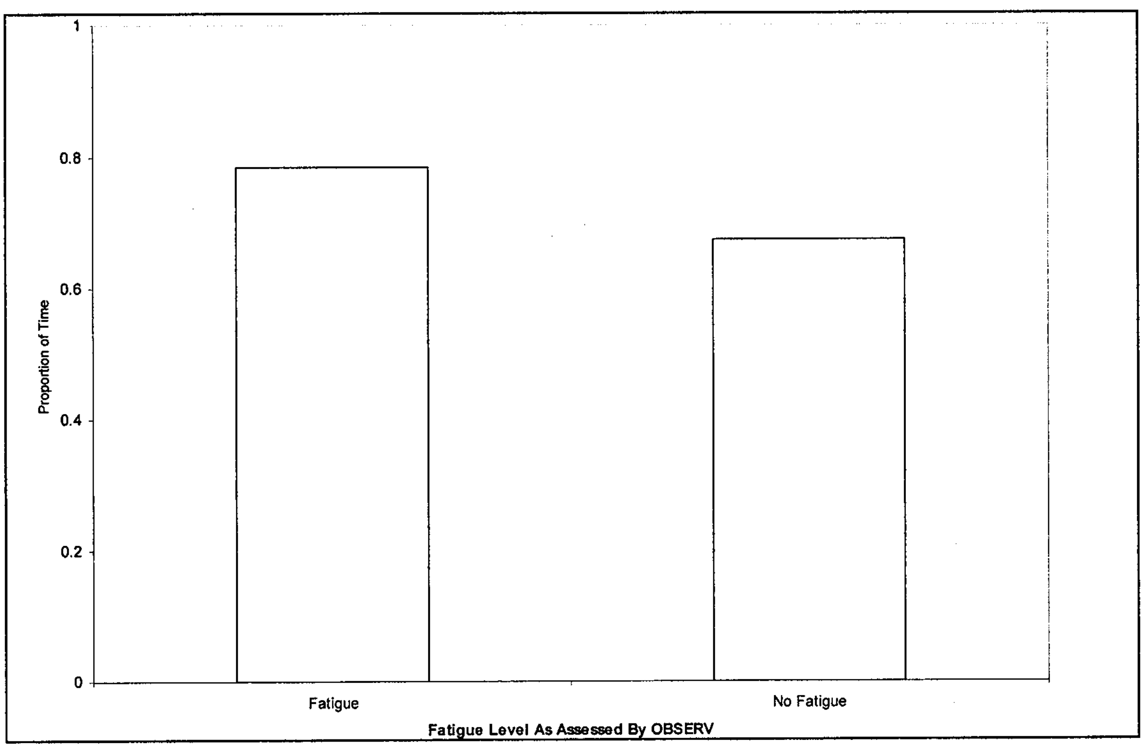


Figure 58. Proportion of time spent looking center-forward as a function of assessed driver fatigue using OBSERV.

As shown in figure 59, the proportion of time spent looking in "other" locations (other than out-the-windshield, out-the-windows, at the mirrors, or at the instrument panel) was greater for drivers involved in critical incidents when making a lane change. The mean proportion of time that drivers involved in critical incidents spent looking at "other" locations was 0.079 as compared to 0.028 for drivers completing lane changes with no associated critical incidents. This result proved to be reliable, $F(1, 270) = 31.35, p = 0.0001$. In addition, despite a very small "n," the proportion of time drivers spent looking at "other" locations varied as a function of driver fatigue; drivers who were judged to be fatigued, using the PERCLOS measure, had a mean proportion of 0.121, as compared to non-fatigued drivers whose proportion was 0.029. Again, this result was statistically significant, $F(1, 270) = 20.52, p = 0.0001$. The interaction of the type of incident and the assessed fatigue was also significant, $F(1, 270) = 26.69, p = 0.0001$. Even though these results are statistically reliable, they should be interpreted with caution because of the small sample sizes in the fatigue cells (which may include an outlier for the Incident x Fatigue cell), and the likelihood of violating the assumption of homogeneity of variance. Nonetheless, the results make sense intuitively in that drivers involved in critical incidents may not be paying attention to the road and are looking at "other" locations.

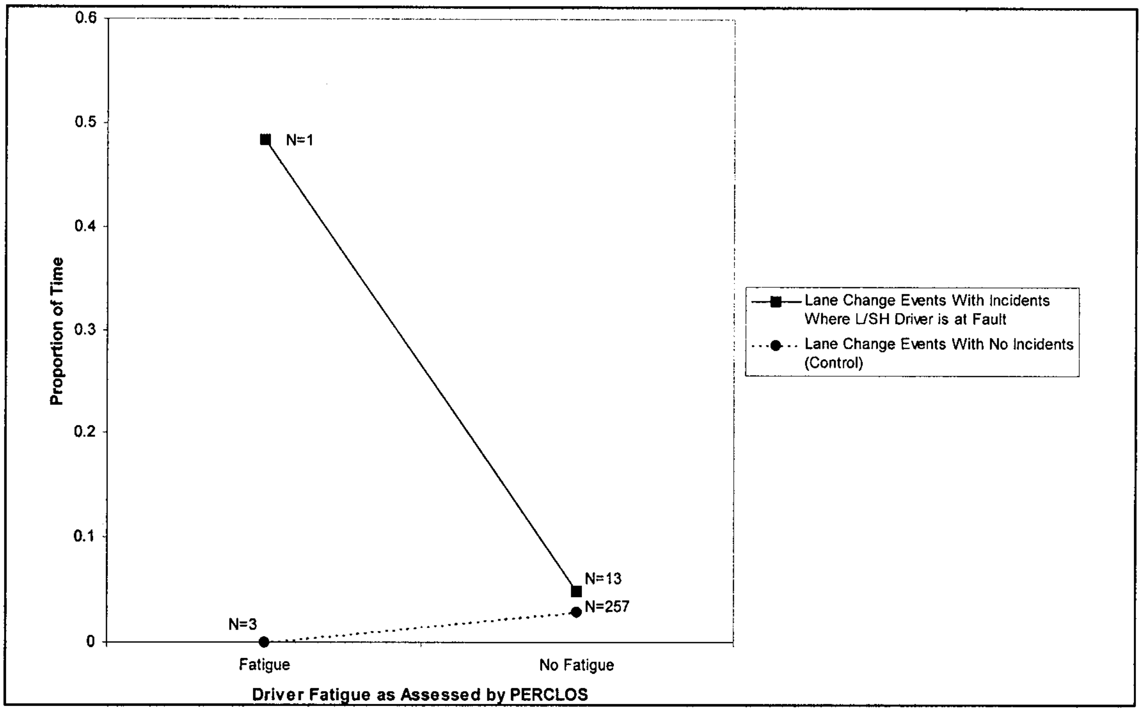


Figure 59. Proportion of time spent looking at "other" locations as a function of lane change category and assessed driver fatigue using PERCLOS.

BACKING EVENT ANALYSIS RESULTS AND DISCUSSION

Like the lane change analysis, the backing event analysis is divided into two sections: analysis of the normative (non-incident) data, and multiple univariate ANOVAs conducted on the critical incident data. The results from these analyses are outlined in the following two sections.

Normative (Non-Incident) Backing Events

A taxonomy was developed to classify the road type or condition in which a backing maneuver took place. Table 31 outlines the taxonomy that was used and the number of backing events that were classified. The results are shown in frequency-of-occurrence order. Recall that the total number of normative backing events was 260. Note that all 260 events were classified into one of the categories. Also, it should be pointed out that, as in the case of the lane change taxonomy, the categories were developed as the data were being analyzed. Put another way, as the event unfolded, a category was created to represent it. It should be pointed out that the "Other" category included miscellaneous road conditions such as gravel or dirt roads, and road types that were difficult to distinguish (for example, the event occurred when it was dark outside).

Table 31. Taxonomy categories and the frequency with which each backing event type occurred (shown in descending order).

Backing Event Type	Frequency
To Loading Zone/Parking Space in Lot	149
To Loading Dock	47
Parking Lot Turning Maneuver (e.g., 3-pt turn)	29
Other	12
Urban Undivided	10
Rural Undivided	6
One-way Road	4
Alleyway	2
Rural Divided (Median)	1

Using the categories outlined in the taxonomy, descriptive statistics were calculated. Table 32 shows the mean and standard deviations for a sample of the measures that were collected. Note that except for "Shuttle" replacing "PkLatAcl," the measures are the same as those shown in the lane change analysis. As outlined previously, "Shuttle" refers to a backing maneuver whereby the driver went from reverse, to forward, and then back to reverse (this sequence equaled one shuttle).

Table 32. Descriptive statistics for the backing event taxonomy categories. Upper value in each row is mean (M) and lower value is the standard deviation (S).

	Taxonomy Categories								
Measures	To Loading Zone/Parking Space	To Loading Dock	Parking Lot Turning Maneuver	Other	Urban Undivided	Rural Undivided	One-way Road	Alleyway	Rural Divided (Median)
Duration	M=20.8	M=33.8	M=9.20	M=19.8	M=16.8	M=16.4	M=16.0	M=28.3	M=29.8
	S=19.6	S=31.5	S=9.00	S=16.2	S=13.8	S=16.4	S=9.22	S=11.8	S=0.00
Eyetrans	M=26.4	M=31.5	M=29.2	M=30.2	M=27.4	M=25.4	M=24.7	M=28.7	M=20.67
	S=10.9	S=11.7	S=8.66	S=11.1	S=7.84	S=6.00	S=9.40	S=1.41	S=0.00
PropCFw	M=0.14	M=0.10	M=0.20	M=0.17	M=0.16	M=0.16	M=0.23	M=0.06	M=0.31
	S=0.10	S=0.10	S=0.16	S=0.10	S=0.13	S=0.11	S=0.0.12	S=0.01	S=0.00
PropLFw	M=0.08	M=0.03	M=0.11	M=0.05	M=0.13	M=0.12	M=0.02	M=0.05	M=0.00
	S=0.09	S=0.03	S=0.13	S=0.07	S=0.14	S=0.08	S=0.01	S=0.01	S=0.00
PropRFw	M=0.10	M=0.08	M=0.07	M=0.13	M=0.06	M=0.07	M=0.02	M=0.02	M=0.03
	S=0.13	S=0.10	S=0.08	S=0.12	S=0.08	S=0.03	S=0.02	S=0.02	S=0.00
PropLMir	M=0.35	M=0.45	M=0.24	M=0.25	M=0.24	M=0.41	M=0.28	M=0.57	M=0.45
	S=0.19	S=0.20	S=0.15	S=0.13	S=0.19	S=0.19	S=0.08	S=0.00	S=0.00
PropRMir	M=0.24	M=0.29	M=0.23	M=0.29	M=0.30	M=0.15	M=0.28	M=0.30	M=0.22
	S=0.15	S=0.20	S=0.16	S=0.18	S=0.18	S=0.09	S=0.20	S=0.03	S=0.00
PropLWin	M=0.05	M=0.02	M=0.09	M=0.06	M=0.06	M=0.09	M=0.03	M=0.01	M=0.00
	S=0.09	S=0.04	S=0.14	S=0.09	S=0.07	S=0.18	S=0.05	S=0.02	S=0.00
PropRWin	M=0.01	M=0.01	M=0.03	M=0.03	M=0.02	M=0.00	M=0.00	M=0.00	M=0.00
	S=0.04	S=0.03	S=0.09	S=0.08	S=0.06	S=0.00	S=0.00	S=0.00	S=0.00
PropIP	M=0.01	M=0.01	M=0.01	M=0.00	M=0.02	M=0.00	M=0.00	M=0.00	M=0.00
	S=0.03	S=0.02	S=0.04	S=0.01	S=0.06	S=0.00	S=0.01	S=0.00	S=0.00
PropOther	M=0.01	M=0.01	M=0.02	M=0.02	M=0.01	M=0.00	M=0.10	M=0.00	M=0.00
	S=0.04	S=0.02	S=0.05	S=0.04	S=0.02	S=0.00	S=0.20	S=0.00	S=0.00
Shuttle	M=0.23	M=0.23	M=0.06	M=0.33	M=0.00	M=0.67	M=0.00	M=0.00	M=0.00
	S=0.56	S=0.63	S=0.37	S=0.89	S=0.00	S=1.21	S=0.00	S=0.00	S=0.00

Backing Event Critical Incidents

Table 33 presents the narratives of the eight backing events that were also classified as critical incidents. As can be seen, for two of the events, the driver backs up into a stationary object. For some of the other events, a rear-end crash nearly occurred due to the driver's backing maneuver.

Table 33. Narratives from the eight backing events also classified as critical incidents.

Event Number	Narrative
1	Subject: 9 Age: 26 Gender: Male Company: Beverage Truck: Straight Truck Date: 12/10/98 Time: 9:28:56 AM Event: Critical Incident #11 Begin Sync: 428605 The truck is making a left turn/U turn into a loading dock for delivery. However, the turn is too tight and the driver has to back up into the street to complete the turn. In the process it blocks the way of a pick up coming down the street, which slows down to a stop. The driver looks alert. The weather is clear and the roads are dry. The sync numbers are stopping intermittently and hence it is not possible to do the eye transition, eyes off, and eye glance.
2	Subject: 11 Age: 25 Gender: Male Company: Beverage Truck: Straight Truck Date: 12/30/98 Time: 8:21:06 AM Event: Critical Incident #10 Begin Sync: 601795 The driver attempts to make a U turn at a narrow grassy median. However there is a pick-up truck following (whose driver probably gets confused) which brakes hard and skids almost leading to a rear end crash. The truck must swing wide. It still can't make the turn and has to back-up while partly in the median and then complete the turn. Cars in the lane behind the truck slow down as the truck is completing the turn. The driver does not appear to be drowsy. It is early in the morning and the weather is clear. The road condition is dry.
3	Subject: 12 Age: 27 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 12/30/98 Time: 3:28:34 PM Event: Critical Incident #1 Begin Sync: 32262 The driver was in the right lane of a two lane one-way road through an urban downtown area. As he stopped in the road and began backing to parallel park, two pedestrians ran across the road and crossed behind his truck. They did not come in close contact with the backing vehicle, but it is questionable whether the driver was aware of their presence. It appears that while the driver was glancing at the rearview mirrors, the pedestrians were not seen because the driver just happened to be looking at the opposite mirror. The driver did not press the critical incident button. This is also included as a backing event.
4	Subject: 13 Age: 22 Gender: Male Company: Beverage Truck: Straight Truck Date: 1/14/99 Time: 11:10:33 AM Event: Critical Incident #3 Begin Sync: 405700 The driver is backing the truck in a gas station. He backs the truck on to a post bearing the gas station name/sign. Incident picked up by analyst. Driver does not press "I." The road condition is wet. There is a car to the right of the truck in the rear. The weather is cloudy. The visibility is unlimited. The driver appears to be wide awake but makes an error in judgment and bangs into the post.

5	Subject: 13 Age: 22 Gender: Male Company: Beverage Truck: Straight Truck Date: 1/21/99 Time: 11:48:28 AM Event: Critical Incident #7 Begin Sync: 1013930 The driver is backing the truck in a back alley. He hits a wall trying to turn around a corner. The driver does not look drowsy during the 3 minute period but did show signs of fatigue prior to the 3 minute interval. The road is of gravel/sand. The visibility is unlimited. The weather is cloudy. There are no other vehicles in the alleyway. The eye glance analysis could not be done as the sync had passed the 1 million mark and the sync on the screen was changing in seconds, not in frames. The drivers cabin is dark and it is difficult to see his eyes.
6	Subject: 21 Age: 26 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 4/19/99 Time: 4:03:58 PM Event: Critical Incident #5 Begin Sync: 175530 The driver is attempting a U-turn on a one lane street. However, he is unable to complete the turn properly and has to back up on the street. He doesn't check to see if there is any traffic behind him and backs up into oncoming traffic. The cars have to swerve into the opposite lane to avoid the truck. The driver is extremely inattentive. The weather is clear and the roads are dry.
7	Subject: 26 Age: 21 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 7/1/99 Time: 1:35:38 PM Event: Critical Incident #2 Begin Sync: 243403 The driver backs into an intersection. The road opposite the intersection is probably closed. There is not much traffic around and hence no one is affected. He backs up the vehicle very slowly and hence he is completely blocking the intersection for a long time. The driver looks alert. The weather is clear and dry and the roads are dry. Due to two discontinuities in the 3 minute interval before the event, the EYETRANS, PERCLOS and EYESOFF was done for a 51.4 sec period. This period extends from 3 minutes prior to the event till the first interruption.
8	Subject: 29 Age: 42 Gender: Male Company: Beverage Truck: Straight Box Truck Date: 8/24/99 Time: 12:53:11 PM Event: Critical Incident #2 Begin Sync: 362901 The driver pulls out of a gas station parking lot and into the road. The truck pulls out way too far and ends up past the stop bar. The driver has to back up at two different occasions to make sure no one hits his truck. The driver is at a four way intersection.

As in the lane change analysis, a 2 x 2 (Critical Incident x Drowsiness) ANOVA was conducted on the backing/critical incident data set and the results are presented in appendix L. Because of the small number of backing critical incidents and the resultant small number of degrees of freedom, the Critical Incident x Fatigue interaction could not be determined. Those results that were statistically significant at $p < 0.05$ are outlined in the text below.

Figure 60 shows the proportion of time drivers spent looking at the center-forward location. As can be seen, drivers involved in critical incidents while backing spent significantly more time looking center-forward than did drivers who were not involved in critical incidents while backing, $F(1, 265) = 21.79, p = 0.0001$. The mean proportion of time looking center-forward for the critical incident group was 0.34 compared to 0.14 for the control group. One possible explanation for this result is that the drivers involved in critical incidents spent too much time looking forward while performing the backing maneuver. The next result supports this hypothesis.

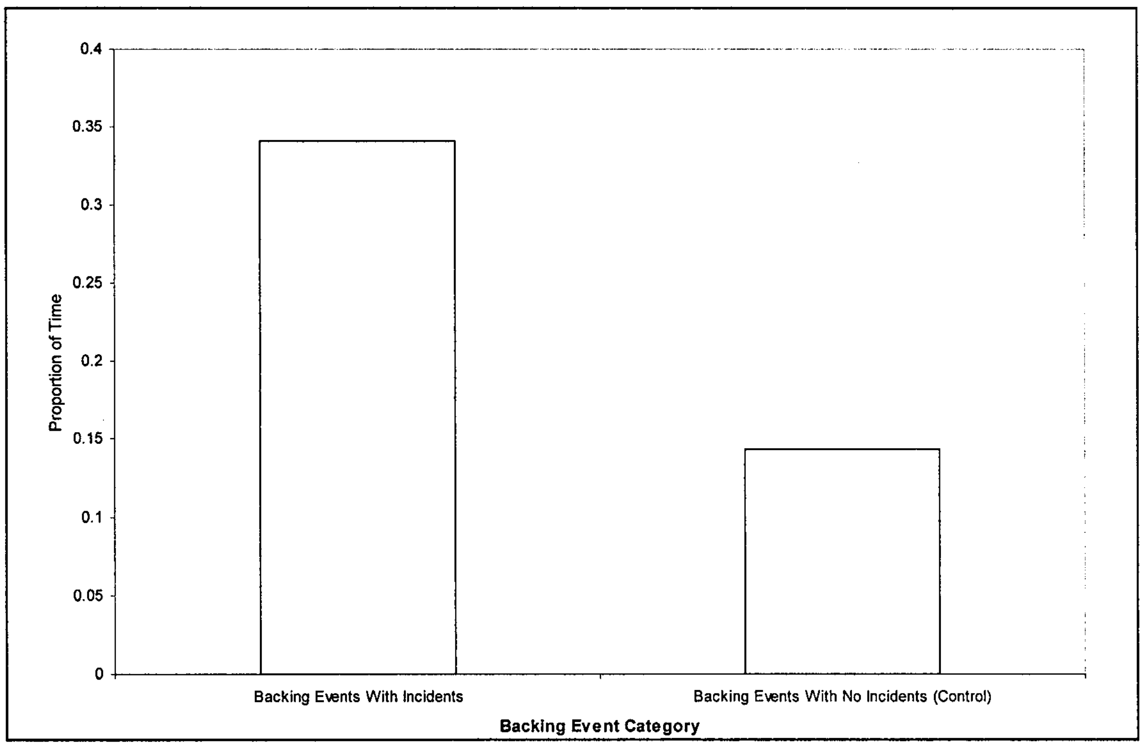


Figure 60. Proportion of time spent looking center-forward as a function of backing event type.

Figure 61 shows that drivers in the critical incident group also spent significantly greater time looking left-forward, $F(1, 265) = 4.37, p = 0.0375$. The proportions for the two conditions were 0.14 for the critical incidents and 0.07 for the non-critical incidents. The involvement in critical incidents may be explained by the drivers not scanning the environment enough or, specifically, not looking in the mirrors.

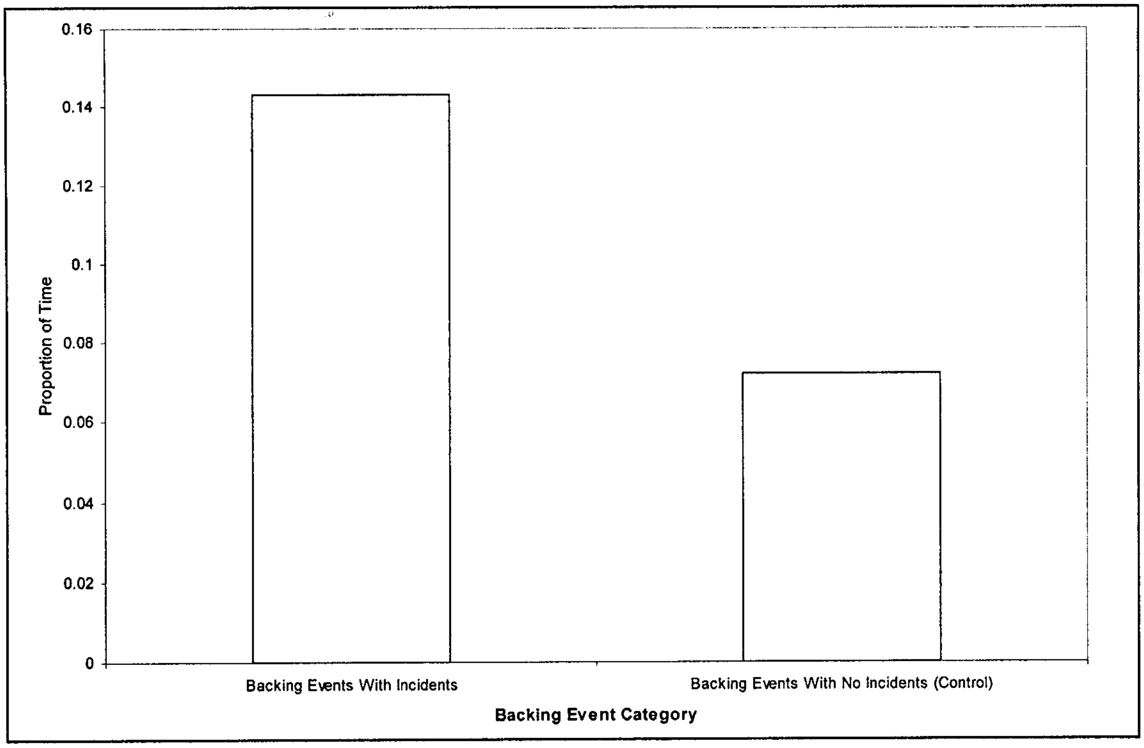


Figure 61. Proportion of time spent looking left-forward as a function of backing event type.

Figure 62 shows that drivers who performed backing maneuvers without being involved in a critical incident spent 0.35 (proportion) of their time looking in the left-mirror, as compared to 0.17 for drivers who were involved in a critical incident while backing. This result was statistically significant, $F(1, 265) = 6.55, p = 0.0110$. This finding supports the explanation that drivers who had critical incidents while backing may not have been scanning their environment, or using their mirrors, to a sufficient degree to avoid being involved in the incident.

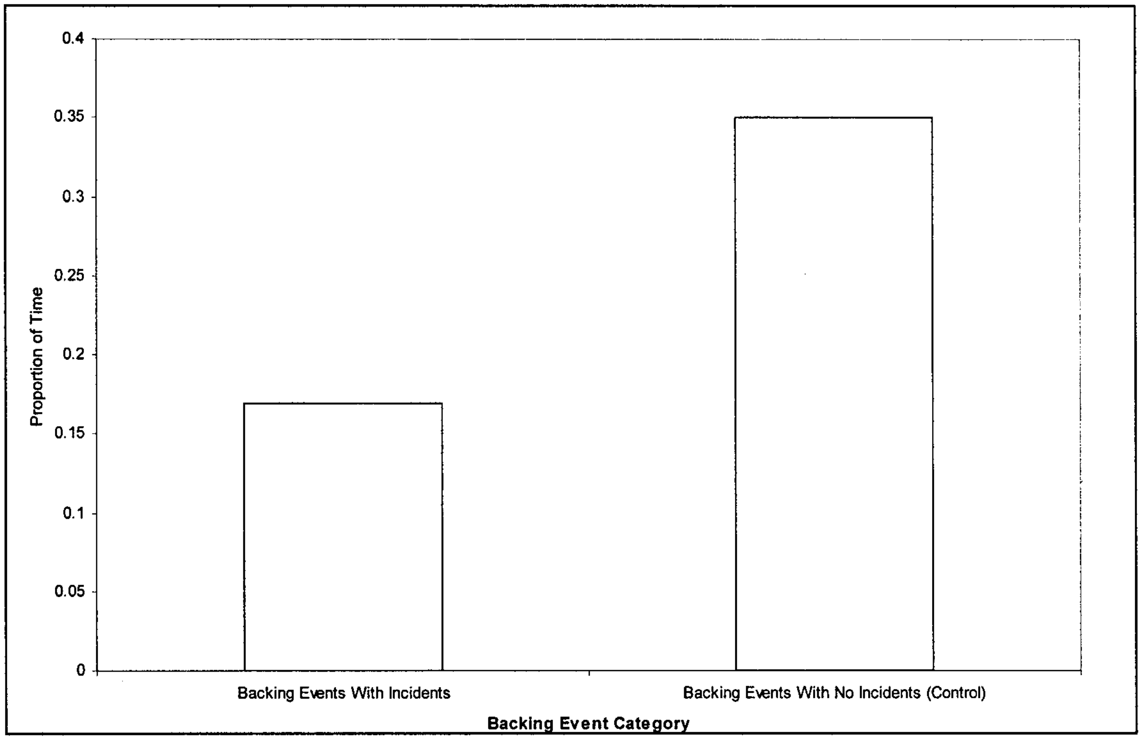


Figure 62. Proportion of time spent looking left-mirror as a function of backing event type.

As shown in figures 63 and 64, fatigued drivers spent a greater proportion of their time looking at the right-forward location. With regard to drivers who were assessed to be fatigued using the PERCLOS measure, the proportion of time spent looking right-forward was 0.26, compared to 0.09 for non-fatigued drivers. Despite a sample size of n=2 for the "fatigue" category, this result was statistically significant, $F(1, 265) = 4.43, p = 0.0363$. Similarly, using the OBSERV measure to assess fatigue, the proportion of time spent looking right-forward for fatigued drivers was 0.20 (n = 6) as compared to 0.09 (n = 262) for no-fatigue group. Once again, this result was significant, $F(1, 265) = 5.25, p = 0.0227$. Note that the mean values across the two methods of judging fatigue are, not surprisingly, very similar. The results suggest that fatigued drivers tended to fixate more on the relatively unimportant right forward section of the field of view.

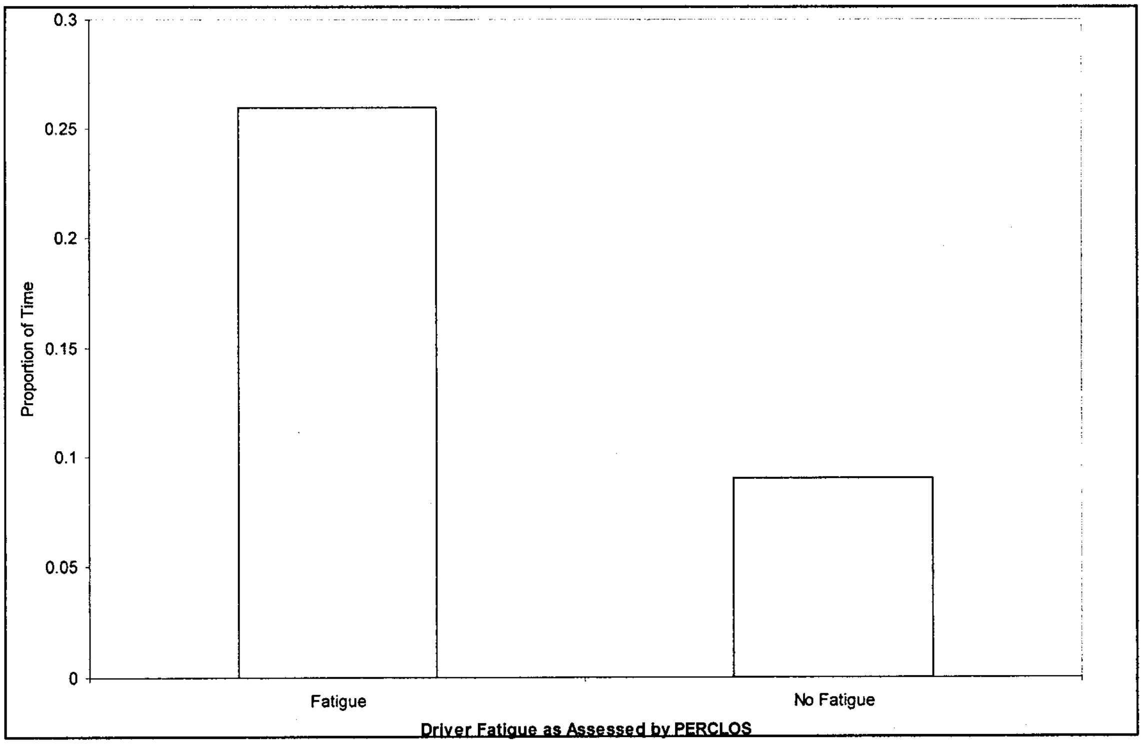


Figure 63. Proportion of time spent looking right-forward as a function of PERCLOS.

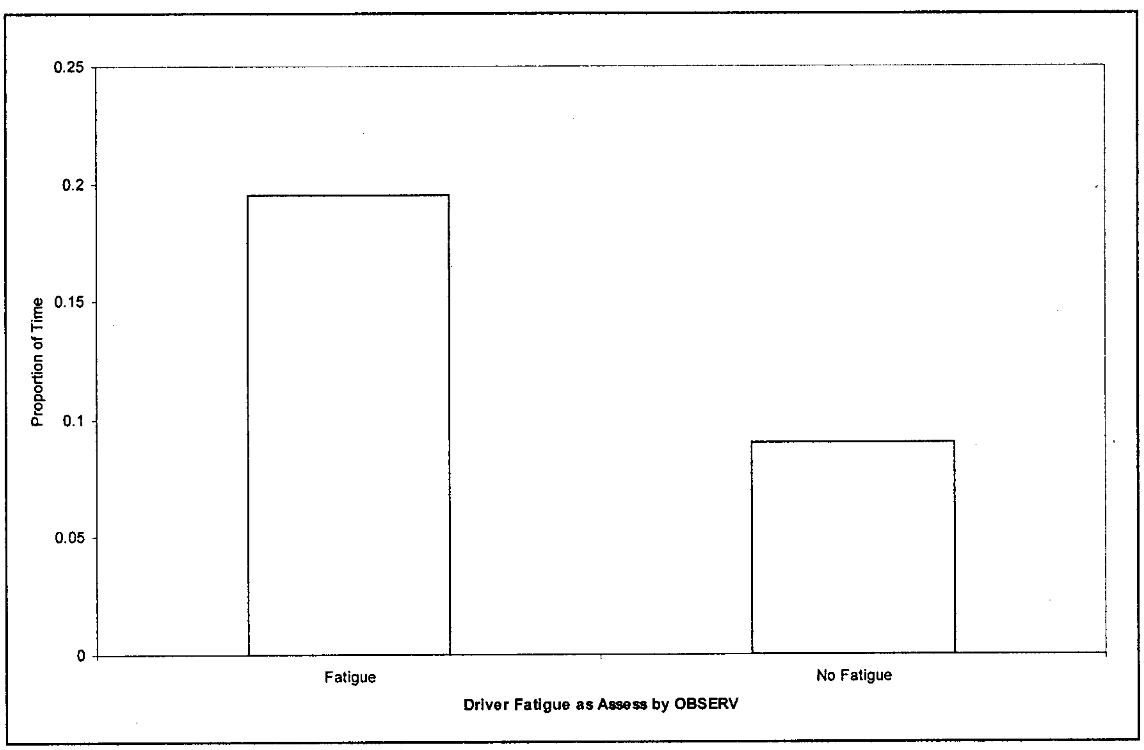


Figure 64. Proportion of time spent looking right-forward as a function of OBSERV.

SUMMARY OF THE LANE CHANGE AND BACKING ANALYSIS

Based on the lane change/critical incident and backing/critical incident results presented, the proportion of time spent looking at certain locations was shown to be different for drivers when they were involved in critical incidents as compared to drivers when they were not involved in critical incidents. Drivers involved in critical incidents during lane change events spent more time looking at "other" locations as compared to drivers who were not involved in incidents. In a similar fashion, drivers involved in critical incident backing events spent a greater proportion of their time looking forward and less time looking in the left mirror. Similarly, the glance behavior for fatigued drivers differed from non-fatigued drivers. During lane change maneuvers, fatigued drivers spent more time looking straight ahead than did drivers who were not fatigued. For backing incidents, fatigued drivers also spent a significantly greater proportion of their time looking in the right forward direction. Further investigation of the role of fatigue in the lane change incidents determined that 15.4 percent of the lane change critical incidents had drowsiness as a contributing factor. This compared to 6.9 percent for non-critical incident lane changes.

It should be pointed out that further insight into the characteristics of the lane change and backing events captured in this study are expected to be gained from the analysis being conducted by NHTSA researchers. Note that as part of the currently reported research effort, over 500 lane change and backing events were captured, reduced, and sent to NHTSA researchers for analysis. The analysis presented here was directed at critical incidents that occurred during lane change and backing events, and only high-level analyses were conducted on the normative data. It is believed that the NHTSA analysts will focus their efforts on the normative data. Along with the results presented here, the results from the NHTSA analysis on the normative lane change and backing data will provide further insight into safety and human factors issues in the L/SH trucking industry.

VALIDATION OF FATIGUE FACTORS

Hanowski et al. (1999) listed a number of fatigue-related issues that L/SH drivers in focus groups cited as being important. For the field study, a questionnaire was administered at the end of each workday, which asked drivers to consider a list of items that may have contributed to how tired/fatigued they felt that day. Note that the items from this list were selected based on the focus group findings. The results of this questionnaire, ranked in terms of response frequency, are shown if table 34. Also shown in table 34 are the issues listed and ranked by drivers in the focus groups. A Spearman Rank-Order Correlation test was conducted on the rankings for the two columns. The results proved significant, $r_s = 0.76$, $p < 0.001$ (two-tailed), and indicate that the rankings from the two research phases are similar (i.e., there is association between the rankings).

Table 34. Comparison of the fatigue-related items listed in the focus groups (Phase I) and field study (Phase II).

Rank	Fatigue-Related Issues: Phase I	Rank	Fatigue-Related Issues: Phase II
1	Not Enough Sleep	1	Hard or Physical Workday
2	Hard or Physical Workday	2	Long Hours
3	Heat or No Air Conditioning, or Both	3	Not Enough Sleep
4.5	Waiting to Unload	4	Frustration
4.5	Irregular Mealtimes	5	Irregular Mealtimes
6.5	Long Hours	6	Heat or No Air Conditioning, or Both
6.5	Irregular Workshift	7	Waiting to Load or Unload
8	Sick	8	Stress From Traffic
9.5	Frustration	9	Balance Work and Personal Life
9.5	Balance Work and Personal Life	10	Poor Equipment
11	Partying Night Before	11	Unfamiliar Route
12	Unfamiliar Route	12	Driving at Night, Dusk, Dawn
13	Stress From Traffic	14	Partying Night Before
15.5	Temperature Changes	14	Sick
15.5	Poor Equipment	14	Temperature Changes
15.5	Reprimanded by Management	16	Start or End of Day
15.5	Driving in Snow or Putting Chains on Tires	17	End of Week
18	Start or End of Day	18	Irregular Workshift
19	Driving at Night, Dusk, Dawn	19	Driving in Snow or Putting Chains on Tires
21	Shift Work	20.5	Reprimanded by Management
21	End of Week	20.5	Working Two Jobs
21	Working Two Jobs	22	Shift Work

In addition to the subjective data, objective measures were also collected with regard to potential fatigue-related items. Recall the model presented earlier that outlined the five variable categories (figure 5). Recall also that within each category there were a number of measures that were collected. As shown in table 35, several of the measures can be re-categorized using the fatigue-related items as category headings. Note that some of the measures are in multiple categories as they may relate to more than one fatigue-related issue. Also, not all issues, such as "Irregular Mealtimes," had measures collected in the field study.

Table 35. Re-classification of the fatigue-related measures using focus group issues.

Fatigue-Related Issues	Field Study Measures
Hard or Physical Workday	• PHYSDEM • EFFORT • HRSLOAD • NUMSTOPS
Long Hours	• HRSTOTAL • HRSDRIV • HRSLOAD • TOTMILE • NUMSTOPS
Not Enough Sleep	• ACTIHRS • LOGHRS • ACTIQUAL • LOGQUAL • PREFAT
Frustration	• FRUSTRAT
Heat or No Air Conditioning, or Both	• WEATHER
Stress From Traffic	• POSTSTRS
Driving at Night, Dusk, Dawn	• TIMEDAY • ILLUMIN • VISIBIL
Start or End of Day	• TIMEDAY • ILLUMIN • VISIBIL
End of Week	• DAYWEEK • SHIFT
Driving in Snow or Putting Chains on Tires	• WEATHER • VISIBIL

As a means of objectively determining which fatigue-related items were most important in the drivers workday, consider the ANOVA results presented previously for the data set that comprised critical incidents where the driver was judged to be at fault *and* showed signs of fatigue. These were compared with critical incidents where the driver was at fault but showed no signs of fatigue. As indicated, for this data set, a driver was judged as "fatigued" if the PERCLOS value for the time period immediately preceding the incident was greater than or equal to 0.08, or if the analyst rating of drowsiness (OBSERV) was 40 or greater (a value of 25 referred to "Slightly Drowsy" while a value of 50 was "Moderately Drowsy"). Table 36 lists the measures that changed significantly ($p < 0.05$) as well as those with $p < 0.10$.

Table 36. Measures exhibiting changes between driver at fault, fatigued and driver at fault, not fatigued.

Measure	Prob > F
AGE	0.0084
LOGHRS	0.0374
LOGQUAL	0.0048
ACTIHRS	0.0753
ACTIQUAL	0.0799
EYETRANS	0.0181
EYESOFF	0.0317
THINKING	0.0949
HRSDRIV	0.0474
HRSLOAD	0.0274
EXPERIEN	0.0217
LSHEXP	0.0248
DRIVEXP	0.0605
SHIFT	0.0207

If the assumption holds that the measures listed in table 35 are valid measures of the fatigue-related issues, then it can be seen that "Long Hours," "Not Enough Sleep," "Hard or Physical Workday," and "End of Week" have associated field study measures that changed with p-values of 0.10 or smaller (shown in table 36). However, because the shift measure related to "End of Week" indicated that it was early in the week that most L/SH driver at fault, fatigue apparent, critical incidents occurred, the "End of Week" issue is not supported by the objective measures.

GUIDELINE DEVELOPMENT

OVERVIEW

Based on the results of the data analyses described previously, the following are a set of pragmatic guidelines that are suggested as a means of reducing the frequency with which L/SH drivers are involved in at-fault critical incidents. It should be stressed that because the goal of this research was directed at investigating fatigue in L/SH operations, the measures collected and the guidelines presented are biased toward minimizing driver fatigue.

GUIDELINE 1: DRIVER EDUCATION WITH REGARD TO ON-THE-JOB DROWSINESS/INATTENTION

L/SH companies should encourage drivers to monitor their level of drowsiness and inattention and should make them aware of strategies to reduce drowsiness and inattention. L/SH companies should institute policies that allow drivers to recover from fatigue/inattention without reprimand. Driver fatigue and inattention were found, to a statistically significant degree, during the interval preceding driver-at-fault critical incidents (see figure 35). It is recommended that L/SH drivers be educated of the dangers of driving fatigued and be encouraged to remedy such situations before continuing to drive.

GUIDELINE 2: DRIVER EDUCATION WITH REGARD TO SLEEP HYGIENE

L/SH drivers should be encouraged to come to work well-rested. Additionally, it is suggested that further research be conducted to investigate the effectiveness of random "fatigue testing" at the beginning of the shift to ensure that drivers come to work well-rested. It is suggested that most people have felt the fatiguing effects of not getting enough sleep. However, most have not had to operate a heavy vehicle with less-than-adequate rest. L/SH drivers should be trained as to the hazards of operating heavy equipment when tired and reminded that sufficient sleep at night will reduce fatigue during the day. The data from this study suggest that drivers who show signs of fatigue and are involved in an at-fault critical incident had less sleep and poorer quality of sleep than drivers who do not show outward signs of fatigue (see figures 47 and 48). The findings certainly agree with the common sense notion that sleep quantity and sleep quality influence the level of fatigue experienced the next day.

GUIDELINE 3: DRIVER TRAINING

A mandatory driver training program should be set up for all younger and/or inexperienced drivers. At a minimum, training programs should be carried out by individual L/SH companies for their drivers. Consideration should also be given to requiring all L/SH drivers to obtain special licenses to operate L/SH trucks. Presently, L/SH drivers are required to obtain special licenses (e.g., Class B) if they operate articulated trucks or trucks with air brakes. However, at present, no special license or training is required to operate most L/SH vehicles (e.g., panel vans, box trucks). It is suggested that because the level of difficulty is arguably greater in operating a L/SH vehicle when compared to a passenger vehicle, a training/ licensing/permit program should be implemented in order to educate young/inexperienced drivers who are unfamiliar with operating a larger vehicle. The impetus for this recommendation is the data analysis that indicated a more prominent involvement in driver-at-fault critical incidents by younger/inexperienced drivers (see figure 41).

GUIDELINE 4: DRIVER SCREENING

A driver screening program should be in place within L/SH companies so that unsafe drivers can be identified prior to being hired. Recall that the results of this research found that the majority of critical incidents were caused by very few L/SH drivers (see *Miscellaneous Findings*). Further research is required to determine methods to identify unsafe drivers. Suggested research would closely examine common characteristics of unsafe drivers. For example, it is hypothesized that unsafe and improper driving of passenger vehicles is likely to be correlated with unsafe and improper driving of L/SH vehicles. As such, screening should include, at a minimum, consideration of a driver's passenger vehicle record.

As a further means to screen for unsafe drivers, consideration should be given to implementing on-board safety monitoring devices in commercial vehicles. This idea is similar to that suggested elsewhere (Knipling and Olsgard, 2000) where real-time in-vehicle displays of driver alertness levels (i.e., "alertometers") are present in the truck cab. Taking this idea one step further, data on driver alertness, as well as other measures of driver performance such as speed, headway, and lateral acceleration, could be collected and used to identify, and screen for, unsafe L/SH drivers. These monitoring devices can be thought of as "black box" systems, installed in the L/SH vehicle, that monitor and record driver performance. Knipling and Olsgard (2000) note that one such system, called the Accident Prevention Plus™, is currently being tested.

GUIDELINE 5: PUBLIC MONITORING OF L/SH DRIVER PERFORMANCE

It is suggested that companies should consider implementing a program whereby the general public has a way to report drivers who drive safely and do not drive safely. This suggestion follows the practice implemented by many long-haul trucking companies where a "how's my driving" sticker is placed on the back of the truck. The sticker has a phone number for the public to call. Though not based on any of the results from the field study, some drivers who participated in the focus groups mentioned that they have such stickers on their trucks. The drivers in the focus groups also suggested that signs on the back of trailers would be an effective way to communicate with the motoring public. Neither of the companies that participated in the field study had signs or stickers on their trucks or trailers.

CONCLUSIONS

The primary goal of this research was to determine if fatigue is an issue in L/SH trucking operations. To investigate this issue, Phase II of the project involved instrumenting L/SH trucks with a variety of unobtrusive data collection equipment, and having L/SH drivers use the instrumented vehicles on their regular delivery routes. The data collection equipment was set up to capture the daily events and interactions that drivers encountered.

Of primary interest in this research were critical incidents where drivers were involved in near-crashes. These events were analyzed and, in regard to the primary research question related to fatigue, drivers demonstrated, to a statistically significant level, signs of fatigue for a time period immediately preceding incident involvement where the L/SH driver was judged to be at fault. As such, the answer to the primary research question is yes; fatigue does appear to be an issue in L/SH trucking operations. Because this was a field study, it is difficult to determine with certainty *why* fatigue was present. However, based on the results of the multiple analyses that were conducted, it seems apparent that much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job. That is, poor sleep quantity/quality were prominent for drivers who demonstrated signs of fatigue on the job. Therefore, it is suggested that the off-duty behavior of the drivers was the primary contributing factor in the level of fatigue that was demonstrated during the workday. In addition, it is suggested that those L/SH drivers who demonstrated fatigue on the job would have shown characteristics of fatigue on any job inside or outside the L/SH trucking industry.

A number of statistical tests were conducted on several different data sets that were collected during the field study. Several of the significant findings were grouped into three major categories. The first such finding is that driver fatigue and inattention were found to a significant degree prior to involvement in driver-at-fault incidents. As described in the previous paragraph, drivers showing signs of drowsiness and fatigue were significantly over-represented in the number of critical incidents occurring. A second particularly interesting finding was that drivers who demonstrated signs of fatigue and were involved in driver-at-fault incidents had less sleep and poorer quality sleep as compared to drivers who did not show signs of fatigue. The third major finding was that younger, inexperienced drivers were more likely to be involved in critical incidents, to cause incidents, and to be fatigued prior to incidents.

The conclusions drawn in this research are in the form of guidelines that might be considered useful in reducing the involvement of L/SH drivers in at-fault critical incidents. It is believed that the analyses that were conducted and presented in this dissertation support the proposed guidelines and that these recommendations are reasonable approaches at improving safety in L/SH operations.

There are a number of future research efforts that are recommended to build from the research reported here. Four such efforts include: (1) an investigation of car-truck interactions, (2) a study of cellular phone use by L/SH drivers, (3) an examination of the impact of driver age on L/SH driving performance, and (4) research to determine effective on-board systems to monitor driver fatigue and inattention. Each of these recommended research efforts is briefly described.

For the first recommended study, there are at least three reasons for investigating car-truck interactions: (1) to gain a better understanding of incidents occurring when light vehicles and heavy vehicles interact on the roadways, (2) to develop a classification scheme and corresponding contributing factors list for incidents occurring between light vehicles and heavy vehicles, and (3) to provide background information that would serve as a necessary prerequisite to the development of countermeasures for interaction problems. Cars and trucks differ greatly in their handling, size, ability to accelerate and brake, visibility, and use. Both types of vehicles use the highway system and therefore must necessarily interact with one another. While there are proposals to separate light and heavy vehicles on high-volume travel routes, the likelihood that this will occur in most cases is small. The costs and other difficulties associated with new or modified road construction are of such a magnitude that, for the foreseeable future, the two types of vehicles will have to continue to share the road. Thus, a better understanding of light vehicle/heavy vehicle interaction is needed and would serve as a necessary foundation for countermeasures to relieve or eliminate car-truck interaction problems.

With regard to the second recommended follow-on study, investigating cellular phone use by L/SH drivers, it was noticed that of the 41 drivers who participated in the research presented in this dissertation, 13 of them regularly used a cellular phone. Of these 13 drivers, approximately 200 phone calls were made/received. A study is recommended to investigate the impact of cellular phone use on truck driving performance. A specific research question that might be asked is, "is the driving performance of L/SH drivers effected when using a cellular phone?" This study could be expanded to compare the impact of cellular phone use to the impact of other tasks that L/SH drivers typically perform while driving. For example, analyses could also be conducted on eating while driving, and/or using a order/delivery computer while driving.

With regard to the third recommended study, investigating the impact of driver age on L/SH driving performance, the results from the present study indicated that younger L/SH drivers were predominantly involved in driver-at-fault incidents. For passenger vehicles, it is well documented that younger drivers are over-represented in crashes. However, there is no research that has been directed at determining the relationship between driver age and crashes in commercial vehicle operations. Results from such an effort may aid in developing training programs for younger commercial vehicle drivers.

The fourth recommended study involves determining the effectiveness of on-board systems that monitor driver alertness. Conceptually, these systems are used to monitor the "fitness" of the driver and provide alerting feedback should the driver demonstrate signs of fatigue or inattention. As shown in the present study, fatigue and inattention often precede critical incidents. A research effort is recommended that would evaluate, compare, and contrast different monitoring systems and identify those that have the most promise of being effective at improving driver fitness. Once one or more systems have been identified, a field study could be carried out where these systems are instrumented and tested in commercial vehicles. To determine system effectiveness, driver performance data could be collected with and without these systems. The goal of this recommended research is to identify one or more promising systems that would effectively warn drivers when degraded driving performance due to fatigue and inattention is detected.

It is suggested that there is a large window of opportunity for conducting research in the L/SH trucking industry. As suggested, L/SH operations have received little attention from the research community. It is hoped that the present *in-situ* effort, and the research questions that have arisen from it, will serve as a catalyst for more research in this field.

REFERENCES

Beilock, R. (1995). Schedule-induced hours-of-service and speed limit violations among tractor-trailer drivers. *Accident Analysis and Prevention, 27*(1), 33-42.

Bills, A.G. (1931). *Blocking: A new principle of mental fatigue.* American Journal of Psychology, 43, 230-245.

Bittner, A.C., Jr. (1992). Robust testing and evaluation (T&E) of systems: Framework, approaches, and illustrative tools. *Human Factors, 34*, 477-484.

Cameron, C. (1973). A theory of fatigue. *Ergonomics, 16*, 638-648.

Cerelli, E. C. (May, 1992). *Crash data and rates for age-sex groups of drivers, 1990.* Research Note, U.S. Department of Transportation, National Highway Traffic Safety Administration. Washington, DC: National Center for Statistics & Analysis - Research & Development.

Chapanis, A. (1959). *Research techniques in human engineering.* Baltimore, MD: Johns Hopkins Press.

Dingus, T. A., Hetrick, S., and Mollenhauer, M. (1999). Empirical methods in support of crash avoidance model building and benefits estimation. *ITS Journal, 5*, 93-125.

Dingus, T., McGehee, D., Hulse, M., Jahns, S., Manakkal, N., Mollenhauer, M., and Fleischman, R. (June, 1995). *TravTek evaluation task C3 camera car study.* Pub. No. FHWA-RD-94-076. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Hanowski, R. J., Dingus, T. A., Gallagher, J. P., Kieliszewski, C. A., and Neale, V. L. (1999). Driver response to in-vehicle warnings. *Transportation Human Factors Journal, 1*(1), 91-106.

Hanowski, R. J., and Kantowitz, B. H. (1997). Driver memory retention on in-vehicle information system messages. *Transportation Research Record, 1573*, 8-16.

Hanowski, R. J., Wierwille, W. W., Dugger, M., and Dingus, T. A. (August, 1999). *Impact of local/short haul operations on driver fatigue: Summary report of Tasks 3, 4, and 5, with a discussion of protocol for task 6.* Contract No. DTFH61-96-C-00105. Blacksburg, VA: Virginia Tech Center for Transportation Research.

Hanowski, R. J., Wierwille, W. W., Gellatly, A. W., Early, N., & Dingus, T. A. (August, 1998). *Impact of local/short haul operations on driver fatigue: Task 1 report – Focus group summary and analysis*. FHWA-MC-98029. Washington, DC: Federal Highway Administration, Office of Motor Carriers.

Heinrich, H. W., Peterson, D., and Roos, N. (1980). *Industrial accident prevention*. New York: McGraw Hill.

Hockey, R. (1983). *Stress and fatigue in human performance*. New York: John Wiley & Sons.

Kerlinger, F. N. (1986). *Foundations of behavioral research, third edition*. Fort Worth, TX: Holt, Rinehart and Winston, Inc.

Kroemer, K. H. E., Kroemer, H. J., and Kroemer-Elbert, K. E. (1990). *Engineering physiology bases of human factors/ergonomics*. New York: Van Nostrand Reinhold.

Mackie, R. R., and Miller, J. C. (October, 1978). *Effects of hours of service regularity of schedules, and cargo loading on truck and bus driver fatigue*. DOT Contract No. DOT-HS-5-01142. Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Massie, D. L., Blower, D., and Campbell, K. L. (1997). *Short-haul trucks and driver fatigue* (DTFH61-C-00038). Washington, DC: Office of Motor Carriers, Federal Highway Administration.

McFarland, R. A., and Moseley, A. L. (1954). *Human factors in highway transport safety*. Boston, MA: Harvard School of Public Health.

Mitler, M. M., Miller, J. C., Lipsitz, J. L., Walsh, J. K., and Wylie, C. D. (September, 1997). The sleep of long-haul truck drivers. *The New England Journal of Medicine, 337*(11), 755-761.

Mollenhauer, M. (November, 1998). *Proactive driving safety evaluation: An evaluation of an automated traveler information system and investigation of hazard analysis data.* Unpublished doctoral dissertation, University of Iowa, Iowa City.

National Safety Council (1994). *Accident facts, 1994 edition*. Itasca, IL: Author.

National Transportation Safety Board (January, 1995). *Factors that affect fatigue in heavy truck accidents, volume 1: Analysis*. Safety Study NTSB/SS-95/01, Notation 6511. Washington, D.C.: National Transportation Safety Board.

National Transportation Safety Board (January, 1995). *Factors that affect fatigue in heavy truck accidents, volume 1: Analysis*. Safety study NTSB/SS-95/01, Notation 6511. Washington, DC: Author.

O'Neil, T. R., Kruegar, G. P., Van Hemel, S. B., and McGowan, A. L. (January, 1999). *Effects of operating practices on commercial driver alertness*. Report No. FHWA-MC-99-140. Washington, DC: U.S. Department of Transportation, Federal Highway Administration.

Orris, P., Hartman, D. E., Strauss, P., Anderson, R. J., Collins, J., Knopp, C., Xu, Y., and Melius, J. (1997). Stress among package truck drivers. *American Journal of Industrial Medicine, 31*: 202-210.

Stewart, D. W., and Shamdasani, P. N. (1990). *Focus groups theory and practice*. Newbury Park, CA: SAGE Publications, Inc.

Tepas, D. I., and Monk, T. H. (1987). Work schedules. In G. Salvendy (Ed.) *Handbook of human factors* (pp. 819-843). New York: John Wiley & Sons.

U.S. Department of Commerce (November, 1994). *Truck inventory and use survey, 1992 census of transportation*. Washington, DC: U.S. Government Printing Office.

United States Department of Transportation, Federal Highway Administration (November, 1996). Proposed rules. *Federal Register, 61*(215).

United States Department of Transportation, Federal Highway Administration (July, 1997). *Summary of driver fatigue programs*. Washington, DC: Author.

United States Department of Transportation, Federal Motor Carrier Safety Administration (January, 2000). *Large truck crash profile: The 1998 national picture*. Washington, DC: USDOT, FMCSA.

Wierwille, W. W. (1999). Historical perspective on slow eyelid closure: Whence PERCLOS? *Ocular Measures of Driver Alertness, Technical Conference Proceedings* (pp.31-52). Silver Spring, MD: Transportation Safety Associates.

Wierwille, W. W., and Ellsworth L. A. (1994). Evaluation of driver drowsiness by trained raters. *Accident Analysis and Prevention,26*(5), 571-581.

Wierwille, W. W., Hanowski, R. J., and Dingus, T. A. (1998). *Impact of local/short haul operations on driver fatigue. Task 2 report: Development of experimental protocols*. Contract No. DTFH61-96-C-00105. Blacksburg, VA: Virginia Tech Center for Transportation Research.

Winer, B. J., Brown, D. R., and Michels, K. M (1991). *Statistical principles in experimental design*, (3rd ed.). New York: McGraw-Hill.

Wylie, C. D., Shultz, T., Miller, J. C., Mitler, M. M., and Mackie, R. R. (November, 1996). *Commercial motor vehicle driver fatigue and alertness study: Technical summary.* FHWA report no. FHWA-MC-97-001. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

APPENDIX A: INFORMED CONSENT FOR PARTICIPANTS OF INVESTIGATIVE PROJECTS

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY:

Title of the Project: IMPACT OF LOCAL/SHORT HAUL OPERATIONS ON DRIVER FATIGUE

Investigators: Walter Wierwille, Thomas Dingus, Richard Hanowski, Melissa Dugger

I. The Purpose of this Research

The purpose of this research is to evaluate the impact of fatigue and inattention in Local/Short Haul (L/SH) operations, and to assess the role of fatigue/inattention in relation to driving performance and safety. This will be determined by collecting on-road behavior and performance data from L/SH drivers during their workday.

II. Procedures

We would like you to drive your truck and complete your work route as you normally would. However, because this is a research effort, we will need for you to complete several other tasks. These tasks include:

1. Read and sign this Informed Consent Form (if you agree to participate).
2. Complete a Daily Sleep Log.
3. Wear, for the length of your participation, a wrist Activity Monitor.
4. Complete a Pre-Shift Fatigue Questionnaire.
5. Complete a Daily Work/Activity Log.
6. Complete a Post-Shift Fatigue/Workload Questionnaire.
7. Participate in a training session in which you will learn about specific features of the experimental vehicle.

The experiment will last for two weeks, including ten working days. It is important for you to understand that we are collecting data from many L/SH drivers like yourself. The key aspect in this research is that you act and drive as you normally would. Only in this way can our findings be used to help your industry.

III. Risks

There are some risks and discomforts to which you will be exposed in volunteering for this research. The risks are:

- The risk of an accident associated with driving a truck as you usually do.
- The slight additional risk of an accident that might possibly occur while pressing a button to indicate that a critical incident has occurred.

While driving the vehicle, you will be videotaped by cameras. Because of this, we ask that you not wear sunglasses. If this, at any time during the course of your driving, impairs your ability to drive the vehicle safely, you may wear the glasses. Otherwise, we ask you not to do so.

The following precautions will be taken to ensure minimal risk to the subjects:

- Drivers will be trained on how to operate the critical incident button.
- All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable way.
- None of the data collection equipment interferes with any part of the driver's normal field of view.

IV. Benefits of this Project

While there are no direct benefits to you from this research (other than payment), you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Your participation will help to improve the body of knowledge in L/SH trucking, including areas related to driver fatigue.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participating, drivers' names will be separated from their data. A coding scheme will be employed to identify the data by subject number only (e.g., Subject No. 3).

While you are driving the vehicle, a camera will videotape your face with some additional space around the head to accommodate any head-movements. Additionally, video cameras will capture views looking in front, to the side, and behind the vehicle.

The videotape will also contain a sound recording taken from a microphone in the cab of your vehicle. If an incident occurs, we'll ask you to describe it by speaking aloud a brief description.

The videotapes from this study will be stored in a secured area at the Virginia Tech Center for Transportation Research. Access to the tapes will be under the supervision of Dr. Walter Wierwille, the Principle Investigator for the project. Richard Hanowski, senior researcher, and Melissa Dugger, graduate research assistant, will also have access to the tapes. The tapes will not be released to your employer or unauthorized individuals.

In addition, a Certificate of Confidentiality has been obtained, which grants confidentiality to research participants. This confidentiality is provided for by the Public Health Services Act (§ 301(d), 42 U.S.C. 8241(d)). It ensures protection against compulsory legal process for personally identifiable research information.

VI. Compensation

You will be paid for participating in this study. In addition, you will be paid a bonus for completing the study. You will be paid at the end of your voluntary participation in this study for the portion of the experiment that you complete. For each day that you participate as a driver, you will be paid $30. For each day that you participate, but are off duty, you will be paid $15. (This pay is compensation for filling out the sleep log and wearing the activity monitor.) If you complete all ten driving days, you will also receive a bonus of $45. Thus, you will be paid $375 in total for your participation, assuming you have two days off and complete the entire study. Payment will be made directly to you by the experimenter.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. However, you will not be eligible for the bonus. Furthermore, you are free not to answer any question or respond to experimental situations without penalty.

VIII. Approval of Research

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

IX. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities: (1) To be physically free from any illegal substances (alcohol, drugs, etc.) while driving, (2) to conform to the laws and regulations of driving on public roadways, (3) to follow the experimental procedures as well as you can, and (4) to inform the experimenters if you incur difficulties of any type.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I understand that I may withdraw at any time without penalty. I agree to abide by the rules of this project.

__________________________________ ____________________

Participant's Signature Date

Should I have any questions about this research or its conduct, I may contact:

Walter Wierwille, Principle Investigator	(540) 231-8831
Thomas A. Dingus, Co-Principle Investigator	(540) 231-8831
Richard Hanowski, Senior Research Associate	(540) 231-9897
H. T. Hurd, Director of Sponsored Programs	(540) 231-5281

APPENDIX B: LOCAL/SHORT HAUL PROJECT PARTICIPANT INSTRUCTIONS

The following is a brief description of the tasks that you will have to complete during the next two weeks as part of this study.

DRIVING

It is very important that you drive as you normally do. In addition, work your route as you typically would.

CRITICAL INCIDENT BUTTON

A button has been set up for you to press should you encounter a "critical incident." A critical incident is an event that could have lead to an accident. It could involve an accident or a near-miss (a close call). For example, if a four-wheeler cuts you off and you have to slam on the brakes, this is a critical incident.

After you experience the critical incident, push and hold the button for about one second. Press it after the incident is over and only when it is safe to do so. If you are unsure as to whether an unusual event was a critical incident, press the button anyway. The researchers will examine the recordings of the event carefully at a later time.

Critical incidents may involve your vehicle in one way or another, or they may not. Others may cause you to respond to an emergency, or you may do something yourself that causes the problem. In either case, press the button. As researchers, we are not involved in fault finding. Our job is to determine problems and recommend solutions. Also, if you should see a critical incident ahead, for example, in which your vehicle is not involved, press the button.

Shortly after you have pressed the button, we would like you to verbally describe the incident. Just speak as you normally would, using your own description of what you think happened. The in-cab microphone will pick this up and record it for use by the researchers.

SLEEP LOG

Make entries in the Sleep Log whenever you go to sleep or wake up. Sleep might be at night, or a nap during the day. Each entry should include (1) the month, (2) the day, (3) the time of day, (4) what the sleep activity was (e.g., waking up, going to bed at night, taking a nap, waking up from a nap), (5) what the quality of the sleep or rest was, (6) whether you took the Actiwatch off at any time, and (7) any comments you have.

Fill out Sleep/Rest Quality for "Awake" entries only. Ask yourself when you wake up from sleeping or resting, "What was the quality of my sleep?"

Sleep Quality:

1- Excellent

2- Good

3- Average

4- Poor

5- Terrible

Each time you make a new entry in the Sleep Log, ask yourself, "Did I wear the activity monitor for the entire time since my last entry?" If it was off for any reason, indicate how long it was off for and the approximate time that it was off of your wrist in the Actiwatch Off? column.

The comments section is very important, so please fill it out with each entry. Your comments should involve how rested you feel. Ask yourself, "What was the quality of my sleep?" You might have had a good night's sleep, or perhaps you tossed-and-turned and slept poorly. You might also ask yourself, "Do I feel well rested?" You might feel refreshed after having an afternoon nap, or perhaps it makes you even more tired.

Please note that we would like you to continue your sleep log entries on your days off (within the experimental period). Doing so will give us a more complete picture of your sleep/work patterns.

Your sleep log might look like the following:

Month	Day	Time	Activity	Sleep/Rest Quality	Actiwatch Off?	Comments
June	10	5:30 AM	Awake	4		Watched late night TV; poor sleep
		1:02 PM	Nap	X		In cab; waiting to be unloaded
		1:20 PM	Awake	2		Unloading; feel rested
		10:19 PM	Sleep	X	10:00-10:15	Long day; very tired
	11	5:30 AM	Awake	2		Slept better; had good night's sleep
		10:07 PM	Sleep	X		No time for nap; feel tired

WRIST ACTIVITY MONITOR

Throughout the two-week period, it is important that you continuously wear the Wrist Activity Monitor. It is the same size as a wristwatch and should not interfere with your workday or off-work time. It is important that you keep it on during the day and at night. It is durable and waterproof so you don't have to worry about damaging it; it will stand up to normal daily activities. You may take the monitor off while bathing or performing other "personal" activities. However, please don't forget to put it back on afterward and please try not to let these other activities exceed one hour. If you do take off the monitor, please try to wear it in the same manner, such as placing it on the same place on your wrist. This consistency is very important.

As with the sleep log, we are asking you to wear the monitor on your days off within the experimental period. This will help us check your activity and sleep quality.

PRE-SHIFT SLEEP/FATIGUE QUESTIONNAIRE

Once in the morning, before your shift begins, you will fill out a Sleep/Fatigue Questionnaire. You should complete this with the rest of your morning paperwork (i.e., pre-trip).

DAILY WORK/ACTIVITY LOG

The Daily Work/Activity Log is similar to a trucker's log book, except that it includes other types of information, such as the number of pickups and deliveries you made and the amount (weight) of cargo you loaded/unloaded, etc. Please complete this form as you are involved in the activities described, and verify during your post-trip paperwork that you have completed all relevant parts of the log.

POST-SHIFT SLEEP/FATIGUE & WORKLOAD QUESTIONNAIRE

At the end of the day, you will fill out a Post-Shift Sleep/Fatigue & Workload Questionnaire. You should complete this with the other paper work you complete at the end of your day (i.e., post-trip).

APPENDIX C: LOCAL/SHORT HAUL PROJECT DEMOGRAPHIC QUESTIONNAIRE

A local/short haul driver is a truck driver:

- who usually operates within a 100-air mile radius of his/her normal work-reporting location or home base,
- who usually returns to his/her home base at the end of the shift (typically not working more than 12 hours),
- who usually spends at least 8 consecutive hours off duty before returning to work,
- who may at least occasionally drive state to state.

Questions

1. Based on this definition of local/short haul drivers, would you consider yourself one?

Yes_____ No_____ At Least 50% of the Time______

2. In your daily operations, do you drive from one state to another?

Yes_____ No_____ Occasionally______

If so, in what states? ____

What is the city/state of your home base?____

3. Does your work ever involve hauling outside the 100 air-mile radius?

Yes_____ No_____

If so, how often (estimate of instances per week)?____________________________________

4. How much of your workday is spent driving?

Less Than Half_____ About Half_____ More Than Half_______

5. How many hours per week do you work?_______________________
6. How old are you? _________
7. Gender? _______________
8. How long have you been a truck driver?____
9. How long have you been a local/short haul driver? _______________________________

10. How long have you held any type of drivers' license? ____________________

11. Do you have a CDL? ____________________

12. If so, what endorsements do you hold? ____________________

13. Did you have any special training before you began L/SH driving? ____________

If so, please detail (e.g., school, in-house training, etc.) ____________________

____

14. Have you had any special training or safety courses since beginning L/SH driving? _____

____

15. When was the last time you had any driver or safety training? ____________

Type: ____________________

16. How often do you get driver or safety training? ____________________

Type: ____________________

17. What hours do you usually work? ____________________

Is this shift work?____________________

18. What product(s) do you usually haul? ____________________

19. For whom do you haul? ____________________

20. What other duties, besides driving, do you perform?____________________

____

21. Is the company that you work for private delivery (e.g., like UPS, Coca-Cola, Kroger), for-hire (e.g., independent trucking company), or "other" (if "other," please explain)?

____

22. What is your pay structure (e.g., hourly wage, salary, pay-per-load, percentage, etc.)? ____

____

____

23. What type of truck(s)/trailers do you usually drive (e.g., class 8, panel van; articulated)? ___
____

24. Does your drivers' license require you to wear corrective eyewear (i.e., glasses or contact lenses)? ____

If yes, what type of eyewear do you wear? _______________________

25. Do you ordinarily wear glasses when driving (e.g., prescription, non-prescription, sunglasses)? ____

26. If your license does NOT require you to wear glasses, would you be willing to NOT wear glasses for a two-week data gathering period while driving for this study? ____________
____

27. If your license DOES require you to wear corrective lenses, and you have contact lenses, would you be willing and able to wear them for a two-week data gathering period while driving for this study?_______________________________

28. Do you have any holidays/vacations/other events coming up that would interfere with your driving the truck for a two-week period? _______________________

APPENDIX D: PRE-SHIFT SLEEP/FATIGUE QUESTIONNAIRE

____

Driver name

____

Month Day Year

____________________AM PM (Circle)

Present time

INSTRUCTIONS: Complete this one-part questionnaire in the morning before your shift. You should fill this out with your other morning paper work; complete this as part of your pre-trip routine.

Part 1

Circle the number of the statement that best reflects how you feel right now.

1- Wide Awake (feeling active and vital; alert)
2- Functioning at a high level, but not at peak (able to concentrate)
3- Relaxed (not at full alertness; awake; responsive)
4- A little foggy (not at peak; letdown)
5- Fogginess (beginning to lose interest in remaining awake; slowed down)
6- Sleepiness (prefer to be lying down; fighting sleep; woozy)
7- Losing struggle to remain awake (sleep onset soon; almost in reverie)

APPENDIX E: POST-SHIFT SLEEP/FATIGUE & WORKLOAD QUESTIONNAIRE

____

Driver name

____

Month Day Year

_______________ AM PM (Circle)

Present time

INSTRUCTIONS: Complete this four-part questionnaire at the end of your shift. You should fill this out with your other after-shift paper work; complete this as part of your post-trip routine.

Part 1

Circle the number of the statement that best reflects how you feel right now.

1- Wide Awake (feeling active and vital; alert)
2- Functioning at a high level, but not at peak (able to concentrate)
3- Relaxed (not at full alertness; awake; responsive)
4- A little foggy (not at peak; letdown)
5- Fogginess (beginning to lose interest in remaining awake; slowed down)
6- Sleepiness (prefer to be lying down; fighting sleep; woozy)
7- Losing struggle to remain awake (sleep onset soon; almost in reverie)

Preceding Page Blank

Part 2

Which item or items listed below made your job more difficult today? Check all that apply.

	Items	Check Below
1	**PROBLEMS CAUSED BY DRIVERS OF LIGHT VEHICLES**	
2	Stress or Time Pressure	
3	Inattention	
4	Problems Caused by Roadway or Dock Design	
5	Fatigue	
6	Weather	
7	Carelessness on Your Part	
8	Vehicle Design	
9	Mirrors on Your Truck	
10	Road Construction	
11	Store or Delivery Location	
12	Poor Roadside Signs	
13	Lack of Driver Education on Your Part	
14	Traffic Congestion	
15	Over-Confidence on Your Part	

Part 3

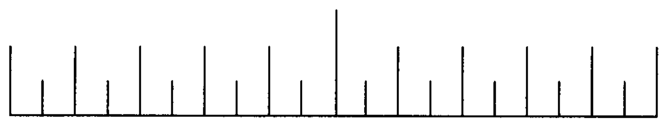
Which item or items listed below had an effect on how tired/fatigued you felt today? Check all that apply.

	Items	Check Below
1	Hard/Physical Workday	
2	Not Enough Sleep	
3	Long Hours	
4	Heat/No Air Conditioner	
5	Irregular Meal Times	
6	Balancing Work and Personal Life	
7	Frustration	
8	Irregular Workshift	
9	Partying Night Before	
10	Sick	
11	Waiting to Load or Unload	
12	Driving at Night/Dusk/Dawn	
13	Shift Work	
14	Start/End of Day	
15	Stress from Traffic	
16	Unfamiliar Route	
17	End of Week	
18	Poor Equipment	
19	Reprimanded by Management	
20	Snow/Chaining Tires	
21	Temperature Changes (e.g., Going From Trailer to Dock)	
22	Working Two Jobs (i.e., Moonlighting)	

Part 4

Instructions: Read through each paragraph and give your response based on a scale of 0 to 100. A rating of 0 is extremely low, and a rating of 100 is extremely high.

1. How much thinking was required to operate this vehicle and complete your route? For example, consider the work involved in reading and responding to the displays on your dash and the decisions that you had to make while working your route.

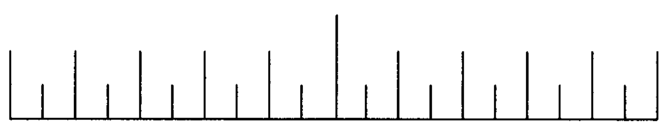


0 — **Very Low**

100 — **Very High**

Level of Thinking

2. How much physical activity was required to operate this vehicle and complete your route? Consider the work involved in steering, shifting gears, and loading and unloading.

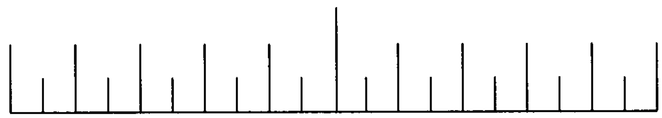


0 — **Very Low**

100 — **Very High**

Physical Demand

3. How much time pressure did you feel today? Consider the question, was the pace at which you were doing your job slow and leisurely or rapid and frantic?

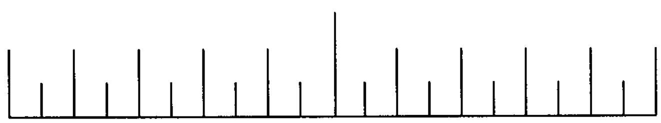


0 — 100

Very Low — **Very High**

Time Pressure

4. How successful do you think you were in accomplishing your job? Consider the question, how satisfied are you with your performance?

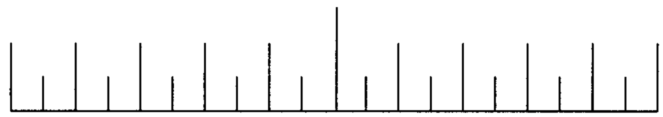


0 — 100

Failure — **Perfect**

Degree of Success

5. How much effort did you put into doing your job? Consider the question, how hard did you have to work to get the results you did?

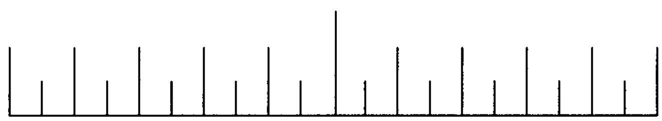


0 Very Low

100 Very High

Effort Level

6. How frustrating was your day? Consider your feelings of being irritated, stressed, and annoyed.



0 Very Low

100 Very High

Frustration Level

Daily work/activity log

Instructions: Complete this questionnaire at the end of your shift. You should fill this out with your other after-shift paper work; complete this as part of your post-trip routine.

______________________________________ __________________________

Driver name Company

__________________________ ________________

Month Day Year Total mileage today

_________________ AM PM (Circle)

Present time

Estimated number of stops (pickups and deliveries)

____

List type of cargo____

Estimated total weight of cargo you personally loaded/unloaded today, if any: _____________

Shift start time ________________ AM PM (Circle)

Shift end time _________________AM PM (Circle)

In the following, please use hours and minutes, or hours and fractions of hours, when filling in the blanks.

Number of hours on shift (difference between shift end time and shift start time)

__________________ hrs. or hrs. & mins.

<u>Sum of All Entries</u>
<u>Should Equal Total Shift Time</u>

____
Total shift time
(from above)

Driving........................ ________

Personally loading/
unloading.................... ________

Other assigned duties,
but not driving and not
personally loading/unloading ________

Non-work related activities

Waiting.................... ________

Eating........................ ________

Resting/napping......... ________

Other.................... ________

From the previous page, please describe the "other assigned duties, but not driving and not personally loading/unloading," if any. (What were these duties?)

____

____

____

From the previous page, please describe each of the following non-work related activities:

Under "Waiting," if any, what did you wait for?

____

____

Under "Eating," if any, what meals/snacks did you eat and when?

____

____

Under "Resting/Napping," if any, please describe when and the approximate quality.

____

____

Under "Other," if any, please describe.

____

____

What stimulants have you had today?

Instant coffee: ____________ cups

Brewed coffee: ____________ cups

Tea: ____________ cups

Caffeinated soft drinks: ____________ bottles/cans/cups

Brand(s) of soft drink:____

Other stimulants (please describe) ____

Number of rest breaks taken __________________

Type of rest breaks taken (check all that apply and indicate time; specify for "other")

Breakfast ______ time: ___________ Coffee (AM) _____ time: _________

Lunch _____ time: _______________ Coffee (PM) ______ time: _________

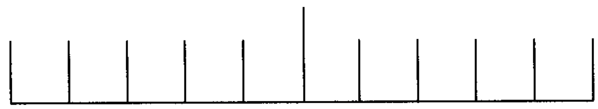
Nap ______ time: _______________ Snack ____________ time: _________

Other ____________ time: ________ Other _______________time: ________

Other ____________ time: ________ Other _______________time: _______

Total time spent for all breaks _____________________________

Assessment of level of stress. Mark on the line to indicate how stressful your day was.



0 **Very Low** — 100 **Very High**

What, if anything, caused your stress today? (list) ______________________________

____

____

Estimate number of critical incidents witnessed where your vehicle was NOT involved in any way ____________________

Estimate number of critical incidents involving your vehicle in some way ________________

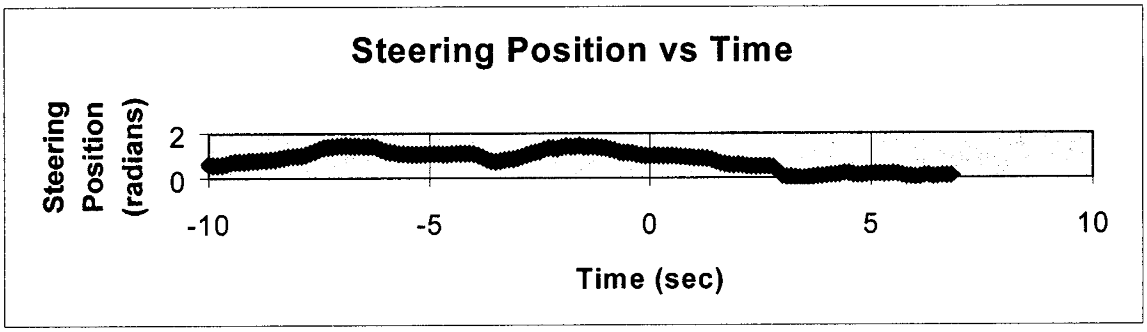
APPENDIX F: SLEEP LOG

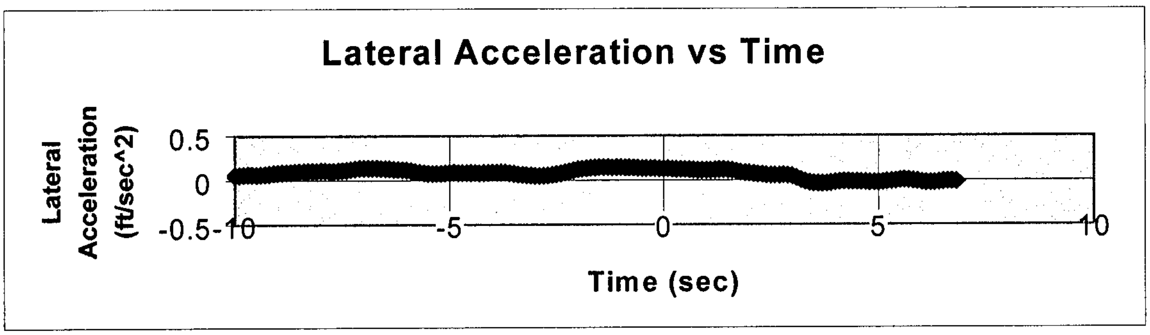
Name____

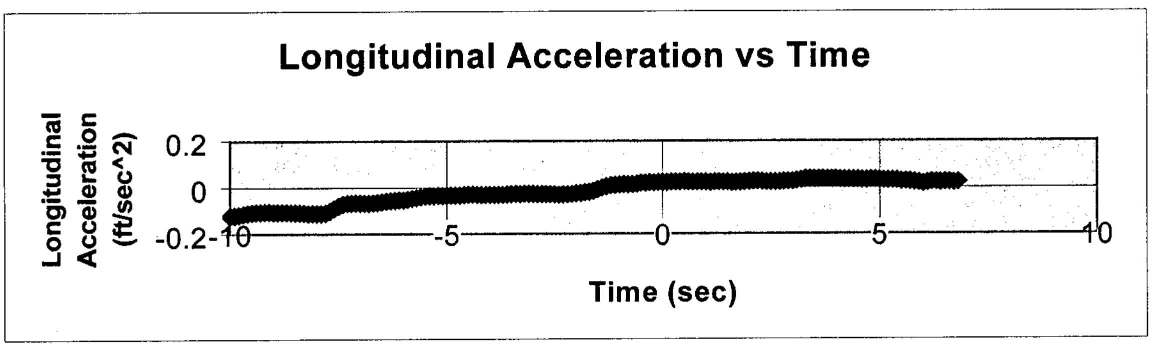
Month (1)	Date (2)	Go to Sleep Time (3)	Wake Up Time (4)	Sleep/Rest Quality (5) 1=Excellent, 5=Terrible	Comments (6)	Actiwatch Off? (7)
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM
		AM PM	AM PM			AM PM

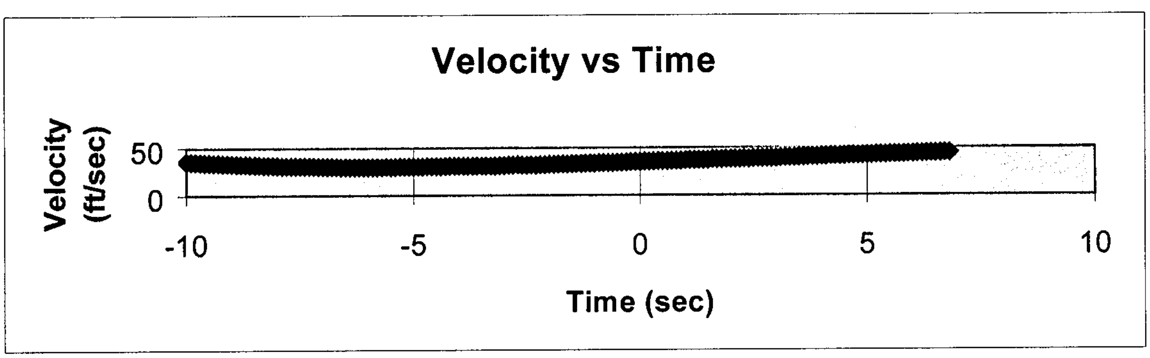
APPENDIX G: SAMPLE PLOTS

Plots for Lane Change Event #16









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Description of Lane Change Event #16

Subject: 12

Age: 27

Gender: Male

Company: xxx

Truck: Straight Box Truck

Date: 12/30/98

Time: 5:07:39 PM

Event: Lane Change #16

Begin Sync: 74265

The driver was traveling on a rural divided highway. He exited one road and was then merging from his right lane onto another road with two lanes in his direction of travel. There were no vehicles in front of him, but one of the cars behind him pulled around him into the left lane as he was merging.

APPENDIX H : ANOVA TABLES FOR DATA SET COMPRISED OF DRIVER AT FAULT EVENTS AND LANE CHANGE EVENTS (CONTROL)

Dependent Variable: AGE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***1437.423***	***1437.423***	***18.19***	***0.0001***
Error	335	26471.236	79.019		

Dependent Variable: TIMEDAY

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	13.875	13.875	0.95	0.3293
Error	330	4796.330	14.534		

Dependent Variable: OBSERV

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***2984.370***	***2984.370***	***11.78***	***0.0007***
Error	325	82338.902	253.350		

Dependent Variable: PERCLOS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.240***	***0.240***	***53.63***	***0.0001***
Error	314	1.406	0.004		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.00	0.9493
Error	319	3.132	0.010		

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	266.942	266.942	2.25	0.1346
Error	318	37732.013	118.654		

APPENDIX I: ANOVA TABLES FOR DATA SET COMPRISED OF DRIVER AT FAULT EVENTS AND DRIVER NOT AT FAULT EVENTS (CONTROL)

Dependent Variable: AGE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***1584.928***	***1584.928***	***22.50***	***0.0001***
Error	212	14934.286	70.445		

Dependent Variable: SHIFT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	4.732	4.732	2.65	0.1054
Error	205	366.746	1.789		

Dependent Variable: TIME OF DAY

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***58.182***	***58.182***	***5.27***	***0.0228***
Error	200	2209.240	11.046		

Dependent Variable: OBSERV

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***5238.297***	***5238.297***	***19.17***	***0.0001***
Error	185	50553.478	273.262		

Dependent Variable: PERCLOS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.184***	***0.184***	***21.19***	***0.0001***
Error	156	1.358	0.009		

Dependent Variable: LOGHRS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	1.450	1.450	0.88	0.3501
Error	183	302.237	1.652		

Dependent Variable: LOGQUAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***4.182***	***4.182***	***3.97***	***0.0479***
Error	178	187.555	1.054		

Dependent Variable: ACTIHRS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	1.869	1.869	1.43	0.2342
Error	135	176.640	1.308		

Dependent Variable: ACTIQUAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	309.054	309.054	1.67	0.1985
Error	134	24799.827	185.073		

Dependent Variable: PREFAT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.050	0.050	0.04	0.8413
Error	200	246.267	1.231		

Dependent Variable: POSTFAT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.640	0.640	0.36	0.5509
Error	193	345.955	1.793		

Dependent Variable: POSTSTRS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	522.430	522.430	0.70	0.4050
Error	201	150793.737	750.218		

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***458.807***	***458.807***	***3.83***	***0.0521***
Error	166	19895.808	119.854		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.009	0.009	0.83	0.3637
Error	167	1.897	0.011		

Dependent Variable: THINKING

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	556.904	556.904	0.90	0.3432
Error	198	122141.091	616.874		

Dependent Variable: PHYSDEM

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	481.725	481.725	0.81	0.3689
Error	198	117617.855	594.030		

Dependent Variable: TIMEPRES

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	591.564	591.564	0.70	0.4046
Error	205	173883.865	848.214		

Dependent Variable: DEGSUCC

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	516.245	516.245	1.83	0.1771
Error	205	57697.407	281.451		

Dependent Variable: EFFORT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	74.801	74.801	0.20	0.6554
Error	205	76788.078	374.576		

Dependent Variable: FRUSTRAT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	1160.980	1160.980	1.54	0.2154
Error	205	154108.015	751.746		

Dependent Variable: HRSTOTAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***9.228***	***9.228***	***3.04***	***0.0826***
Error	203	615.472	3.032		

Dependent Variable: HRSDRIV

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***19.003***	***19.003***	***8.81***	***0.0033***
Error	205	442.103	2.157		

Dependent Variable: HRSLOAD

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	12.753	12.753	2.62	0.1070
Error	205	997.658	4.867		

Dependent Variable: EXPERIEN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***269.702***	***269.702***	***11.94***	***0.0007***
Error	212	4789.639	22.593		

Dependent Variable: LSHEXP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***240.740***	***240.740***	***10.96***	***0.0011***
Error	212	4654.747	21.956		

Dependent Variable: YRSDRIV EXP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***1356.997***	***1356.997***	***20.14***	***0.0001***
Error	212	14282.812	67.372		

Dependent Variable: TOTMILE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***6381.930***	***6381.930***	***3.55***	***0.0613***
Error	181	325729.048	1799.608		

Dependent Variable: NUMSTOPS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***118.992***	***118.992***	***4.87***	***0.0285***
Error	203	4962.988	24.448		

Dependent Variable: WEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	3244302.802	3244302.802	1.49	0.2236
Error	187	406891922.6	2175892.634		

Chi-Square Table

Variable	DF	Value	Prob > F
DAYWEEK	5	7.112	0.212
SHIFT	4	4.671	0.323
TRAINING	1	5.236	0.022
ILLUM2	1	0.790	0.374
WEATH2	1	1.928	0.165
VISIB2	1	0.002	0.960

APPENDIX J: ANOVA TABLES FOR DATA SET COMPRISED OF DRIVER FATIGUED AND AT FAULT EVENTS AND DRIVER NOT FATIGUED AND AT FAULT EVENTS (CONTROL)

Dependent Variable: AGE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***268.258***	***268.258***	*7.32*	***0.0084***
Error	75	2746.963	36.626		

Dependent Variable: TIME OF DAY

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	2.859	2.859	0.25	0.6220
Error	70	816.007	11.657		

Dependent Variable: LOGHRS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	*7.461*	*7.461*	***4.51***	***0.0374***
Error	66	109.163	1.654		

Dependent Variable: LOGQUAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***8.972***	***8.972***	***8.57***	***0.0048***
Error	62	64.888	1.0466		

Dependent Variable: ACTIHRS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***6.742***	***6.742***	***3.31***	***0.0753***
Error	46	93.664	2.036		

Dependent Variable: ACTIQUAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***712.413***	***712.413***	***3.21***	***0.0799***
Error	45	9987.156	221.937		

Dependent Variable: PREFAT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	1.801	1.801	1.27	0.2631
Error	70	99.074	1.415		

Dependent Variable: POSTFAT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.728	0.728	0.33	0.5685
Error	68	150.715	2.216		

Dependent Variable: POSTSTRS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	36.213	36.213	0.04	0.8344
Error	72	59223.571	882.550		

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***752.058***	***752.058***	***5.91***	***0.0181***
Error	58	7376.413	127.180		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.077***	***0.077***	***4.84***	***0.0317***
Error	59	0.940	0.016		

Dependent Variable: THINKING

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***1816.231***	***1816.231***	***2.86***	***0.0949***
Error	72	45663.931	634.221		

Dependent Variable: PHYSDEM

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	657.987	657.987	0.89	0.3487
Error	72	53247.162	739.544		

Dependent Variable: TIMEPRES

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	96.142	96.142	0.10	0.7555
Error	73	71852.844	984.286		

Dependent Variable: DEGSUCC

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	82.172	82.172	0.22	0.6370
Error	73	26715.508	365.966		

Dependent Variable: EFFORT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	439.464	439.464	0.98	0.3249
Error	73	32653.682	447.311		

Dependent Variable: FRUSTRAT

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	99.263	99.263	0.11	0.7453
Error	73	68150.124	933.563		

Dependent Variable: HRSTOTAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	4.546	4.546	1.37	0.2462
Error	73	242.850	3.327		

Dependent Variable: HRSDRIV

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***11.248***	***11.248***	***4.07***	***0.0474***
Error	73	201.956	2.767		

Dependent Variable: HRSLOAD

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***13.819***	***13.819***	***5.07***	***0.0274***
Error	73	198.972	2.726		

Dependent Variable: EXPERIEN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***46.221***	***46.221***	***5.50***	***0.0217***
Error	75	630.335	8.404		

Dependent Variable: LSHEXP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***37.011***	***37.011***	***5.25***	***0.0248***
Error	75	529.204	7.056		

Dependent Variable: YRSDRIV EXP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***132.956***	***132.956***	***3.63***	***0.0605***
Error	75	2745.356	36.605		

Dependent Variable: TOTMILE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	3101.277	3101.277	1.89	0.1734
Error	67	109738.361	1637.886		

Dependent Variable: NUMSTOPS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	17.675	17.675	0.79	0.3771
Error	71	1588.489	22.373		

Chi-Square Table

Variable	DF	Value	Prob > F
DAYWEEK	5	9.014	0.109
SHIFT	***4***	***10.949***	***0.027***
TRAINING	1	2.590	0.108
ILLUM2	1	1.893	0.169
WEATH2	1	0.988	0.320
VISIB2	1	0.146	0.702

APPENDIX K: ANOVA TABLES FOR LANE CHANGE EVENT ANALYSIS

CRITICAL INCIDENT VS. NO CRITICAL INCIDNET EVENTS

Dependent Variable: PERCLOS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI TYPE	*1*	*0.010*	*0.010*	*13.05*	*0.0004*
Error	271	0.217	0.0008		

Dependent Variable: OBSERV

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI TYPE	1	125.565	125.565	0.75	0.3881
Error	271	45541.138	168.048		

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI TYPE	1	7.905	7.905	0.07	0.7942
Error	271	31415.608	115.925		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI TYPE	1	0.001	0.001	0.13	0.7176
Error	271	2.199	0.008		

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CRITICAL INCIDENT X DROWSINESS

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	95.342	95.342	0.83	0.3626
ObsScore	***1***	***436.812***	***436.812***	***3.81***	***0.0520***
CIType X Obscore	1	178.881	178.881	1.56	0.2127
Error	269	30834.614	114.627		

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	200.749	200.749	1.73	0.1894
PerScore	1	38.952	38.952	0.34	0.5627
CIType X PerScore	1	210.841	210.841	1.82	0.1787
Error	269	31202.117	115.993		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.003	0.003	0.35	0.5523
ObsScore	1	0.003	0.003	0.32	0.5694
CIType X Obscore	1	0.002	0.002	0.23	0.6335
Error	269	2.196	0.008		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.006	0.006	0.7	0.4029
PerScore	1	0.011	0.011	1.35	0.2465
CIType X PerScore	1	0.011	0.011	1.42	0.2344
Error	269	2.184	0.008		

Dependent Variable: DURATION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***58.802***	***58.802***	***12.49***	***0.0005***
ObsScore	1	4.462	4.462	0.95	0.3312
CIType X Obscore	1	3.131	3.131	0.66	0.4156
Error	270	1271.625	4.710		

Dependent Variable: DURATION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***32.662***	***32.662***	***7.06***	***0.0084***
PerScore	***1***	***26.102***	***26.102***	***5.64***	***0.0183***
CIType X PerScore	1	9.487	9.487	2.05	0.1534
Error	270	1249.830	4.629		

Dependent Variable: PKLTACL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.014	0.014	1.15	0.2849
ObsScore	1	0.004	0.004	0.33	0.5675
CIType X Obscore	1	0.003	0.003	0.22	0.6397
Error	270	3.329	0.012		

Dependent Variable: PKLTACL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.001	0.001	0.10	0.7537
PerScore	1	0.024	0.024	1.92	0.1672
CIType X PerScore	1	0.015	0.015	1.17	0.2802
Error	270	3.367	0.0124		

Dependent Variable: PROPCFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.014	0.014	0.40	0.5268
ObsScore	***1***	***0.1367***	***0.1367***	***3.95***	***0.0478***
CIType X Obscore	1	0.033	0.033	0.95	0.3295
Error	270	9.342	0.035		

Dependent Variable: PROPCFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.052	0.052	1.48	0.2248
PerScore	1	0.035	0.035	1.00	0.3183
CIType X PerScore	1	0.051	0.051	1.43	0.2323
Error	270	9.533	0.035		

Dependent Variable: PROPLFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.001	0.001	0.13	0.7143
ObsScore	1	0.003	0.003	0.27	0.6039
CIType X Obscore	1	0.000	0.000	0.04	0.8388
Error	270	3.00	0.011		

Dependent Variable: PROPLFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.04	0.8417
PerScore	1	0.004	0.004	0.34	0.5622
CIType X PerScore	1	0.000	0.000	0.00	0.9461
Error	270	3.00	0.011		

Dependent Variable: PROPRFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.01	0.9086
ObsScore	1	0.005	0.005	0.81	0.3688
CIType X Obscore	1	0.001	0.001	0.14	0.7090
Error	270	1.574	0.006		

Dependent Variable: PROPRFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.008	0.008	1.38	0.2408
PerScore	1	0.001	0.001	0.1	0.7527
CIType X PerScore	1	0.012	0.012	2.14	0.1450
Error	270	1.562	0.006		

Dependent Variable: PROPLMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.002	0.002	0.21	0.6501
ObsScore	1	0.014	0.014	1.19	0.2763
CIType X Obscore	1	0.010	0.010	0.82	0.3663
Error	270	3.201	0.012		

Dependent Variable: PROPLMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.005	0.005	0.46	0.4974
PerScore	1	0.013	0.013	1.07	0.3025
CIType X PerScore	1	0.002	0.002	0.13	0.7198
Error	270	3.189	0.012		

Dependent Variable: PROPRMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.02	0.8769
ObsScore	1	0.000	0.000	0.04	0.8504
CIType X Obscore	1	0.000	0.000	0.04	0.8417
Error	270	2.469	0.009		

Dependent Variable: PROPRMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.012	0.012	1.35	0.2466
PerScore	1	0.001	0.001	0.11	0.7382
CIType X PerScore	1	0.008	0.008	0.85	0.3562
Error	270	2.454	0.009		

Dependent Variable: PROPLWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.18	0.6696
ObsScore	1	0.000	0.000	0.11	0.7371
CIType X Obscore	1	0.000	0.000	0.11	0.7371
Error	270	0.688	0.003		

Dependent Variable: PROPLWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.10	0.7462
PerScore	1	0.000	0.000	0.10	0.7462
CIType X PerScore	1	0.000	0.000	0.10	0.7462
Error	270	0.692	0.003		

Dependent Variable: PROPRWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.17	0.6792
ObsScore	1	0.000	0.000	0.00	0.9553
CIType X Obscore	1	0.000	0.000	0.00	0.9553
Error	270	0.119	0.000		

Dependent Variable: PROPRWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.09	0.7688
PerScore	1	0.000	0.000	0.26	0.6139
CIType X PerScore	1	0.000	0.000	0.25	0.6191
Error	270	0.389	0.001		

Dependent Variable: PROPIP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.17	0.6792
ObsScore	1	0.000	0.000	0.00	0.9553
CIType X Obscore	1	0.000	0.000	0.00	0.9553
Error	270	0.119	0.000		

Dependent Variable: PROPIP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.24	0.6242
PerScore	1	0.000	0.000	0.05	0.82540
CIType X PerScore	1	0.001	0.001	0.46	0.4979
Error	270	0.389	0.001		

Dependent Variable: PROPOTH

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.002	0.002	0.30	0.5820
ObsScore	1	0.010	0.010	1.57	0.2116
CIType X Obscore	1	0.004	0.004	0.58	0.4482
Error	270	1.703	0.006		

Dependent Variable: PROOTH

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.179***	***0.179***	***31.35***	***0.0001***
PerScore	***1***	***0.117***	***0.117***	***20.52***	***0.0001***
CIType X PerScore	***1***	***0.152***	***0.152***	***26.69***	***0.0001***
Error	270	1.549	0.006		

APPENDIX L: ANOVA TABLES FOR BACKING EVENT ANALYSIS

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***391.834***	***391.834***	***3.36***	***0.0681***
ObsScore	1	93.614	93.614	0.80	0.3713
Error	262	30580.785	116.721		

Dependent Variable: EYETRANS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***399.719***	***399.719***	***3.41***	***0.0658***
PerScore	1	0.559	0.559	0.00	0.9450
Error	262	30673.841	117.076		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.021	0.021	1.54	0.2157
ObsScore	1	0.028	0.028	1.99	0.1598
Error	262	3.651	0.014		

Dependent Variable: EYESOFF

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.020	0.020	1.45	0.2289
PerScore	1	0.000	0.000	0.01	0.9416
Error	262	3.679	0.014		

Dependent Variable: DURATION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	1.125	1.125	0.00	0.9612
ObsScore	1	161.195	161.195	0.34	0.5607
Error	265	125859.771	474.943		

Dependent Variable: DURATION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	1.343	1.343	0.00	0.9576
PerScore	1	247.127	247.127	0.52	0.4712
Error	265	125773.839	474.618		

Dependent Variable: SHUTTLE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.364	0.364	1.11	0.2938
ObsScore	1	0.275	0.275	0.84	0.3613
Error	265	87.091	0.329		

Dependent Variable: SHUTTLE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.353	0.353	1.07	0.3017
PerScore	1	0.090	0.090	0.27	0.6012
Error	265	87.275	0.329		

Dependent Variable: PROPCFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.303***	***0.303***	***21.65***	***0.0001***
ObsScore	1	0.002	0.002	0.13	0.7157
Error	265	3.711	0.014		

Dependent Variable: PROPCFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.305***	***0.305***	***21.79***	***0.0001***
PerScore	1	0.001	0.001	0.07	0.7951
Error	265	3.712	0.014		

Dependent Variable: PROPLFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.038***	***0.038***	***4.37***	***0.0375***
ObsScore	1	0.004	0.004	0.41	0.5232
Error	265	2.331	0.009		

Dependent Variable: PROPLFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.039***	***0.039***	***4.40***	***0.0370***
PerScore	1	0.007	0.007	0.76	0.3836
Error	265	2.328	0.009		

Dependent Variable: PROPRFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.001	0.001	0.07	0.7852
ObsScore	***1***	***0.065***	***0.065***	***5.25***	***0.0227***
Error	265	3.269	0.012		

Dependent Variable: PROPRFW

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.001	0.001	0.06	0.8076
PerScore	***1***	***0.055***	***0.055***	***4.43***	***0.0363***
Error	265	3.729	0.012		

Dependent Variable: PROPLMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.247***	***0.247***	***6.55***	***0.0110***
ObsScore	1	0.073	0.073	1.95	0.1642
Error	265	9.990	0.038		

Dependent Variable: PROPLMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	***1***	***0.256***	***0.256***	***6.74***	***0.0100***
PerScore	1	0.007	0.007	0.20	0.6581
Error	265	10.056	0.038		

Dependent Variable: PROPRMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.074	0.074	2.72	0.1003
ObsScore	1	0.045	0.045	1.64	0.2013
Error	265	7.197	0.027		

Dependent Variable: PROPRMIR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.071	0.071	2.61	0.1074
PerScore	1	0.002	0.002	0.09	0.7647
Error	265	7.239	0.027		

Dependent Variable: PROPLWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.01	0.9348
ObsScore	1	0.012	0.012	1.49	0.2235
Error	265	2.207	0.008		

Dependent Variable: PROPLWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.00	0.9517
PerScore	1	0.005	0.005	0.54	0.4628
Error	265	2.215	0.008		

Dependent Variable: PROPRWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.01	0.9155
ObsScore	1	0.001	0.001	0.55	0.4579
Error	265	0.683	0.003		

Dependent Variable: PROPRWIN

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.00	0.9449
PerScore	1	0.003	0.003	1.31	0.2543
Error	265	0.681	0.003		

Dependent Variable: PROPIP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.44	0.5090
ObsScore	1	0.000	0.000	0.49	0.4863
Error	265	0.202	0.001		

Dependent Variable: PROPIP

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.000	0.000	0.42	0.5163
PerScore	1	0.000	0.000	0.23	0.6301
Error	265	0.202	0.001		

Dependent Variable: PROPOTH

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.001	0.001	0.49	0.4861
ObsScore	1	0.001	0.001	0.53	0.4672
Error	265	0.586	0.002		

Dependent Variable: PROOTH

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
CI Type	1	0.001	0.001	0.50	0.4782
PerScore	1	0.000	0.000	0.17	0.6772
Error	265	0.587	0.002		

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