# Impact of Sleeper Berth Usage on Driver Fatigue

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Federal Motor Carrier Safety Administration

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## Forward

## Notice

As of February 2000, our organization name and address have been changed to:

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16. Abstract:

The goal of this project was to assess the impact that sleeper berth usage has on operator alertness. Forty-seven males and nine females participated in this study, constituting 13 teams and 30 single drivers. All drivers who participated in this study were recruited from one of four for-hire commercial trucking companies. Two tractors, a 1997 Volvo L4 VN-series tractor and a 1995 Peterbilt 379, with functionally identical instrumentation packages and data collection systems, were used for the study. The data acquisition system functioned to record four camera views, including the drivers face; driving performance information, including steering, lane departure, and braking; sleeper berth environmental data, including noise, vibration, and temperature; subjective alertness ratings; and data from the Nightcap sleep-monitoring system. The following results were obtained:

1. Sleeping in either a stationary or moving sleeper berth was shown to adversely affect sleep quality and quantity when compared to the home sleep data. This was particularly true for team drivers in moving trucks.
2. Team drivers generally acquired more sleep (greater than one hour per day on average) than did single drivers, with single drivers reporting six hours of sleep per 24-hour period and team drivers reporting just over seven hours per 24-hour period.
3. Team drivers had significantly more sleep disturbances than did single drivers. A primary cause of these disturbances appeared to be noise and vibration present in the sleeper berth of a moving truck.
4. In general, single drivers were rated as “not drowsy” more often and team drivers, who were rated as “somewhat drowsy” or “moderately drowsy” more often. However, of the 20 “very/extremely drowsy” episodes captured by Observer Ratings of Drowsiness, 16 were from single drivers.
5. Single drivers had many more critical incidents at all levels of severity relative to team drivers.
6. The frequency of critical incidents and driver errors varied significantly by the Hour of Day. However, many more incidents occurred during the afternoon and early evening as opposed to late at night.
7. Single drivers were more alert in the morning and gradually become fatigued during the day, whereas team drivers maintained a relatively constant level of alertness throughout the 24-hour clock.

17. Key Words:
sleeper berth, long-haul, OTR, on the road, CMV, commercial motor vehicle, team drivers, single drivers, fatigue, sleepiness ratings, Nightcap, Karolinska, observer rating of drowsiness, focus groups, sleep schedule, length of trip, collision, driver error, home sleep, road sleep, truck environment, vibration, illumination, noise, temperature, truck design, driver distraction, hours of service

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | LENGTH | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | AREA | | |
| in$^2$ | square inches | 645.2 | square millimeters | mm$^2$ |
| ft$^2$ | square feet | 0.093 | square meters | m$^2$ |
| yd$^2$ | square yards | 0.836 | square meters | m$^2$ |
| ac | acres | 0.405 | hectares | ha |
| mi$^2$ | square miles | 2.59 | square kilometers | km$^2$ |
| | | VOLUME | | |
| fl oz | fluid ounces | 29.57 | milliliters | ml |
| gal | gallons | 3.785 | liters | l |
| ft$^3$ | cubic feet | 0.028 | cubic meters | m$^3$ |
| yd$^3$ | cubic yards | 0.765 | cubic meters | m$^3$ |
| | | MASS | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lbs) | 0.907 | megagrams | Mg |
| | | TEMPERATURE (exact) | | |
| °F | Fahrenheit temperature | 5(F-32)/9 or (F-32)/1.8 | Celsius temperature | °C |
| | | ILLUMINATION | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/m2 | cd/m2 |
| | | FORCE and PRESSURE or STRESS | | |
| lbf | pound-force | 4.45 | newtons | N |
| psi | pound-force per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | LENGTH | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | Yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | AREA | | |
| mm$^2$ | square millimeters | 0.0016 | square inches | in$^2$ |
| m$^2$ | square meters | 10.764 | square feet | ft$^2$ |
| m$^2$ | square meters | 1.195 | square yards | yd$^2$ |
| ha | hectares | 2.47 | acres | ac |
| km$^2$ | square kilometers | 0.386 | square miles | mi$^2$ |
| | | VOLUME | | |
| ml | milliliters | 0.034 | fluid ounces | fl oz |
| l | liters | 0.264 | gallons | gal |
| m$^3$ | cubic meters | 35.71 | cubic feet | ft$^3$ |
| m$^3$ | cubic meters | 1.307 | cubic yards | yd$^3$ |
| | | MASS | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg | megagrams | 1.103 | short tons (2000 lbs) | T |
| | | TEMPERATURE (exact) | | |
| °C | Celsius temperature | 1.8 C + 32 | Fahrenheit temperature | °F |
| | | ILLUMINATION | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/m2 | candela/m2 | 0.2919 | foot-Lamberts | fl |
| | | FORCE and PRESSURE or STRESS | | |
| N | newtons | 0.225 | pound-force | lbf |
| kPa | kilopascals | 0.145 | pound-force per square inch | psi |

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

# EXECUTIVE SUMMARY

## BACKGROUND

Driver fatigue is recognized as a major causal factor in accidents involving long-haul truck drivers. To provide an efficient means to obtain sleep, long-haul truck drivers often use tractors equipped with sleeper berth units. Nonetheless, the quality and quantity of sleep that a driver may obtain in a sleeper berth may not equal that obtained during home sleep. The goal of this project was to assess the impact that sleeper berth usage has on operator alertness.

### Focus Group Findings

To better understand the issues surrounding commercial driver reliance upon in-vehicle sleeper berths for rest, ten focus groups were conducted with long-haul operators (Neale *et al.*, 1998a and 1998b). These focus groups were held in eight cities across seven states to provide a geographically diverse sample of long-haul drivers. For-hire and owner-operator drivers were represented as well as union and non-union drivers. Issues that were explored included factors affecting the quality and quantity of sleep that drivers receive in sleeper berths, drivers' physical and mental fatigue while on the road, and other related safety issues associated with long-haul truck operations where sleeper berths are used. Of particular interest to the goals of this study were the following insights obtained from the focus group interviews:

- Related to team driving:
  - Many drivers can only receive quality sleep in a stationary truck; therefore, team drivers should be selected based on their ability to sleep in a moving truck.
  - If teaming, drivers should be allowed a voice in selecting their driving partner so that drivers are teaming with someone they trust.
  - If teaming, both drivers should know their schedules far enough in advance to allow the drivers to come to a consensus on who will be driving first. This will allow the partner driving first to prepare by getting adequate sleep before departure.
  - Team drivers should be equipped with conventional (as opposed to cabover), air-ride (as opposed to spring-ride) tractors.

- Related to equipment issues:
  - Clean sleeper berths are important for drivers who drive different trucks.
  - Better noise insulation is needed between the cab and sleeper berth. This issue was highlighted by every focus group.
  - Better noise insulation is needed between the inside and outside of the cab.
  - Better thermal insulation is needed for the tractor.
  - Dual escape hatches (on both sides of the sleeper) are needed.
  - A well-maintained air-ride truck provides a less fatiguing ride and is necessary equipment for teaming operations.
  - A conventional, long wheel-base truck (as opposed to a cabover) is necessary equipment for teaming operations.

### Current Study Objectives

Based on the results of the focus group analyses and a literature review (see Neale, 1998a), specific objectives for the study were outlined as follows:

1. Determine the quality and quantity of sleep that truck drivers get in both a stationary and moving sleeper berth relative to home sleep.
2. Determine if any environmental variables (specifically noise, vibration, illumination, and temperature) appear to disrupt sleep.
3. Determine the level of driver alertness for differing types of trips (single versus team), length of shift, shift pattern, and length of trip.
4. Determine the relationship, if any, between the levels of sleep quality and quantity and driver alertness.
5. Determine the level of driving performance, as measured by the frequency and type of triggered critical incidents/driver errors, for differing types of trips (single versus team), length of shift, shift pattern, and length of trip.
6. Determine the relationship, if any, between the level of sleep quality or quantity and the frequency or type of critical incidents/driver errors.
7. Determine the relationship, if any, between the level of driver alertness and the frequency or type of critical incidents/driver errors.

Researchers from the Virginia Tech Transportation Institute (VTTI), the Virginia Tech Department of Industrial and Systems Engineering (VT ISE), and Harvard Medical School teamed to develop the Method and Protocol as described.

## METHOD

### Drivers

The intent of the study was to instrument two Class 8 tractors and loan them to truck drivers and/or trucking companies to carry their own revenue-producing loads. Due to legal reasons related to the licensing, permitting, and insurance process, participating drivers represented for-hire companies only; private drivers and owner-operators were not represented. To ensure that drivers of VTTI’s Class 8 vehicles were not stopped by DOT authorities for seemingly not complying with Motor Carrier regulations, VTTI obtained Motor Carrier Operating Authority, the apportioned (IRP) plates, and motor fuel tax permits. As a standard of practice, the for-hire companies displayed their own Motor Carrier number and fuel tax information when using VTTI’s tractors. The for-hire companies signed a “lease agreement” to use VTTI’s trucks that stipulated what insurance coverage VTTI would provide (covering the instrumentation of the truck) and what insurance coverage the company would provide (all other necessary insurance). A fee was not charged to the company for the lease agreement.

Forty-seven males and nine females participated in this study, constituting 13 teams and 30 single drivers. All drivers who participated in this study were recruited from one of four for-hire commercial trucking companies. Two of these companies hauled primarily perishable items and used refrigerated trailers. The other two companies hauled primarily dry goods and used standard trailers. None of the companies had a union affiliation. The average age of the drivers was 43 years of age (range: 28 through 63 years old) with an average of 13 years of driving experience (range: 1 to 42 years of driving experience).

### Trucks and Instrumentation

The two VTTI-owned tractors included a 1997 Volvo L4 VN-series tractor and a 1995 Peterbilt 379. Functionally identical instrumentation packages and data collection systems were installed in both trucks. The data acquisition system functioned to record four camera views, including the drivers face; driving performance information including steering, lane departure, and braking; sleeper berth environmental data including noise, vibration, and temperature; subjective alertness ratings; and data from the Nightcap sleep system.

Because the data collection runs conducted in the Sleeper Berth project were 6 to 10 days long (up to 240 hours), recording data continuously was infeasible. As such, some method of reducing the bulk of the data without losing information relevant to the goals of the project had to be devised. It was therefore decided to implement a data collection system based on the occurrence of critical incidents and collect vehicle and driver performance data only when specific triggered events occurred.

Driver interaction with the data collection system was minimal. The drivers' only required activities were to: (i) indicate when an unusual critical incident occurred by pressing a button located on the dashboard, (ii) respond to random inquiries as to their subjective feelings of sleepiness by pressing one of nine buttons on a panel mounted on the dashboard, (iii) don the Nightcap sleep monitoring device before going to sleep, (iv) rate their subjective feelings of sleepiness when they woke up by pressing one of nine buttons on a panel mounted in the sleeper berth, and (v) fill out two paper-based surveys each day. No other operation of data collection hardware was required of the drivers. When the drivers were at home, they were also requested to wear the Nightcap sleep monitoring system to collect 2 to 3 nights of home sleep.

### Data Analysis

A critical incident is operationally defined as a measured variable that exhibits a pre-determined "signature" or exceeds a "trigger criterion" that may be indicative of fatigue, lapses in performance, a safety-related external event, or potentially hazardous driving behavior. The system relies upon a set of *a priori* criteria to determine the presence of a critical incident. The types of triggered events for which the data acquisition system installed in the trucks had been programmed included lane deviations and steering deviations. Whenever one of these "triggers" was detected, the video and computer data for a period of time 1.5 minutes before and 0.5 minutes after the trigger event were automatically saved. The cause, contributing factors, and circumstances surrounding the incident could then be determined via post-hoc video analysis. Severity of the trigger was also assessed as being either a "driver error without a hazard present," a "driver error with a hazard present," a "near collision," a "collision," or as being attributable to another driver. Trigger descriptions included information on driver distraction, driver judgment errors, impediments in the roadway, and so forth.

## RESULTS AND DISCUSSION

### Implications for Type of Operation: Singles vs. Teams

Team drivers in this study were generally very successful in avoiding circumstances of extreme drowsiness. Despite evidence pointing to the fact that they get a lower quality of sleep in a moving sleeper berth, team drivers appear to compensate by spending more time sleeping (or at least resting) relative to single drivers, and by utilizing their backup drivers effectively.

Conversely, the findings of this study strongly suggest that single drivers are greatly affected by drowsiness, which in turn compromises their ability to safely operate their vehicles. The benefits of reducing drowsiness are highlighted by the team driving operation. Unlike extremely tired single drivers, who may have felt compelled to continue to drive even when it was dangerous to do so, the individual drivers in a team operation generally had no similar compulsion to operate the vehicle when they were extremely tired. From the data collected in this study, it was apparent that the team driving operation translates into fewer bouts of drowsiness, fewer critical incidents, and, in general, safer trucking operations.

### Implications for Driver Screening, Driver Training, and Fatigue Management

The single drivers in this study had many more critical incidents at all levels of severity as compared to team drivers. This difference was very large at all trigger severity levels. In looking at only the most severe of the critical incidents, over one-half of the incidents were caused by four single drivers. This result is similar to that found by Wylie, et al. (1996). No team driver had more than one severe critical incident.

In addition, single drivers were involved in four times the instances of “very/extremely drowsy” observer ratings than were team drivers. It appeared throughout various analyses of the data in this report that single drivers tended to push themselves to drive on occasions when they were very tired.

In contrast to single drivers, team drivers appeared to drive much less aggressively, make fewer errors, and rely effectively on their relief drivers to avoid instances of extreme drowsiness while driving. In effect, it appears that team drivers undergo a natural “screening” process. This was indicated by a number of the truck drivers during the focus groups conducted earlier in this project. Drivers indicated that team drivers must be both considerate of their resting partner and trustworthy with regard to their driving ability. Thus, the level of “acceptance” necessary to be a successful team driver seems to serve as an effective screening criterion.

Based upon these results, it is recommended that research in the areas of driver screening/monitoring, driver training, and fatigue management be enhanced. Clearly, if systems and procedures could be developed to identify and either screen or rehabilitate the relatively few drivers that account for the greatest risk in trucking, the potential exists for a large positive impact in the trucking industry.

### Hours-of-Service Violations

As found by Wylie *et al.* (1996), there were relatively few instances (about 2.2 percent) of “extreme drowsiness.” Most of these instances were experienced by single drivers, and there was a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive. Thus, it appears to be the combination of long driving times and multiple days that provide the greatest concern. Several results point to the presence of cumulative fatigue; thus, the length of shifts in the later stages of a trip must be carefully considered.

The hours beyond the regulation (i.e., greater than 10 hours of driving in one shift) did not show an increase in critical incidents or driver errors. In fact, there was a substantial decrease in the rate of critical incidents during some of the more extreme violations. However, one should exercise great caution when interpreting these results to mean that the hours-of-service should be expanded. For example, it seems likely that the drivers were making a point to drive more carefully and cautiously *because* they were operating outside of the regulation and did not want to get stopped by law enforcement officials. Alternatively, they may have only risked driving outside of the regulations because they felt alert and knew that they could continue to drive safely. Expanding the permissible driving hours could then reduce safety by driver decision-making with respect to driving longer hours. That is, drivers may not compensate by driving more safely or only when very alert during long drives if the long drives are *legal* in the first place.

### Implications for Sleeper Berth Design

There were a number of findings as part of this study that indicated that the quality and depth of sleep was worse on the road, particularly for team drivers. Team drivers have significantly more sleep disturbances than do single drivers. When the environmental factors were considered, it was found that many of the sleep disturbances that occurred for single drivers could not be attributed to an environmental factor. For team drivers, who sleep while the vehicle is in motion, factors such as vibration and noise affected their sleep. Lighting and temperature aspects of the environment did not appear to be much of a factor.

These findings suggest that while the vehicle was in motion, the noise and motion environment in the sleeper berth degraded the drivers' sleep. This finding has design implications for sleeper berths and indicates that, when the truck is in motion, greater attention should be paid to reducing the amount of vibration and noise that invade the sleeper berth. In particular, more effective noise abatement between the cab and the sleeper berth could improve sleep quality, perhaps relatively inexpensively. Improvement in the vibration/motion environment is a much more difficult problem, but also has potential to improve sleep if practical.

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| ANSI | American National Standards Institute |
| CDL | Commercial Driver’s License |
| DOT | Department of Transportation |
| EEPROM | Electronically Erasable, Programmable, Read-Only Memory |
| ELM | Eyelid Movement |
| IRP | International Registration Plate |
| LTL | Less Than Truck Load |
| *M* | Mean |
| *N* | Sample Size |
| ORD | Observer Rating of Drowsiness |
| OTR | On The Road |
| REM | Rapid Eye Movement |
| *SD* | Standard Deviation |
| SSS | Stanford Sleepiness Scale Visual Analogue Scales |
| VAS | Visual Analogue Scale |
| VTTI | Virginia Tech Transportation Institute |

# INTRODUCTION

Driver fatigue is recognized as a major causal factor in accidents involving long-haul truck drivers. To provide an efficient means to obtain sleep, long-haul truck drivers often use tractors equipped with sleeper berth units. Nonetheless, the quality and quantity of sleep that a driver may obtain in a sleeper berth may not equal that obtained during home sleep.

The goal of this project was to assess the impact that sleeper berth usage has on operator alertness. To better understand the issues surrounding commercial driver reliance upon in-vehicle sleeper berths for rest, ten focus groups were conducted with long-haul operators (Neale, *et al.*, 1998a and 1998b). The results of these focus groups are presented below.

## LONG-HAUL DRIVER FOCUS GROUPS

Ten focus groups were held in eight cities across seven states to provide a geographically diverse sample of long-haul drivers. Issues that were explored included factors affecting the quality and quantity of sleep that drivers receive in sleeper berths, drivers' physical and mental fatigue while on the road, and other related safety issues associated with long-haul truck operations where sleeper berths are used.

### Focus Group Method

Seventy-four drivers, 61 men and 13 women, participated in the focus groups. The drivers ranged in age from 27 to 70 years, with a mean age of 45.5 years (ages were not recorded for 8 of the 74 drivers). Twenty-four union drivers participated, 23 of whom were in a single, union-only focus group. Drivers represented single and team operators, company drivers and owner-operators (who may have been contracted to work with one particular company), and haulers of flat-beds, vans (single, doubles, and triples), refrigerated units, and hazardous materials. Focus groups were conducted between the dates of September 1997 and February 1998 in eight cities: Blacksburg, VA; Albuquerque, NM; Los Angeles, CA; Spokane, WA; Memphis, TN; Iowa City, IA; Cedar Rapids, IA; and Buffalo, NY. Two focus groups were held each in Los Angeles and Spokane for a total of ten focus groups.

Three techniques were used to recruit a representative sample of drivers for participation. The most successful technique was placing an advertisement in local newspapers indicating that over-the-road drivers were needed for a focus group study. A second technique of recruiting drivers was to request the drivers who responded to the advertisement to contact their co-workers if they might be interested. This technique resulted in one of the company-specific focus groups being arranged after a driver volunteered to contact a group of her co-workers. Also, this technique occasionally resulted in team drivers contacting their driving partners for participation. A third technique of recruiting drivers was to "cold call" company managers and request to arrange company-specific focus groups or, at the very least, invite companies to send a "driver representative." This technique resulted in one company-specific focus group being arranged and, in a separate instance, three drivers from one company attending an arranged focus group. The criterion for inclusion in the study was experience as a long-haul truck driver who used the sleeper berth as the sole means of obtaining rest while on the road; in other words, long-haul drivers who slept in hotels were not included.

With each recruitment technique, respondents were told that the focus group was part of a federally-funded study to examine the impact of sleeper berth usage on driver fatigue. It was the perception of the moderator that many of the drivers who chose to participate did so because they thought the focus group would provide a forum for them to voice their concerns about the long-haul trucking industry. In fact, several drivers in different sessions would make comments such as, "You let the people in Washington know that…" Across the groups, a number of similar comments were repeatedly made, indicating that the problems or challenges they described are common to commercial drivers across the country.

During each focus group, great care was taken to ensure an informal, comfortable atmosphere in which the drivers felt at ease to speak candidly. At the beginning of each focus group, drivers were told that the focus group provided the opportunity for the moderators to learn about sleeper berth and related fatigue issues from the drivers. Drivers would often ask, "Do you want to hear the truth or my official answer?" To this, the moderator would reply, "We know what the hours-of-service regulations say, but we'd like to know what really happens." Precautions to protect the drivers' anonymity were clearly expressed by the moderator and documented in the Informed Consent Form (Appendix A). In light of the comments made *in every session* regarding illegal conduct, it was the perception of the moderators that drivers were forthright and honest with their comments.

The template for the interview guide was based upon that used for local/short haul drivers in the study by Hanowski *et al.*, 1999, which was revised to address sleeper berth and related fatigue issues associated with long-haul trucking. The revised interview guide was pre-tested during a pilot focus group with researchers familiar with the long-haul trucking industry, and was subsequently revised again before the first focus group session. Based upon feedback during the sessions, the interview guide also received minor modification after each of the first two focus groups. The interview guide contained questions organized into several broad categories: the design and functionality of the sleeper berth, drivers' sleep/wake cycles at home and on the road, driving duty cycles, recognizing and combating fatigue, time spent at the delivery terminal, and the role of fatigue in accidents and close calls. The drivers were also encouraged to discuss any other issues that they felt affected their ability to obtain rest while on the road.

### Focus Group Results and Discussion

Over the course of the 10 focus groups, drivers discussed issues describing two types of fatigue: physical fatigue caused by lack of both quantity and quality of sleep, and mental fatigue caused by stress factors associated with the job of long-haul trucking. Drivers' recommendations and comments are summarized below.

- Team driving:
  - Many drivers can only receive quality sleep in a stationary truck; therefore, team drivers should be selected based on their ability to sleep in a moving truck.
  - If teaming, drivers should be allowed a voice in selecting their driving partner so that drivers are teaming with someone they trust.
  - If teaming, both drivers should know their schedules far enough in advance to allow the drivers to come to a consensus on who will be driving first. This will allow the partner driving first to prepare by getting adequate sleep before departure.

  - Team drivers should be equipped with conventional (as opposed to cabover), air-ride (as opposed to spring-ride) tractors.

- Equipment issues:
  - Clean sleeper berths are important for drivers who drive different trucks.
  - Better noise insulation is needed between the cab and sleeper berth. This issue was highlighted by every focus group.
  - Better noise insulation is needed between the inside and outside of the cab.
  - Better thermal insulation is needed for the tractor.
  - Dual escape hatches (on both sides of the sleeper) are needed.
  - A well-maintained air-ride truck provides a less fatiguing ride and is necessary equipment for teaming operations.
  - A conventional, long wheel-base truck (as opposed to a cabover) is necessary equipment for teaming operations.

- Facilities:
  - Drivers need rest stops located at regular and adequate intervals.
  - Drivers must be able to find parking at rest areas.
  - Safety measures to protect drivers while parked at rest areas and truck stops should be provided.
  - Many drivers would appreciate the ability to get regular exercise while on the road. Gym facilities at rest and truck stops may be appropriate.
  - Drivers require clean and safe facilities at which to shower.

- Enforcement issues:
  - Consistent enforcement of federal and state regulations should be supported.
  - Trucks should be allowed to drive the same speed limit as private drivers.

- Private driver education:
  - Private drivers should be educated regarding the maneuverability of trucks.
  - Private drivers should be educated regarding how to interact with trucks.

- Terminus Issues:
  - Drivers should be able to sleep while waiting to load and unload without fear of losing their place in line. This issue was highlighted by every focus group.
  - Drivers should always have the option to sleep if they feel it is necessary as opposed to loading or unloading. This issue was highlighted by every focus group.
  - If drivers are loading or unloading a vehicle, equipment necessary to do the task should be provided to them.
  - Drivers should be able to load or unload as scheduled. If this is not possible, drivers should be provided with a place to park so they may use their sleeper to sleep.

- Company and dispatcher issues:
  - Practices that encourage dispatchers to coerce drivers to continue driving if the driver feels he or she must rest should be eliminated. The issue of feeling pressure to drive was highlighted by every focus group.

  - For drivers on call, the company should provide enough notice to drivers to allow drivers to plan and obtain an adequate amount of sleep before going on the road.
  - Drivers should have the time available to stop driving and sleep during particularly fatiguing driving times, which are different for each driver. The fatigue issues associated with driving during particular times of the day were highlighted by every focus group.

- Training issues:
  - The criteria for awarding CDLs should be reviewed.
  - Trainers should be given extra time while working with a trainee so that the truck can be stopped to ensure that both the trainer and trainee get adequate rest.

Other than these comments taken from the focus group sessions, there was another important issue mentioned by drivers. Many of the drivers who participated were paid by the mile only and were not compensated for time working while their truck was not moving (loading and unloading, waiting but required to stay awake, and so forth). Some drivers implied that this method of payment leads to hours-of-service violations and provides an incentive to speed.

For example, most of the drivers commented that it is very difficult to sleep when their trucks are being loaded or unloaded. Some of these drivers openly admitted to sometimes misrepresenting time spent at the terminal as sleeper berth time in order to have more hours available to drive and thus make money. As one driver put it, “You try to keep your logbook as neat and to the letter of the law as possible, but there are times when you didn’t get that eight hours sleep because of all these different factors and you have to….you can’t be showing up to your destination late all the time because of all these things so you have to learn how to live with it…you have to learn how to get the logbooks done so that you’re not going to get fined.”

Regarding speeding, one driver who drove a truck that was not governed said to other members of the same focus group who drove trucks that were governed, “I don’t know how you guys make any money with governors.” The reply from one individual was, “It ain’t easy.”

Similarly, drivers are paid by the mile regardless of the weather. In poor weather, a driver may need to stop and park or drive more slowly (15 to 20 miles per hour). In such situations, drivers lose money. One could hypothesize that this would encourage drivers to make inaccurate logbook entries or increase their speed to make up for the lost time. Either action could be seen as particularly dangerous in light of the fact that driving in poor weather was stated as being particularly fatiguing; therefore, the driver may be driving when seriously impaired by fatigue.

For example, one driver related his experience in dealing with a company he had worked for in the past. “I was working for [*company name deleted*]. Those guys set you a schedule and they don’t care what happens between point A and point B. Those trailers have to be at B regardless and if something happens, you’re responsible for making up the time, whether it’s legal or illegal.” The driver then went on to describe a particular instance in which he had been delayed in poor weather and felt he had to make up the time illegally, even though the experience of driving in poor weather was very fatiguing. Related to this last example, it appears that perceived company policies have a strong effect on the driver's ability to abide by the hours-of-service regulations and obtain sleep while on the road.

Of particular interest to the goals of this study were those issues related to team driving and driving equipment. Based on these results and on a literature review (Neale, et al., 1998a), specific objectives for the study were outlined as follows:

1. Determine the quality and quantity of sleep that truck drivers get in both a stationary and moving sleeper berth relative to home sleep.
2. Determine if any environmental variables (specifically noise, vibration, illumination, and temperature) appear to disrupt sleep.
3. Determine the level of driver alertness for differing types of trips (single versus team), length of shift, shift pattern, and length of trip.
4. Determine the relationship, if any, between the levels of sleep quality and quantity and driver alertness.
5. Determine the level of driving performance, as measured by the frequency and type of triggered critical incidents/driver errors, for differing types of trips (single versus team), length of shift, shift pattern, and length of trip.
6. Determine the relationship, if any, between the level of sleep quality or quantity and the frequency or type of critical incidents/driver errors.
7. Determine the relationship, if any, between the level of driver alertness and the frequency or type of critical incidents/driver errors.

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# METHOD

## TRUCK LICENSING AND LEASE AGREEMENT

The intent of the study was to instrument two Class 8 tractors and loan them to truck drivers and/or trucking companies to carry their own loads. However, there are several licensing and insurance requirements for transporting interstate goods that dictated what type of driver/company could participate in the study. These basic requirements are explained.

The three basic classes of drivers/companies are “private,” for-hire,” and “owner-operator.” A private company is one that transports goods that it manufactures; for example, a driver employed by Pepsi hauling Pepsi products. A for-hire company will transport goods for several customers for a fee. An owner-operator is a driver who owns and drives his or her own truck to carry goods for one or more companies. If hauling for one company exclusively, the owner-operator is called a “contract carrier.”

To transport goods across state lines, all three types of carriers must have Motor Carrier Operating Authority, which entails obtaining a “single state” (interstate) registration and a Motor Carrier number. In addition to this, any vehicle traveling over state lines and weighing more than 26,000 pounds must have an International Registration Plate (IRP) and motor fuel road tax sticker in the carrier’s home state. If the driver is transporting goods into or through New Mexico, Oregon, Idaho, Kentucky, or New York, additional fuel tax permitting is required.

Aside from the licensing and permitting issues, there are requirements for minimum insurance. Since the two Class 8 tractors were owned by Virginia Tech Transportation Institute (VTTI) and there was special instrumentation on-board, and because VTTI did not think it wise legally to provide insurance for the trailer and load of another party, this complicated the matter of insurance coverage.

Therefore, due to legal reasons related to the licensing, permitting, and insurance process, private companies or drivers did not participate in this study, nor did owner-operators. However, for-hire companies and drivers participated. To ensure that drivers of VTTI’s Class 8 vehicles were not stopped by DOT authorities for seemingly not complying with Motor Carrier regulations, VTTI obtained Motor Carrier Operating Authority, the apportioned (IRP) plates, and motor fuel tax permits. As a standard of practice, the for-hire companies displayed their own Motor Carrier number and fuel tax information when using VTTI’s tractors. This made the for-hire companies responsible for reporting all fuel-tax information and paying subsequent fees. The for-hire companies signed a “lease agreement” to use VTTI’s trucks that stipulated what insurance coverage VTTI would provide (covering the instrumentation of the truck) and what insurance coverage the company would provide (all other necessary insurance). A fee was not charged to the company for the lease agreement.

## DRIVERS

Forty-seven males and nine females participated in this study, constituting 13 teams and 30 single drivers. All drivers who participated in this study were recruited from one of four for-hire commercial trucking companies. Two of these companies hauled primarily perishable items and used refrigerated trailers. The other two companies hauled primarily dry goods and used standard trailers. None of the companies had a union affiliation. The average age of the drivers was 43 years of age (range: 28 through 63 years old) with an average of 13 years of driving experience (range: 1 to 42 years of driving experience). Table 1 details other general information about the participants of this study.

## Table 1. Subject information.

| | | Age | Amount of time held Class A CDL (years) | Average length of trip (distance in miles) | Average length of trip (time in days) | Length of breaks between trips (days) | Percent of nights on the road in sleeper berth | How long have you been driving as a team (years) | How long have you been driving with same partner (years) |
|---|---|---|---|---|---|---|---|---|---|
| **Single**<br>**(1=Female; 23= Male)** | **AVERAGE** | 44.5 | 15.1 | 2076.9 | 5.0 | 3.4 | 82% | | |
| | **ST DEV** | 11.2 | 10.6 | 1955.0 | 3.3 | 7.0 | 49% | | |
| | **MIN** | 25.0 | 1.0 | 300.0 | 0.0 | 0.0 | 0% | | |
| | **MAX** | 63.0 | 42.0 | 6735.0 | 14.0 | 36.0 | 250% | | |
| **Team**<br>**(5=Female; 12= Male)** | **AVERAGE** | 39.6 | 10.6 | 3156.5 | 7.1 | 2.2 | 44% | 4.0 | 2.2 |
| | **ST DEV** | 8.9 | 9.9 | 2453.9 | 11.2 | 1.7 | 33% | 5.2 | 2.9 |
| | **MIN** | 28.0 | 1.0 | 360.0 | 0.0 | 0.0 | 0% | 0.0 | 0.0 |
| | **MAX** | 63.0 | 40.0 | 6400.0 | 35.0 | 5.5 | 100% | 20.0 | 7.0 |

| | Haul dry goods | Haul perishables | Drive regular schedule | Drive irregular schedule | Unload own trailer 1 or more times during study |
|---|---|---|---|---|---|
| **Single (1= Female; 23= Male)** | 72% | 28% | 12.5% | 87.5% | 36%* |
| **Team (5=Female; 12= Male)** | 59% | 41% | 29.40% | 70.6% | 13%** |

* This number reflects 17 of 173 driving days (9.8%) in which loading or unloading was a factor for single drivers.
** This number reflects 4 of 192 driving days (2%) in which loading or unloading was a factor for team drivers.

## TRUCK INSTRUMENTATION

The drivers used two VTTI-owned tractors while hauling their normal cargo on regularly-scheduled revenue-producing runs to perform the data collection. These tractors included a 1997 Volvo L4 VN-series tractor and a 1995 Peterbilt 379, shown in Figure 1. Functionally identical instrumentation packages and data collection systems were installed in both trucks.

**Figure 1. VTTI's two Class 8 tractors used in the Sleeper-Berth study.**

### Critical Incident Method

Instrumentation systems implemented in other VTTI research vehicles (Collins, Neale, and Dingus, 1999; Hanowski, Dingus, Gallagher, Kieliszewski, and Neale, 1999; Wierwille and Hanowski, 1998) and in the Volvo tractor (Winters, 1998) for other research projects recorded data continuously throughout the experimental trials. Such trials were typically on the order of 15 minutes to 10 hours in length. Because the data collection runs conducted in the Sleeper Berth project were 6 to 10 days long (up to 240 hours), recording data continuously was infeasible given project resources. As such, some method of reducing the bulk of the data without losing information relevant to the goals of the project had to be devised. It was therefore decided to implement a data collection system based on the occurrence of critical incidents and collect vehicle and driver performance data only when specific triggered events occurred.

A critical incident is operationally defined as a measured variable that exhibits a pre-determined "signature" or exceeds a "trigger criterion" that may be indicative of fatigue, lapses in performance, a safety-related external event, or potentially hazardous driving behavior. The system relies upon a set of *a priori* criteria to determine the presence of a critical incident. The types of triggered events for which the data acquisition system installed in the trucks had been programmed are shown in Table 2. Values listed were determined experimentally. Whenever one of these "triggers" was detected, the video and computer data for a period of time 1.5 minutes before and 0.5 minutes after the trigger event were automatically saved. The cause, contributing factors, and circumstances surrounding the incident could then be determined via post-hoc analysis.

**Table 2. Trigger types and descriptions.**

| Trigger Type | Description |
|---|---|
| Steering | Driver turned steering wheel faster than 3.64 radians/sec. |
| Lateral acceleration | Lateral motion equal or greater than 0.3 g. |
| Longitudinal acceleration | Acceleration or deceleration equal or greater than 0.25 g. |
| Critical Incident Button | Activated by the driver upon pressing a button located on the dashboard when an incident occurred that he/she deemed critical. |
| Lane Deviation | Activated if the driver crossed the solid lane border (Boolean occurrence). |
| Time-to-Collision | Activated if the driver followed the preceding vehicle at a closing rate of 4 seconds or less. |
| Perclos | Activated if the Perclos monitor detected that eyes were closed 8.0% of any given one minute period. |
| Karolinska Sleepiness Rating | Activated if driver subjectively assessed own drowsiness as extremely fatigued/difficult to stay awake (rating of 7 or above on sleepiness scale). |
| Karolinska Sleepiness Rating, No Response | Activated if the driver did not respond to the Karolinska rating query. |
| Timed Trigger | Baseline data for which the data collection system triggered randomly every 45 to 75 minutes. |
| Lane Departure and Steering | Activated if a lane departure (tractor crossed a lane line) was immediately followed by a steering event. Disabled in turn signal was activated. |

### The Data Acquisition System

The data acquisition system was created by the VTTI Hardware Engineering Laboratory. Any commercial off-the-shelf components that were integrated into the instrumentation package are specifically noted in the following system description.

The core of the data acquisition system was a Pentium-based laptop computer. The computer ran custom data acquisition software and communicated with a distributed data acquisition network. Each node on the network contained an independently programmable micro-controller capable of controlling or measuring a large number of signals. This system configuration maximized flexibility while minimizing the physical size of the system. Although capable of being expanded to include 120 nodes, the trucks were configured with 10 nodes. A schematic representation of the system appears in Figure 2.

Each node contained an electronically erasable, programmable, read-only memory (EEPROM), within which were stored the calibration factors for each sensor/device linked to that node. All nodes communicated with the host computer via a high-bandwidth, long-distance, noise-immune serial interface. Set at 10 Hz, the system was programmable for data collection rates from 1 Hz to 30 Hz via a crystal oscillator.

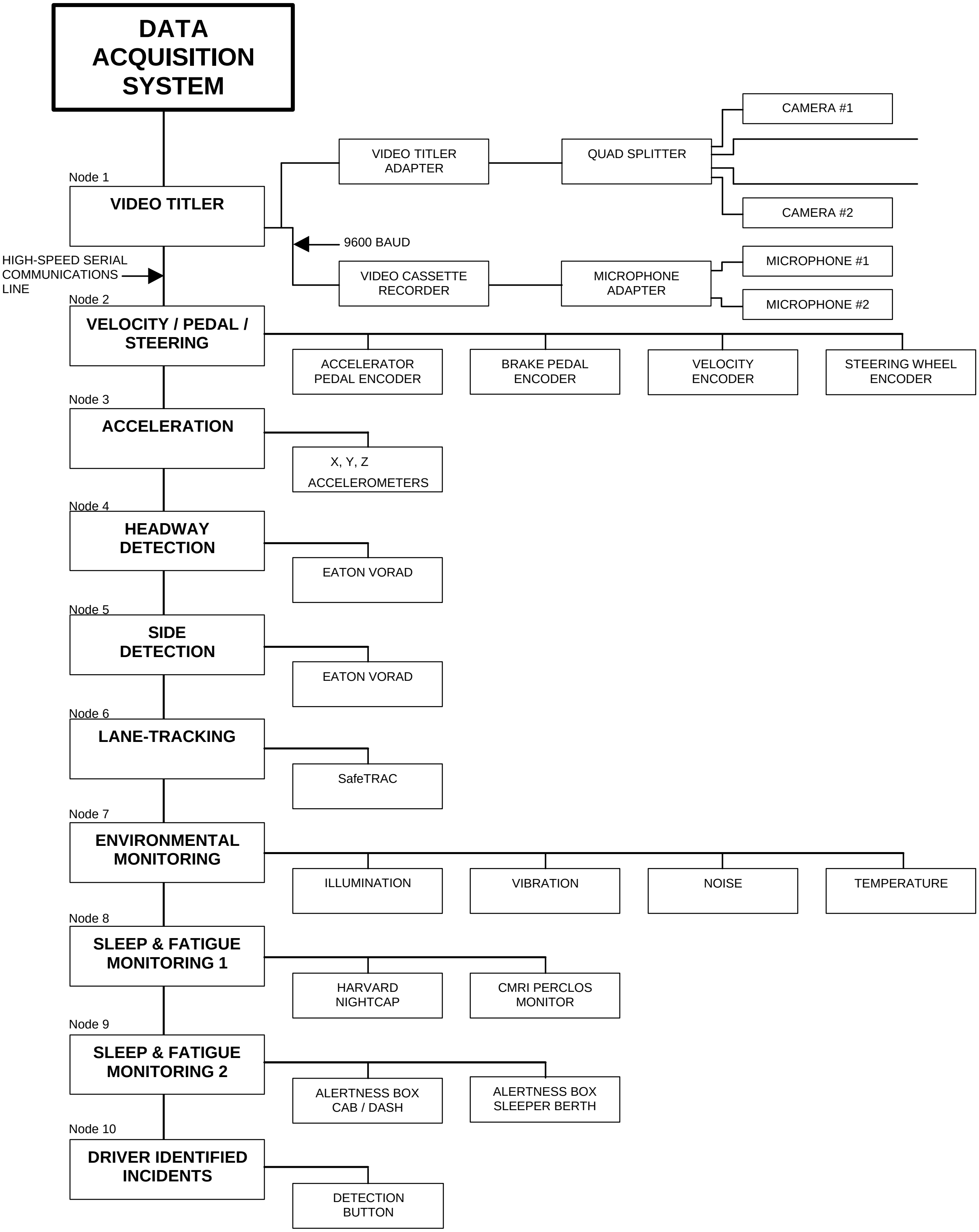


**Figure 2. Schematic representation of the instrumentation package installed in VTTI's tractors.**

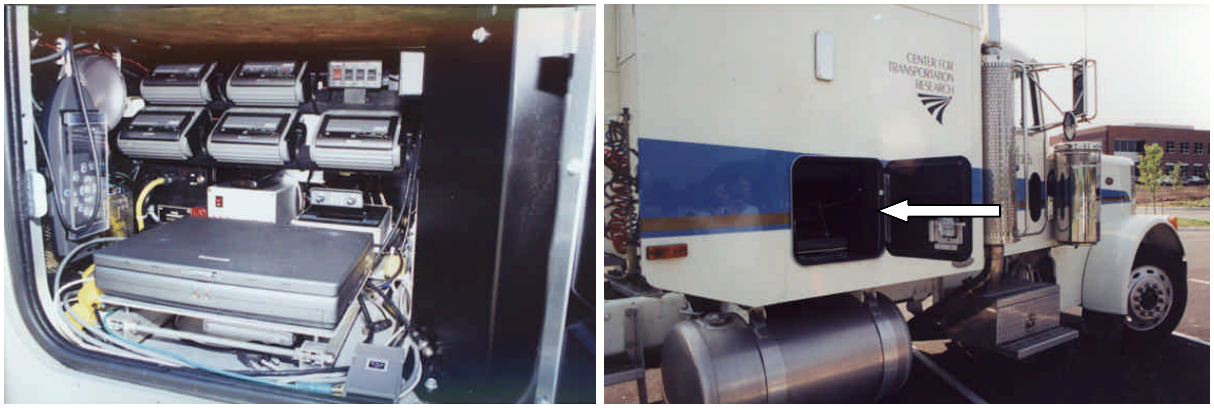
A power inverter supplied the data collection equipment with power from the truck batteries. The total system required less than 150 watts of power and did not draw sufficient current to damage or drain the batteries. No additional power sources (e.g., generators) were required as part of the data collection hardware.

While the truck was in motion, the video, vehicle/driver performance, environmental, and sleep monitoring subsystems were all operational. During extended periods of inactivity, selected subsystems were deactivated. The system automatically switched between modes when it detected inactivity on the velocity, steering, and brake pedal measures and resumed when activity was again detected.

The small size of the individual components used in the data acquisition systems allowed them to be inconspicuously located out of sight of both the driver and a casual observer. This minimized intrusions into the driving task, which resulted in the observation of more natural behavior. This would otherwise not be possible if the driver was constantly reminded that he/she was being observed. For example, the bulk of the data acquisition system including the computer, VCRs, sound level meter, and most of the supporting electronics were concealed in locked compartments under the bunks in the sleeper berths of both trucks (Figures 3 and 4). The only devices visible to the drivers were the Perclos monitor, sleep scale, and the critical-incident pushbutton installed on the trucks' instrument panels as shown in Figure 5.

Driver interaction with the data collection system was minimal. The drivers' only required activities were to: (i) indicate when an unusual critical incident occurred by pressing a button located on the dashboard, (ii) respond to random inquiries as to their subjective feelings of sleepiness by pressing one of nine buttons on a panel mounted on the dashboard, (iii) don the sleep monitoring device before going to sleep, (iv) rate their subjective feelings of sleepiness when they woke up by pressing one of nine buttons on a panel mounted in the sleeper berth, and (v) fill out two paper-based surveys each day. No other operation of data collection hardware was required of the drivers.

**Figure 3. Instrumentation concealed under the bunk in the Volvo. Access was gained from inside the sleeper berth by lifting the mattress platform.**



(a) Instrumentation (b) Access Panel

**Figure 4. Instrumentation concealed under the bunk in the Peterbilt (a). Access was gained from outside the cab through a pre-existing access panel (b).**

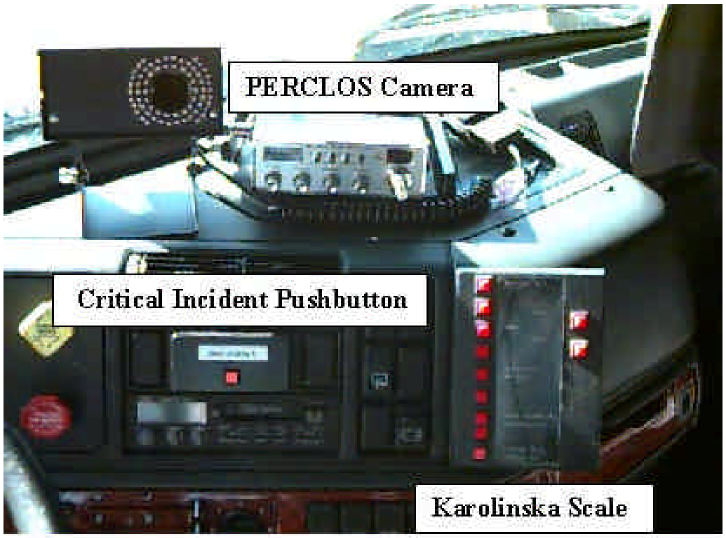


**Figure 5. A view of the Volvo dashboard showing the only instrumentation visible to the driver.**

*Video Subsystem– Node 1*

The first node in the instrumentation system was a serial interface node. This node converted the high-speed serial interface on the distributed data acquisition network to control a video titler. Next were three VCR controllers capable of managing four VCRs, each via a one-wire control L network. The tractors were wired for up to nine cameras (although only four were used in the study) and two microphones. The video cameras were strategically located to observe the driver’s face, the road scene ahead of the truck, and the view down either side of the tractor. The video stream was passed through a video titler where a video frame number was added to the multiplexed video image. (A video frame number was also written to each line of the data file recorded by the data-acquisition computer for subsequent synchronization with the video.) This multiplexed video signal (Figure 6) and the audio signals from the two microphones were then passed to a bank of VCRs that made up the real-time triggered event recording system. Each time a triggered event was detected (Table 2), 1.5 minutes of video preceding the event and 0.5 minute of video following the event (a total of two minutes of video) were saved in real time on the triggered event VCRs. For nighttime video data collection, infrared (non-visible spectrum) LEDs lighted the truck cab without being detectable by the driver(s).

The video cameras themselves were extremely small, measuring only 1.15 inches square and 0.25 inches thick and requiring only a 0.03125 inch diameter aperture through which to view the desired scene, and were placed out of sight of the driver. In both trucks, the camera observing the driver's face was concealed under the Perclos monitor. In the Volvo, the cameras used to observe the scenes down each side of the tractor were concealed *within* the side mirror assemblies. On the Peterbilt, the side-view cameras were mounted beneath the air breather cans located just behind the front fenders.

**Figure 6. Multiplexed image showing the scenes observed by the four strategically-located video cameras (clockwise from upper left): the scene ahead of the truck, the driver's face (obscured here to preserve the driver's anonymity), and the views down the left and right sides of the tractor. The letters on the left are critical incident codes (S: steering, T: time-to-collision) while the numbers on the right are video frame numbers used to synchronize the video and computer data.**

*Vehicle/Driver Performance Subsystems - Nodes 2 through 6*

Nodes 2 through 6 monitored various vehicle- and driver-related performance measures. The second node was a general input node used to measure vehicle velocity and pedal position as well as steering wheel velocity and position. Vehicle velocity was measured via a speed pickup sensor on the transmission. Brake and accelerator pedal positions, as well as steering wheel position, were measured using string potentiometers. Abrupt steering wheel movements, measured by an absolute optical encoder, were used to trigger critical incidents.

The third node on the system was the acceleration measurement node. This node measured the lateral, longitudinal, and vertical accelerations experienced by the tractor. The triaxial accelerometers were place in the center of the cab, left to right, about 45 cm up from the floor board in the dash. The operating range of these devices was 100 Hz. Excessive acceleration (lateral or longitudinal) was also used as a critical incident trigger.

A radar-based front-to-rear crash-avoidance sensor, Figure 7(a), was installed as the fourth node for the purpose of using time-to-collision with a forward vehicle as a trigger criterion. Eaton-Vorad radar sensors were modified to integrate into the data collection systems on the tractors. The factory default sensor settings were maintained throughout the study. Using time-to-forward-collision as a trigger criterion provided a second longitudinal measure in addition to longitudinal deceleration. Similar sensors, Figure 7(b), were also used as side clearance detectors, installed as the fifth node.

(a) Headway Sensor (b) Side Clearance Sensor

**Figure 7. Eaton Vorad headway sensor (a) and side clearance sensor (b) mounted on the Peterbilt.**

Node 6 interfaced with a lane-tracking device (SafeTRAC) based on forward-looking machine vision technology, which provided a recording of lane position. AssistWare Technology, in cooperation with Carnegie Mellon University, developed the SafeTRAC system for estimating the lateral position of a vehicle in its lane and the curvature of the road ahead. The SafeTRAC uses the same technology that Carnegie Mellon developed for use as part of the National Automated Highway System Consortium demonstration, which allowed Carnegie Mellon personnel to drive coast-to-coast under automated lateral control 97 percent of the time. (It should be noted that while Carnegie Mellon used this system for vehicle control, the current research effort used it only for position measurement/tracking.) The SafeTRAC camera and interface unit are shown in Figure 8. All of the SafeTRAC components are small and were mounted so that they were out of sight of the driver.

**Figure 8. The SafeTRAC system by AssistWare Technology.**

The SafeTRAC allows measurements of position in the lane during critical incidents, as well as deviations out of the lane. An unintended lane deviation was used as a trigger criterion. The trigger occurred when any part of the vehicle exceeded a lane boundary by a predetermined amount either to the right or left, *and* a lane change was not completed as part of the process. The resolution of the SafeTRAC system and the transducers used in nodes 2 through 5 are presented in Table 3.

**Table 3. Transducer resolution for driver/vehicle performance measures.**

| **Variable** | **Resolution** |
|---|---|
| Lane Position (SafeTRAC) | ± 5 cm |
| Steering Wheel Position | ± 1 degree |
| Normalized Accelerator Position | ± 1 % of Normalized Range (0 to 1) |
| Normalized Brake Position | ± 1 % of Normalized Range (0 to 1) |
| Velocity | ± 1 mph |
| Acceleration of Cab (in horizontal plane) | ± 0.01 g |

*Environmental Monitoring Subsystem – Node 7*

The seventh node was dedicated to sampling environmental variables: noise, vibration, temperature, and illumination. Unlike the measures discussed previously, the environmental variables were not used to trigger critical incidents. Instead, the data were collected continuously whenever a driver was sleeping in the sleeper berth. The resulting data were then compared to the sleep data to determine if and how these environmental variables correlated with sleep quality and quantity.

Noise

A Larson-Davis 824 real-time spectrum analyzer was installed in each truck. This portable instrument is intended for field applications and meets the requirements for a Type 1 device as specified in ANSI S1.4 (1983), with filters meeting the appropriate requirements of ANSI S1.11 (1986). The microphones were located in the trucks' sleeper berths inside acoustically transparent enclosures (an open framework covered in speaker cloth) as shown in Figure 9. The 824 is unique in that it allows the spectral data (octave band levels) to be downloaded by a computer while it is simultaneously performing a measurement. The instrument was configured to continuously record the Leq sound pressure level. Every minute the data acquisition computer downloaded the octave band Leq and Lmax data and reset the instrument to begin a new measurement.

The resulting dependent measures consisted of the 1-minute octave band Leq and Lmax levels (in dB) for the octave bands centered from 63 to 8,000 Hz. Broadband levels (both linear, dB, and A-weighted, dBA) could be easily calculated from the octave band data. Subsequent statistical analyses (regression, correlation, ANOVA, etc.) were performed using both broadband and band-limited data. For example, it may have been discovered that sleep disturbances were highly correlated with the SPL level in only one band, yet had little or no correlation with the broadband SPL. Because only spectral data were being measured and recorded, it was not possible to identify the specific source of any transient noise peaks.

**Figure 9. Acoustically transparent microphone enclosure located above the bed in the Volvo sleeper berth.**

<u>Vibration</u>

The degree to which the vibration that drivers experienced while in the sleeper berth affected their quality and quantity of sleep was of interest. The goal was to collect vibration measurements in a manner that was unobtrusive to the driver while he or she was sleeping, yet provide a sufficient level of detail for interpretation of the problem frequencies and amplitudes. As such, both spectral and intensity data of the vibration were required.

Vibration experienced while lying on a mattress in a sleeper berth is "whole-body" vibration, that is, vibration transmitted to the body as a whole through the supporting surfaces of the body (i.e., feet, buttocks, back, and so forth). The amount of mechanical impedance due to vibration is dependent on body position and muscle contractions. In other words, the transmission of a vibration of a particular frequency and amplitude to the body is different in someone lying on his/her back as opposed to someone lying on his/her side.

In whole-body vibration research, attenuated frequencies in the range of 1 to 80 Hz are the most interesting since this is the range of resonating frequencies within the body. However, for investigating the effects of vibration on the quality and quantity of sleep, it may have been that a particular frequency did not meet a resonating frequency of the body, but was disruptive to the driver. For example, a frequency of 125 Hz is not a resonating frequency of any internal organ or bone structure, but it is disruptive when felt at the head and shoulders while trying to sleep. Therefore, the goal was to measure the range of frequencies that disrupted sleep. Based upon our calculations of the vibrations that can be produced inside a tractor cab, we concluded that vibrations produced in octave bands with center frequencies of 16 Hz, 31.5 Hz, 63 Hz, 125 Hz, and 250 Hz should be evaluated. These octave band center frequencies are standard for the vibration measurement industry.

Three triaxial piezoelectric accelerometers were installed in each truck's mattress at the head, trunk, and feet. The accelerometers were sampled at a rate of 1 kHz, with the peak and average amplitudes stored each minute for each of the octave bands mentioned above. These data were later correlated with sleep quality measures to determine the effect of vibration on sleep quality.

### Temperature

During the focus groups, many drivers commented about the poor thermal insulation of the sleeper area. As such, the temperature in the sleeper berth was measured in order to determine the degree to which temperature affected sleep quality and quantity. Solid state temperature sensors measuring the "dry-bulb" ambient air temperature in the sleeper berth were interfaced to the data acquisition system and sampled at a rate of 10 Hz. The thermometer was mounted inside the wall about 45 cm above the sleeping person's head (see Figure 10). Each minute the average temperature for the preceding one-minute interval was calculated and saved. Subsequent analyses would determine the degree to which temperature and temperature fluctuation correlated with driving performance as well as objective and subjective measures of sleep quality.

### Illumination

It was also learned during the focus groups that high ambient light levels and fluctuating light in the sleeper compartment prevented many drivers from obtaining adequate sleep. Therefore, illumination in the sleeper compartment was measured during the on-road experiment in order to correlate the data with sleep quality and quantity.

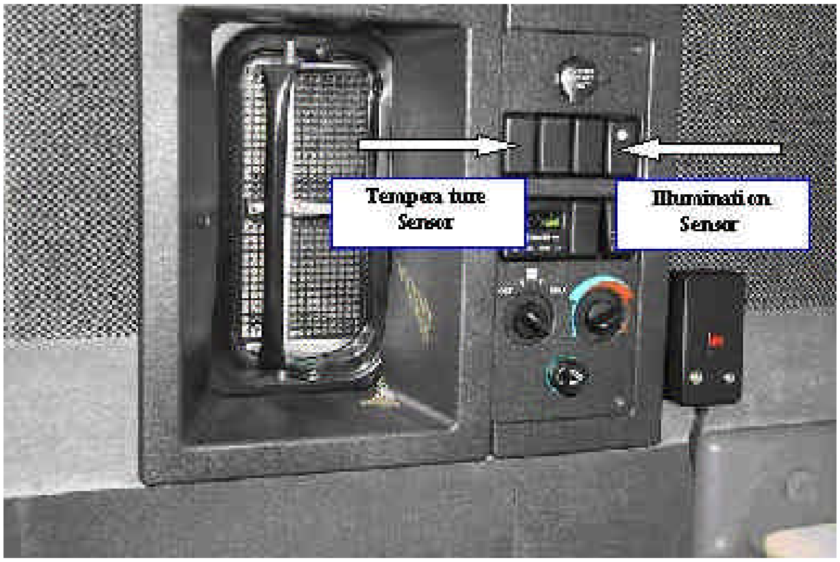


**Figure 10. Location of the illumination and temperature sensors in the Volvo sleeper berth.**

A low-cost (approximately $100) ambient illumination sensor, currently in use in a study investigating driver performance issues in the local/short haul industry (Wierwille and Hanowski, 1998), was developed by VTTI personnel, Figure 11. In this device, a photosensitive transducer is mounted inside a small enclosure and directed toward the interior of the enclosure to minimize the effects of glare. The entire unit was secured inside the sleeper berth in a location near the sleeping driver's head. Sampled at a rate of 10 Hz, the sensor was programmed to distinguish five levels of illumination: total darkness to intense full sunlight (as measured in the sleeper berth). The software was also modified to record transitions from light to dark and dark to light. This allowed for recording fluctuations in illumination that occur in a moving vehicle (when the truck passes under an overpass or through a tunnel) or a parked vehicle (due to the headlights from passing vehicles). The dependent measures obtained were level transitions and intensity readings of the illumination measured over 1-minute periods. The locations of the illumination sensor and the temperature sensor, as they were installed in the Volvo sleeper berth, are shown in Figure 10.

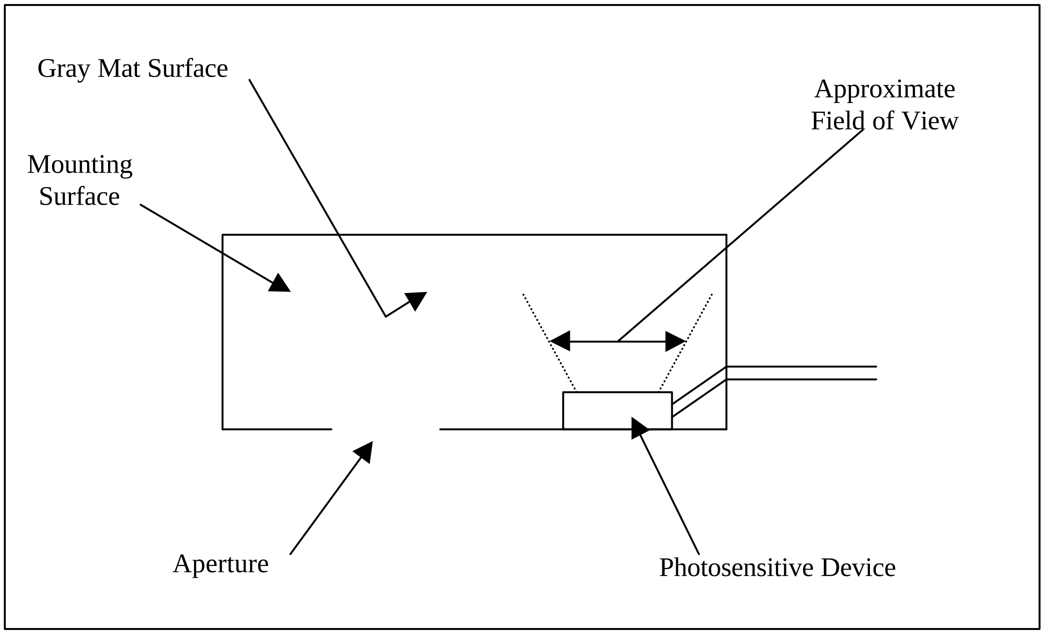


**Figure 11. Sketch of ambient illumination sensor (approximately 3.81 cm long).**

*Sleep and Fatigue Monitoring Subsystems– Nodes 8 and 9*

The eighth node was dedicated to collecting sleep and fatigue measures by using the Nightcap and an infrared eye closure monitoring system (Perclos: Skipper and Wierwille, 1986) developed by the Carnegie Mellon Research Institute. The ninth node collected data relating to the drivers' subjective feelings of sleepiness using keypads located on the dashboards and in the sleeper berths.

Nightcap

The Nightcap (Ajilore *et al.*, 1995; Stickgold *et al.*, 1999) is a two-channel recording device that distinguishes wake, REM sleep, and non-REM sleep and offers simple, safe, inexpensive, non-intrusive, ambulatory sleep monitoring. One channel of the Nightcap monitors eyelid movement and consists of an adhesive-backed piezoelectric film, which is applied to the upper eyelid and detects movements of the eye and lid without restricting eye movement. The other sensor is a cylindrical, multipolar mercury switch capable of detecting head movements. These sensors were connected by 1-meter cables directly to the each truck's data acquisition system via a small interface unit, Figure 12. (For home sleep measurements, the sensors were connected to a separate data acquisition unit: a 7 cm x 11.5 cm x 2.5 cm case containing signal detectors, A/D converters, a clock, an RS-232 serial port for downloading data, and a microprocessor with 32 Kbyte of RAM powered by an internal 9-V battery.) The Nightcap's two sensor signals are produced by deformation of the eyelid sensor's flexible piezoelectric film, Figure 13, and by the shifting of a mercury droplet within the head movement sensor. The Nightcap required approximately fifteen minutes of training and three minutes to self-apply; it enabled detection and collection of a variety of sleep quality parameters such as time of day slept, sleep duration, sleep latency, and sleep efficiency (Stickgold *et al.*, 1999). Activation of the Nightcap system by the driver also initiated the recording of the environmental data discussed earlier. In order to obtain baseline sleep quality data for comparison to the sleeper berth data, two to three nights of Nightcap data were collected from the drivers in their normal sleeping environment.

**Figure 12. Nightcap interface unit located in the Volvo sleeper berth.**

**Figure 13. Nightcap eyelid movement sensor.**

Perclos Monitor

To fulfill the objective of determining the effects of variations in sleep quality on driving performance and/or potentially unsafe driving behavior, it was important to assess driver alertness while driving. To this end, it was decided to use the Perclos alertness monitoring system developed by the Carnegie Mellon Research Institute under contract with the National Highway Traffic Safety Administration. Perclos was developed by Wierwille and his colleagues (Wierwille, 1994) as a measure of drowsiness associated with the degradation of driving performance in a simulated roadway environment. The Perclos system monitors eyelid position through the use of infrared light and machine vision technology to locate and assess the relative size of the driver's corneal reflection (Grace, et al., 1999). A substantial advantage to this approach was that the driver did not have to wear any sensors or devices.

With the Perclos system, it was possible to use driver alertness as a trigger criterion just like the driving performance measures described previously. That is, if the device indicated that the driver was in a less-than-alert state, the video and computer data were saved for a period of time both before and after the trigger event.

### Subjective Sleepiness

The Karolinska Sleepiness Scale (Table 4) was chosen in preference to other popular sleepiness scales such as the Stanford Sleepiness Scale (SSS) and the Visual Analogue Scales (VAS) for a number of reasons related to the restrictions of a field study environment. Space limitations on and near the response buttons within the tractor cab would not accommodate the wordy SSS, and if the scale descriptors were shortened, the scale would have to be completely revalidated. Despite the popularity of the Stanford Sleepiness Scale, its validity has recently been questioned. In recent studies, the SSS exhibited poor correlation with either performance measures or sleep latency measures obtained using the multiple sleep latency test (Johnson *et al.*, 1991; Herscovitch and Broughton, 1981). The use of a knob or slider for implementation of the VAS was also considered, but this would have allowed the drivers to track their previous responses, which could have affected their subsequent responses. Furthermore, use of the VAS in isolation without concurrent use of other scales is not recommended (Brunier and Graydon, 1996). Other more rigorous and lengthy scales (e.g. Fatigue Severity Scales, and Epworth Sleepiness Scales) were discounted due their use of multiple scales. Such scales are too impractical and dangerous to implement in a driving environment.

**Table 4. Karolinska Sleepiness Scale.**

| |
|---|
| 1) Extremely alert |
| 2) |
| 3) Alert |
| 4) |
| 5) Neither alert nor sleepy |
| 6) |
| 7) Sleepy – but no difficulty remaining awake |
| 8) |
| 9) Extremely sleepy – fighting sleep |

The Karolinska Scale has been used successfully to measure absolute levels of sleepiness and has been found to be strongly related to EEG and electrooculogram signs of sleepiness and be highly correlated with reaction times in vigilance tasks (Gilberg, Kecklund, and Akerstedt, 1994). This particular scale has also been found to be highly correlated with the results of other, more rigorous and lengthy subjective sleepiness scales (Gilberg, Kecklund, and Akerstedt, 1994; Akerstedt and Gilberg, 1990).

A bank of nine switches, Figure 14(a), where each switch corresponded to one of the nine ratings used in the Karolinska Sleepiness Scale (KSS: Gilberg, Kecklund, and Akerstedt, 1994), was placed within easy reach of the driver.  A second set of identical switches was placed in the sleeper berth, Figure 14(b).  Randomly, every 45 to 75 minutes, the driver was prompted to rate his subjective feelings of sleepiness by pressing the appropriate switch.  A critical incident was triggered if the driver pressed the switches corresponding to level 7 or above.  Drivers were also requested to use the switches located in the sleeper berth before they went to sleep (even for a short nap) and when they woke up.

(a) (b)

**Figure 14.  The Karolinska Sleepiness Scale as implemented in the trucks.**

*Driver Identified Critical Incidents– Node 10*

A pushbutton (node 10) was mounted on the dashboard of each truck so that the drivers could activate it if they experienced a critical incident. This system acted as a redundant cue to trigger the data collection system in the event that the driver detected some kind of critical or unusual incident that did not have a "signature" that was detectable by the system. The drivers were instructed how and when to use this device prior to their trips. The incident detection box included an audio channel that became active when the incident button was pressed, allowing the driver to give a verbal description of the event. The location of this switch in the Volvo is illustrated in Figure 15. (Also note the location of the Perclos camera and the Karolinska response box.)

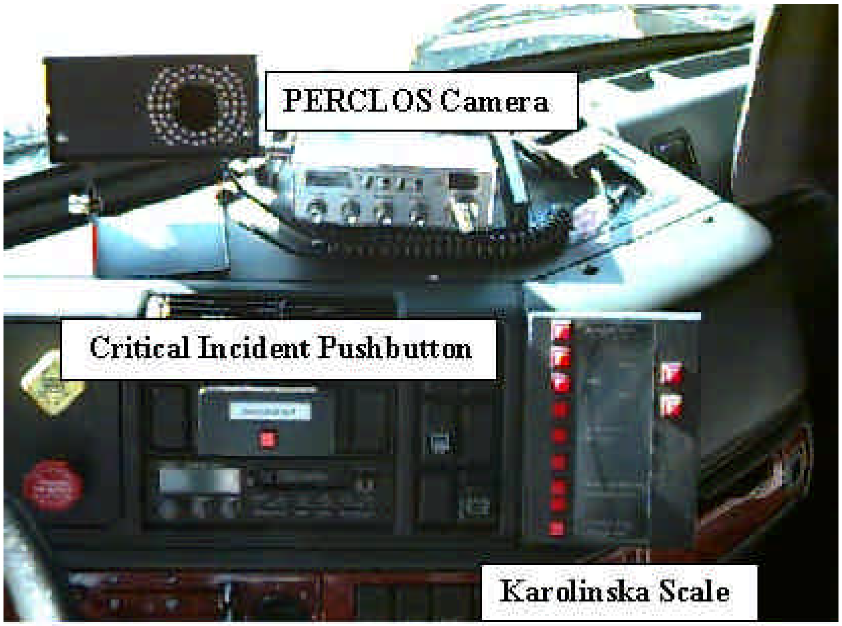


**Figure 15. A view of the Volvo dashboard showing the locations of the pushbutton used to trigger driver-initiated critical incidents, the Karolinska sleepiness scale, and the Perclos camera.**

## Training the Drivers

For each driver, the following training materials were prepared:

- Paperwork:
    - Two informed consent forms.
    - One W-9 tax form.
    - One cell phone use agreement form.
    - One General Information Survey.
    - Approximately 10 Once-a-Day Surveys.
    - Approximately 20 Wake-up Surveys.
    - Approximately 30 Activity Log forms.

- Sleep Materials:
    - Nightcap for the truck (OTR Nightcap).
    - Approximately 10 eyesensors.
    - Approximately 10 ground connectors.
    - Nightcap for homesleep.
    - Two homesleep data collection units (0.6v & 2.5v).
    - Homesleep paperwork (six paper Karolinska rating forms and three Wake-up Surveys).

Prior to soliciting driver participation, human-use approval was obtained. All drivers were trained prior to participation in this study. An experimenter met with each driver prior to participation to present detailed instructions on tasks, procedures, and an orientation of the heavy vehicle. When meeting with the subjects, the experimenter initially gave a brief overview of the study, informed the drivers the nature of the study, and gave them an option to withdraw from participating. After the drivers verbally agreed to participate, the experimenter asked the drivers to read and sign an informed consent form (Appendix A), a W-9 tax form, and a cellular phone use agreement form.

The informed consent form outlined the payment method for participation. Drivers were paid $500 for participating. In addition, drivers who completed their surveys and were diligent about using the Nightcap were given a $100 bonus. Drivers were also paid $10 per night for up to three nights of home sleep data. Therefore, drivers were eligible for up to $630. This amount was separate from, and not related to, their regular company payment amount.

Secondly, the experimenter presented each driver with a three-ring binder containing phone numbers, instructions, and questionnaires that were required to be filled out during the trip. There were four questionnaires that all drivers were instructed to complete while they were on the road: a General Information Survey, Once-a-Day Survey, Wake-up Survey, and Activity Log (Appendix A). The General Information Survey was filled out one time only and requested information about the driver's age, type of driver's license and endorsements, years of experience, and any medical history of sleep disorders and/or medications that could impact sleep efficiency or alertness levels. The Once-a-Day Survey, completed each day of the trip, queried drivers about workload, frustration, effort level, time pressure, etc. for each day of their trip in order to get a measure of workload and stress. The Wake-up Survey, completed every time the drivers woke up from either a nap or a full-night of sleep, queried the drivers as to the time they fell asleep and what time they woke up, as well as instructed them to rate their sleep quality. The activity log was a log of the drivers' activities during their trip. The only activities of interest were whether the drivers were driving, sleeping, resting but performing work related activities (which is "on duty not driving" time), or resting but not sleeping. Whenever the drivers changed activities, they were required to enter the time the activity began and the time it ended throughout the duration of their trip.

Third, the experimenter demonstrated the use of the Nightcap and showed the drivers how to attach the eye sensor and ground connector to the Nightcap, fasten the Nightcap to their head, adhere the eye sensor(s) to their eyelid/ground connector to their cheek, and plug the Nightcap into the data collection system for on-the-road data as well as home sleep data. As part of this demonstration, the experimenter placed the Nightcap on her head, showing the drivers how the head tracker should lie flat against the forehead, the eye sensor should have plenty of slack when applied properly, and the ground connector could be applied anywhere on the face that would allow some slack in the sensor cable. The experimenter also demonstrated the homesleep Nightcap, pointing out that the homesleep Nightcap required the drivers to place eye sensors on both eyes, connect cable to two Nightcap data collection systems, and turn both Nightcap systems on when they were ready to fall asleep.

After all questions were answered about the questionnaires and the Nightcaps, the experimenter took the drivers to the truck to give them an orientation of the truck cab. The shifting pattern, 5th wheel controls, and other specifics about each truck were briefly discussed with each driver. The critical incident button, Perclos monitor, and Karolinska box were discussed, and the drivers' interactions with these units were detailed. The drivers were also shown the Karolinska box in the sleeper berth as well as the Nightcap box so that they knew where to plug the Nightcap in and how to rate their alertness before and after waking up.

After the subject orientation was complete, the experimenter answered all questions and excused the drivers while she turned on the data collection system and ran a diagnostic program on the data collection system to ensure it was working properly.

The entire training procedure lasted approximately 60 to 90 minutes. Generally, drivers began their on-the-road portion of the study immediately following training; however, there were several cases where the drivers completed the home sleep portion first and the on-the-road portion second. If the drivers were unsure about when they were leaving, they were instructed that the nights of home sleep need not be consecutive; therefore in a few cases, the drivers performed one or two nights of home sleep prior to the on-the-road portion of the study and completed their home sleep afterward. There were only a few cases where home sleep data were collected in the middle of the on-the-road portion of data collection.

## DATA COLLECTION OVERVIEW AND LESSONS LEARNED

### Logistics

The data collection process was logistically complex and required a considerable organizational effort to complete. Once a trucking company chose to participate in the research effort, recruiting drivers was the first step. The drivers were generally not available on-site for a researcher to approach since they were either on the road or at home between runs. Therefore, at each company, an employee, usually an operations manager, volunteered to talk to the drivers to determine who would be interested in participating. In addition, the researchers believed that once word of the project spread quickly, drivers at each company would seek out their operations manager and state their interest in participating.

Those individuals who were recruiting drivers were provided with a general explanation of the research purpose and told that it would be appreciated if they would recruit a representative sample of drivers. They were also told that it was not necessary to only recruit drivers who were the "cream of the crop." The researchers were of the opinion that the operations managers did try to recruit representative drivers; however, in the end it did not matter. This project exhausted the supply of all willing drivers of each company that participated.

After a single driver or team was recruited, it was necessary to schedule the time to deliver a truck and to train the drivers. This scheduled time varied between the next day and the next week, depending on the trucking company's schedules or required maintenance for the trucks. To deliver the trucks, VTTI compiled a list of drivers with a valid Commercial Driver's License (CDL) who could drive the Class 8 tractors to the company. To train the drivers and get them on the road, the trainer completed the procedure previously described in the Training section. After training, the driver(s) would usually leave the same day; however, in some cases the driver(s) would not leave for one to three days.

While the trucks were out, the drivers were asked to call in if they noticed the data collection equipment was acting differently than described. Specifically, if the Karolinska box did not query the driver for a response for a day or if the small LED on the Nightcap system did not come on when the system was plugged in, the driver was to call in to a researcher who carried a cellular telephone 24 hours per day, 7 days per week. Likewise, if there was a mechanical failure of the truck, permitting issues, or any other problems on the road relating to the run being completed on time, the drivers were asked to call in. If a driver(s) was out for more than two to three days without calling in, a researcher called the driver(s) to verify that the run was progressing as expected and to get an idea of when the truck would be back to the company trucking yard. When a time was verified for return of the truck, arrangements were made to transport a driver with a CDL to the truck, who would then drive it back to VTTI.

When the truck was delivered back to VTTI, the hardware personnel downloaded the data. It was originally planned that the data would be downloaded on site, but it quickly became apparent that the trucks had to return for servicing of the truck itself or the data collection system after each run. Several components on the data collection system, such as the noise meter and the SafeTRAC, also required relatively complex calibration after each run. The need to return the trucks to VTTI slowed the data collection process considerably, although it was a rare case that a company could have turned a truck around very quickly anyway.

### Data Loss

Although 30 single and 13 team runs were completed, not all runs resulted in all data sets being complete. That is, for a variety reasons, anywhere from a few hours to several days of data were not collected on some runs. The primary causes and descriptions for data loss are outlined in Table 5.

**Table 5. Primary causes and descriptions for data loss.**

| Primary Cause | Description |
|---|---|
| Driver Interference with Equipment | Driving team set sleeper berth heat on high and cab air-conditioning on high causing data collection system in sleeper berth to overheat. |
| | Driver installed his own (illegal) 40 Watt CB radio, the electromagnetic interference from which resulted in extreme noise in the data stream. |
| | Driver unplugged a ground wire while installing his own CD/Radio player, which caused the data collection system to short out when the driver used the CB during rainy weather conditions. |
| | Driver put black electrical tape over the video camera recording the driver's face. |
| Permitting and Taxation Issues | Truck held for a few hours in New Mexico due to permitting issues. |
| | Truck held for a few hours in Oklahoma due to permitting issues. |
| Driver Chose Not to Comply | Driver did not complete the surveys. |
| | Driver did not use the Nightcap to collect home sleep data. |
| | Driver did not use the Nightcap to collect road sleep data. |
| Truck Mechanical Failures | Air conditioning system in the sleeper berth compartment failed when the driver was crossing the desert, resulting in the data collection system overheating. |
| | Truck oil temperature sensor malfunctioned. |
| | Driving lamp module shorted out and caught fire. |
| | U-bolt on the rear axle broke. |
| | Trailing arm broke. |
| | Engine control module malfunctioned. |
| | Batteries expired. |
| | Locking mechanism for the fifth wheel lost the pivot bolt. |
| | Master power relay for the engine control module malfunctioned. |
| | Turbo charger seized. |
| | Thermostat on the oil cooler stuck in the closed position causing the oil line to rupture. |
| | Thermostat on the oil cooler stuck in the closed position and the thermostat was replaced. |
| | Alternator went to over-volt. |
| | Ruptured power steering hoses. |
| Data Collection System Failure | Laptop malfunctioned. |
| | VCR failure. |
| | Video connection vibrated loose. |
| | SafeTRAC camera malfunctioned. |
| | Karolinska box malfunctioned. |
| | Sound and vibration systems malfunctioned. |
| | Perclos computer malfunctioned. |
| | Perclos LEDs malfunctioned, resulting in loss of infra-red light. |
| | Original Vorad system was found to be less reliable and was replaced with a newer model. |
| | Nightcap voltage control vibrated out of position. |
| | Titler failed. |
| | Cameras malfunctioned. |
| | Audio and video wires crossed. |
| | Software "bugs" found for highly unusual circumstances. |

The list shown in Table 5 provides some very important lessons learned for any organization interested in collecting data in the long-haul trucking industry environment.  One lesson shows that collecting data from a representative sample of long-haul truck drivers can be challenging since the drivers who were purposely non-compliant are the same ones who may be inclined to either not volunteer for or not comply with research efforts.  Similarly, non-compliant drivers may inadvertently cause themselves not to be represented.  In one case, a driver installing an illegal wattage CB caused the data collection system to fail.

Another lesson learned was the complexity associated with taxation and permitting issues. Although a local Southwest Virginia company volunteered their services to take care of these issues, there was a great amount of time and effort involved with maintaining the permits and paying the taxes.  A related lesson learned is that even though a truck is in compliance, a state DOT inspector may randomly stop a truck driver, resulting in lost time.

That long-haul trucks require very frequent maintenance and fail at a high rate was another lesson learned.  The researchers were surprised by how often mechanical failures occurred and how those failures affected the timeline of the project and data loss.  Interestingly, the trucking companies involved were never disappointed by a mechanical failure and considered it a part of doing business.  In hindsight, the project would have been well served by having a person responsible solely for keeping track of permitting, licensing, and maintenance issues for the trucks.  It would easily be a full time job.

The data collection system used in this study is probably one of the most complex and capable systems ever installed in a vehicle for this purpose.  The system was designed to be very robust, and performed extremely well.  However, failures in such a system are expected, and the failures associated with this study provide some important lessons learned.  The difficulty of the truck environment, in all seasons of travel, was surprising.  Drivers were often abusive to the trucks, although there is no reason to believe that they were behaving abnormally.  Often, the trucks returned with evidence of some kind of collision (usually minor).  Drivers also “modified” the trucks on several occasions to suit their needs (see Table 5).  These factors added to the difficulty of designing and maintaining very complex hardware with many off-the-shelf components, in a rugged environment, for over 500,000 miles of data collection.

Except for the last two data collection system failures listed in Table 5, most pure data collection hardware problems can be traced back to the extreme temperature changes and vibration of the tractor environment.  Temperatures exceeded 130 degrees in the data collection compartments several times even though a great deal of ventilation was provided.  In a few cases, data was lost because the heat in the sleeper berth was set on high *even though it was very hot outside.*  A separate thermostat had to be installed in the sleeper so that if it got above 90 degrees, the heat would turn itself off.  Off-the-shelf components were especially difficult to work with since most of them were not designed specifically for the truck environment.  For example, at least six VCRs had to be replaced even though they were ruggedized portable units that were shock-mounted.  In many instances, screws simply vibrated loose causing a subcomponent to fail and the related data to be lost.

Despite the difficulties in data collection, it was a rare case where a catastrophic data collection failure occurred. Thus, because of the robust nature of the system design, it was more often the case that if a failure occurred, it only affected one or a few subsystems.

## PROCEDURE FOR DATA REDUCTION AND DATA PREPARATION FOR ANALYSIS

Five types of data came off of the trucks after each run. The video data was recorded on as many as seven 8mm videotapes. A ".dat" file contained all of the driving performance data and data related to the Karolinska Sleepiness rating device. A ".rem" file contained the Nightcap data that was recorded during the driver's sleep bouts. A ".slp" file contained the environmental data that was recorded during the same sleep bouts: noise, temperature, illumination, and vibration. Finally, drivers completed two types of surveys during the course of their trips. In addition, once video data was reduced, a "mega.dat" file was created from the reduced video data and merged with the .dat file. Although these were the main sources of data, several intermediate files were created during data reduction and merging that was necessary for data analysis.

Five video reduction analysts were trained to reduce the video data for this project. All of the analysts had prior experience reducing video for other VTTI research projects (e.g. Local Short Haul, Specialty Vehicles). Three of the analysts held bachelors degrees in Psychology, one held a bachelors degree in Industrial and Systems Engineering with a Human Factors option, and two of the analysts held masters degrees in Human Factors Psychology. All of the analysts were trained in three sessions, consisting of approximately five hours of total training. In the first two-hour session, the trainer demonstrated how to access the video, operate the reduction software, perform objective ratings of drowsiness (ORD), and monitor the video for technical problems. In the second one-hour session the trainee sat with another experienced video analyst watching the experienced analyst reduce video. In the third two-hour session, each analyst practiced reducing video with the trainer present. Finally, the trainee began reducing video alone with either the trainer or another experienced analyst nearby to answer questions.

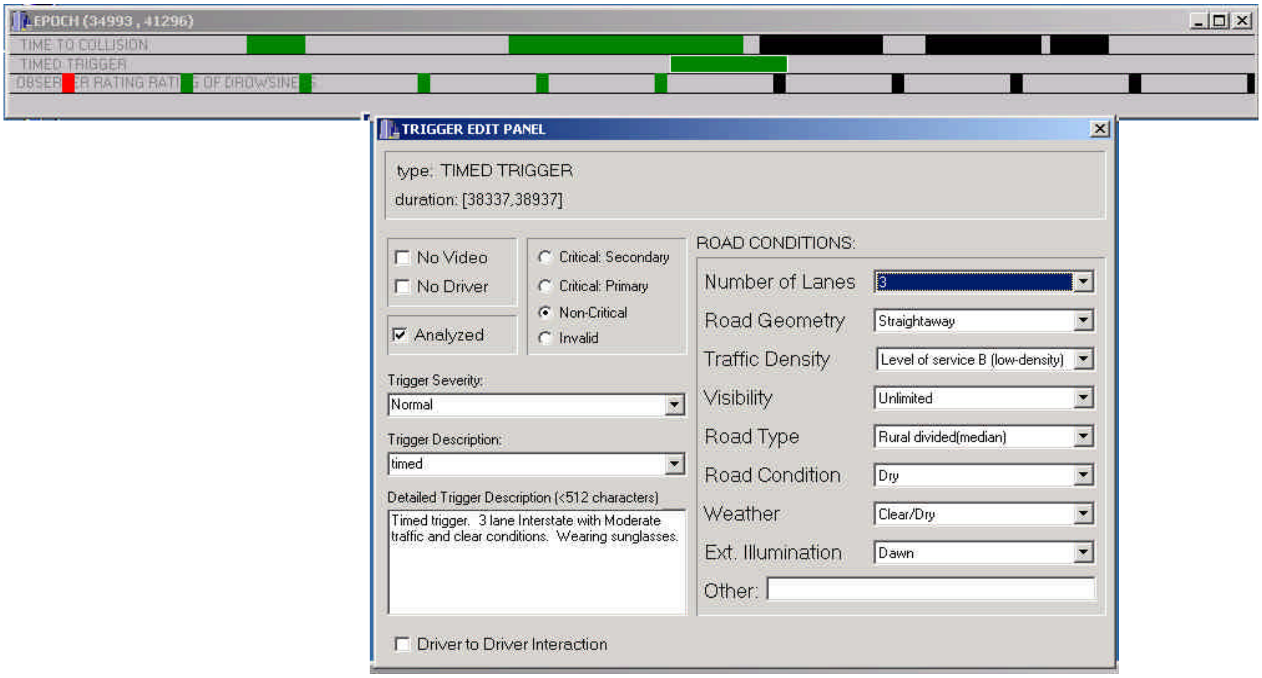
The trainer performed "spot checks" of all the analysts work throughout the entire data reduction process. The trainer held weekly meetings with all the analysts to discuss any questions or issues that came up from either the spot checks or incidents that the reduction analysts encountered. The weekly meetings and spot checks were critical in maintaining a high level of consistency between data reductionists.

The complex nature of the data required that data go through an extensive reduction process. This process is described in the following subsections.

### Video Data Reduction and the Data Reduction Interface

For data analysis, video data had to be coded and merged with the ".dat" files so that a reason for a triggered event could be verified and analysts could make Observer Ratings of Drowsiness. As previously described, the data collection system only recorded video and driver performance data for a period one and one half minutes prior to and thirty seconds following a trigger occurrence. In addition to minimizing the amount of data that needed to be stored on the collection system, this method allowed researchers to quickly analyze significant events without viewing numerous hours of continuous video. VTTI programmers then designed a computer interface that allowed analysts to select and analyze the individual events. If the triggers associated with two or more events overlapped, they were grouped in a single epoch. For example, if a driver deviated from his lane and then immediately braked and made a corrective steering action, the lane deviation, steering, and longitudinal acceleration triggers would be activated. Thus, a single epoch could contain any number of triggers.

The events from the each driver's entire trip were chronologically arranged in the interface so that the analyst could easily move to any point during the trip. This arrangement is referred to as the Trip Navigation Bar and is shown in Figure 16. When an event was selected, the interface displayed each trigger that occurred within the epoch. This display was referred to as the Epoch Bar and is also shown in Figure 16. The analyst could then select an individual event and analyze it in terms of the nature of the trigger, severity of the trigger, or the road conditions. Also, the analyst made an Observer Rating of Drowsiness (ORD) at one-minute intervals during the epoch. The data reduction variables and protocol are discussed in detail below.



type: TIMED TRIGGER
duration: [38337,38937]

☐ No Video
☐ No Driver
☑ Analyzed

○ Critical: Secondary
○ Critical: Primary
● Non-Critical
○ Invalid

Trigger Severity: Normal
Trigger Description: timed
Detailed Trigger Description (<512 characters): Timed trigger. 3 lane Interstate with Moderate traffic and clear conditions. Wearing sunglasses.

ROAD CONDITIONS:
Number of Lanes: 3
Road Geometry: Straightaway
Traffic Density: Level of service B (low-density)
Visibility: Unlimited
Road Type: Rural divided(median)
Road Condition: Dry
Weather: Clear/Dry
Ext. Illumination: Dawn
Other:

☐ Driver to Driver Interaction

**Figure 16. Data reduction interface screen.**

*Event Description*

After viewing the video for an entire event, the analyst determined the criticality of each trigger. Each trigger could be categorized as either "invalid," "non-critical," "critical: primary," or "critical: secondary." A trigger was considered invalid if it was activated when it was clearly not appropriate. An example of an invalid trigger may be a time-to-collision that was activated by a vehicle in an adjacent lane. A trigger was deemed non-critical if the corresponding behavior (i.e. the cause of the trigger) was a safe and legal driving maneuver that nevertheless met the trigger criteria. The timed triggers were always considered non-critical. An example of a non-critical trigger would be a time-to-collision trigger activated after passing a bridge guardrail. All valid triggers were considered critical. Because two or more triggers may have been activated by a single event, such as a driver simultaneously braking hard (Longitudinal Acceleration trigger) and jerking the wheel (time-to-collision trigger), critical triggers were labeled as either primary or secondary. If multiple triggers occurred during an event, the analyst judged which trigger was the most prominent and labeled this as critical: primary; additional triggers related to the same event were labeled critical: secondary. If only one trigger or multiple, unrelated triggers were present, the critical: primary label was used for each. If no video footage was available of the trigger (due to equipment problems) or the driver was not present during the trigger (as may be the case with a Timed Trigger), the analyst could mark “No Video” or “No Driver” in the upper left corner of the reductions screen.

The Trigger Severity category described the apparent danger of the event, ranging from no danger (Driver Error without Hazard) to physical contact with another object or person (Injury/ Accident). The five Trigger Severity Types are listed and defined in Table 6. The Trigger Description category reflects the apparent cause of the event; the eight Trigger Description Types are listed and defined in Table 7.

**Table 6. Trigger Severity definitions.**

| Trigger Severity Type | Description |
|---|---|
| Other Driver | Subject is exhibiting safe driving behavior and is following all rules of the road. |
| Collision | Either property damage or physical injury results from the event. |
| Near Collision | The driver must take evasive action to avoid a collision. |
| Driver Error with Hazard Present | The subject performs an unsafe maneuver while there is a *potential* danger of collision (with another vehicle, pedestrian, etc.) or loss of vehicle control (i.e. driving too fast around a turn). The drivers involved take little or no evasive action. |
| Driver Error without Hazard Present | The subject performs an inappropriate maneuver but there is no apparent risk of a collision or loss of control. For example, deviating into the adjacent lane while no traffic is present. |

**Table 7. Trigger Description definitions.**

| Trigger Description | Definition |
|---|---|
| Undetermined | The cause of the event cannot be determined from the video. May be due to equipment failure, the event being out of camera view, etc. |
| Normal Driving | The driver is exhibiting safe driving behavior and is following all rules of the road. Must only be used to describe a non-critical or invalid trigger. |
| Obstacle Present | There is an unexpected obstacle in the driver's path, *excluding other vehicles*. May be used when the driver reacts to a pedestrian, debris, or an animal in his/ her path. |
| Other Vehicle Present | *Another vehicle* obstructs the driver's path and the driver is not at fault. |
| Impediment Present | The driver must react to an unexpected but deliberate traffic obstruction such as construction zone traffic cones, a police officer directing traffic, or a speed bump. |
| Driver Distraction | The event is the result of the driver's inattention from the primary driving task. |
| Judgment Error | The driver exhibits poor judgment in driving in an otherwise safe situation. For example, cuts off another driver or follows another vehicle too closely. |
| Other | Any event that cannot be categorized by the above descriptions. |

*Road Conditions*

As can be seen on the right side of the Trigger Edit Panel of Figure 16, nine Road Condition categories were used to describe the general environment and traffic conditions at the time of the event. The analyst indicated the number of lanes in a single direction on the roadway in the Number of Lanes box. The Traffic Density was rated by the analyst using the Level of Service definitions detailed in Table 8. The environment and traffic were further described by the following six categories: Road Geometry, Visibility, Road Type, Road Condition, Weather, and Exterior Illumination. Table 9 outlines the six categories and their respective options. The analyst could also enter any relevant information not covered by the above categories in the Other category.

**Table 8. Level of Service definitions** (adapted from Transportation Research Board, 1997)**.**

| Level of Service | Definition |
|---|---|
| Level of Service A | Represents free-flow where vehicles can maneuver within the traffic stream and easily maintain the posted speed limit. The general level of comfort and convenience is excellent. |
| Level of Service B | Represents stable flow where drivers are somewhat restricted in maneuverability, but usually maintain the posted speed limit. The presence of others in the traffic stream begins to affect individual behavior |
| Level of Service C | Still in the zone of stable flow, but the maneuverability and speed are more restricted with high traffic volumes. The general level of comfort and convenience declines noticeably at this level. |
| Level of Service D | Approaches unstable flow where temporary restrictions to the traffic flow may cause substantial drops in the operating speed. Drivers have little freedom to maneuver and pass, and they will experience a generally poor level of comfort and convenience. |
| Level of Service E | Represents the capacity of the facility. The traffic flow is unstable, vehicles are unable to pass, there may be momentary stoppages in the traffic flow, and the vehicles' operating speeds are very low. Comfort and convenience levels are extremely poor, and frustration is generally high. |
| Level of Service F | A forced traffic flow condition, usually with low operating speeds and traffic volumes that are below capacity. Queues form behind such locations. This is often described as stop-and-go conditions. |

Table 9. Road Condition categories.

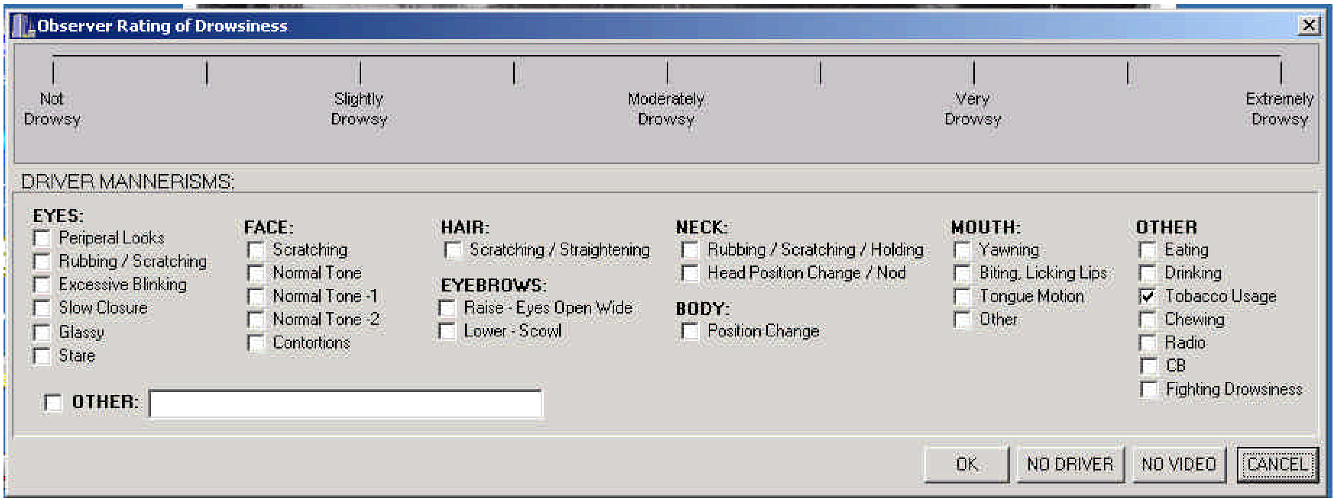
| Road Geometry | Visibility | Road Type | Road Condition | Weather | Exterior Illumination |
|---|---|---|---|---|---|
| Straightaway | Unlimited | Parking lot/ loading area | Dry | Clear/ dry | Dawn |
| Curve left | Rain | Alleyway | Wet | Cloudy | Daylight |
| Curve right | Snow | One way road | Icy/ snow | Drizzle | Dusk |
| S-curve | Fog | Rural undivided | Gravel/ sand on road | Hard rain | Night |
| Intersection on a straightaway | Darkness | Rural divided (median) | Gravel road | Light snow | Other |
| Intersection on a curve | Glare from sun | Rural divided (lane) | Other | Hard snow | |
| Loading area/ parking lot | Glare from headlights | Urban undivided | | Sleet | |
| Merge lane from right | Twilight (dusk/ dawn) | Urban divided (median) | | Other | |
| Merge lane form left | Other | Urban divided (lane) | | | |
| Other | | Other | | | |

Finally, the analyst wrote a short narrative of the event in the Detailed Trigger Description box. The narrative included any relevant information concerning the situation or environment.

After the reduction protocol was established, analysts met periodically to ensure that data reduction was consistent among analysts and to modify and clarify definitions. Also, supervisors spot-checked the reduced data for accuracy and consistency.

*Observer Rating of Drowsiness (ORD)*

In the interest of accurately quantifying each driver's level of fatigue, analysts made an Observer Rating of Drowsiness (ORD) at one-minute intervals during each event/epoch. The ORD scale used was based upon that developed by Wierwille and Ellsworth (1994), which is a form of the Likert (descriptive graphics) scale. The continuous scale contains five descriptors: Not Drowsy, Slightly Drowsy, Moderately Drowsy, Very Drowsy, and Extremely Drowsy. Judgments of drowsiness were made from the driver's facial expression, body movements, and so forth based upon the technique described by Wierwille and Ellsworth. The Observer Rating of Drowsiness window is shown in Figure 17. For analysis purposes, the ORD scale line was programmed to be 100 sequential and discrete units. A mouse click at any point along the line would indicate the rating. Analysts also noted the occurrence of various mannerisms that could potentially indicate fatigue. Note that the ORD scale is shown in the top of the window and numerous mannerisms are listed in the bottom half.



DRIVER MANNERISMS:

**EYES:**
- ☐ Periperal Looks
- ☐ Rubbing / Scratching
- ☐ Excessive Blinking
- ☐ Slow Closure
- ☐ Glassy
- ☐ Stare

**FACE:**
- ☐ Scratching
- ☐ Normal Tone
- ☐ Normal Tone -1
- ☐ Normal Tone -2
- ☐ Contortions

**HAIR:**
- ☐ Scratching / Straightening

**EYEBROWS:**
- ☐ Raise - Eyes Open Wide
- ☐ Lower - Scowl

**NECK:**
- ☐ Rubbing / Scratching / Holding
- ☐ Head Position Change / Nod

**BODY:**
- ☐ Position Change

**MOUTH:**
- ☐ Yawning
- ☐ Biting, Licking Lips
- ☐ Tongue Motion
- ☐ Other

**OTHER**
- ☐ Eating
- ☐ Drinking
- ☑ Tobacco Usage
- ☐ Chewing
- ☐ Radio
- ☐ CB
- ☐ Fighting Drowsiness

☐ **OTHER:**

**Figure 17. Observer Rating of Drowsiness (ORD) window.**

**Reduction of the Remaining Files (".slp," ".rem," and Survey Data)**

The remaining data files went through several filtering processes. First, the survey data was entered into electronic spreadsheets for analysis and to allow that data to be merged with other data sets. The ".rem" (Nightcap) data went through a software filtering process to put the data into a format that researchers at Harvard Medical School could reduce (the data that came off the truck were formatted to optimize storage space). These data, along with the survey data, were used by Harvard to reduce the Nightcap (".rem") files.

All subjects' .rem file data were concatenated, and individual bouts were randomized for hand scoring. An experienced investigator, who was blind as to subject identity or OTR versus stationary-truck recording status of individual files, accomplished hand scoring. The approximately 200 sleep bout files reliably known to be recorded with the Nightcap eyelid sensor threshold for detection of movement set at 2.5 Volts (sampled every 250msec, scored as ± movement, and stored in epochs of 1 min, i.e., per-minute scores vary from 0 to 240) were scored separately from approximately 70 records in which the threshold was set at approximately 0.6 Volts. Once all records were scored and sleep parameters computed, individual files were resorted by subject and date and matched as close as possible with individual Wake-up Surveys completed by the subjects.

Each subject's home sleep was hand-scored via methods used for OTR scoring, but was done without the investigator being blind to subject number. An attempt was made to score the home device set at the voltage corresponding to that subject's OTR setting (2.5 or ≤0.6); however, a small number of home records were scored at another voltage setting if the home recording matching the OTR recording was defective.

The process of hand scoring was accomplished via one of three methods:

1. The first method was used on records showing a clear rhythmicity (see below) and maximum per-minute eyelid movement (ELM) counts approximating those known to be produced by home recordings using Nightcap units with an eyelid movement threshold of 2.5V. In such records, REM, NREM, and waking were differentiated and microarousals (<5 ELM and >2 Body Movements (BM) with activity lasting ≤ 4 min) were scored.
2. In the second method, the REM-NREM distinction was made but high maximum ELM/min and ELM density precluded scoring of microarousals.
3. In the third method, only a sleep-wake differentiation was made due to a high level of noise in the ELM channel.

Records from Nightcaps known to be set at 2.5 volts were scored using one of the three above methods, whereas records from Nightcaps known to be set at ≤0.6 Volts were scored only by methods 2 or 3. Sleep quality parameters were computed from hand-scored records via a series of computations accomplished in MS Excel 4.0.

For each of the hand scored records, a subset of the following sleep quality parameters was computed (Silvestri *et al.*, 2001) with the specific subset computed dependent upon the above scoring method used.

1. *Sleep efficiency (SE)* was defined as the number of hand-scored minutes of sleep (REM and NREM) divided by total number of minutes of Nightcap recording.
2. *Number of awakenings (AWAKE)* corresponded to the number of macro-arousals (≥5 ELM and >2 BM with activity lasting > 4 min) and included the final wake-up of the recording, while *Number of Microarousals* corresponds to total number of very brief signal elevations (<5 ELM and >2 BM with activity lasting ≤ 4 min) likely due to momentary arousals.
3. *Sleep onset latency* was defined as the time to the first 15 minutes of uninterrupted hand-scored NREM sleep (Pace-Schott *et al.*, 2001).
4. *NREM and REM Stage Percent* were defined as the total number of minutes hand-scored as NREM or REM sleep divided by the total minutes of REM and NREM sleep combined.
5. *NREM, REM and Wake Total Time Percent* were defined as the total number of minutes hand-scored as NREM or REM sleep or Waking divided by the total time of Nightcap recording.

6. *Mean Eyelid movements and Body movements per minute* were defined as the total eyelid or head movements respectively in all hand-scored stages of a sleep bout divided by the total time of Nightcap recording.

For the environmental analyses (Objective 2, as defined earlier), the reduced data that came back from Harvard was reformatted to allow researchers in the Virginia Tech Department of Industrial and Systems Engineering to efficiently reduce the data in relationship to the environmental (".slp") data. The first step in the data reduction process involved checking the correspondence of the Harvard data with the environmental data files recorded during the sleep events. This review process involved, for each sleep event in which awakenings were reported, checking to ensure that: a) the number of awakenings corresponded with the number of times given for the awakenings, b) that the time period covered by the awakenings corresponded with the time frame covered by the ".slp" data file, and c) that there actually were environmental data for the sleep event. There was only one instance (Subject 107, sleep period 4) where there was no environmental data available after the data were fully reviewed.

After the data were verified, summary statistics were calculated to determine the number of awakenings per hour. These statistics were calculated based both on the length of time the Nightcap was worn and also the length of time the subject was reported as being asleep. These data are independent of the environmental data.

For each incident of sleep disruption, the environmental data for a period of five minutes prior to the occurrence of the disturbance (the five-minute period ended at the time given for the occurrence of the awakening) were highlighted, examined to determine if a change in the environment might be responsible for the disturbance, and the average magnitude (in the case of the noise levels, the Leq) of each environmental variable for the five-minute period calculated. Notes pertaining to the quality of the data for that five-minute period were also recorded at this time.

The environmental data for each awakening were then examined to determine if the awakening could be attributed to one or more environmental factors. In this process, the five minutes of data preceding the awakening was examined for variability. If variation was found, the data recorded during the preceding 10 to 15 minutes (preceding the beginning of the five minute period before the awakening) were examined to determine if a change in the pattern of the fluctuations in the environmental variable might have been responsible for the awakening. Where changes in one or more of the environmental variables were thought to be possible causes of the awakening, the factors were so noted. Where no possible cause was discernible, the awakening was labeled as "Indeterminate." In the one instance where there was no environmental data (Subject 107, sleep period 4), the awakening was labeled "Indeterminable." In some instances, multiple environmental factors were possible causes of the awakening. In such cases, each possible factor was noted.

Once each awakening had been examined for possible cause, the data were summarized in two ways. First, for each subject, the number of awakenings potentially attributed to each environmental factor were determined and averages calculated for the Single/Team groups.

Second, the number of awakenings occurring within specific ranges of each level of each environmental variable were counted.

## METHOD SUMMARY

Based upon the method and procedures described, statistical analyses were conducted to answer each of the seven research objectives. The next section provides the statistical Results and Discussion of data analyses. The last section provides the Conclusions and Recommendations of the research effort.

# RESULTS AND DISCUSSION

The Results of this study are arranged in separate sections to address the various objectives of this project. In addition, a preliminary section describing the demographics of the drivers used in this study is provided below to give the reader context information for interpreting the results of the subsequent objectives. As was described in the Introduction, there are seven major research objectives associated with this project. These objectives are shown below:

1. Determine the quality and quantity of sleep that truck drivers get in both stationary and moving sleeper berths relative to home sleep.
2. Determine if any environmental variables (specifically noise, vibration, illumination, and temperature) appear to disrupt sleep.
3. Determine the level of driver alertness for differing types of trips (single versus team), length of shift, number of shifts, and length of trip.
4. Determine the relationship, if any, between the levels of sleep quality and quantity and driver alertness.
5. Determine the level of driving performance, as measured by the frequency and type of triggered critical incidents/driver errors, for differing types of trips (single versus team), length of shift, number of shifts, and length of trip.
6. Determine the relationship, if any, between the level of sleep quality or quantity and the frequency or type of critical incidents/driver errors.
7. Determine the relationship, if any, between the level of driver alertness and the frequency or type of critical incidents/driver errors.

There were 56 drivers who participated in this study. Of these 56 drivers, data were used from 41 drivers, in various combinations, for the analyses described in the following sections. As described in the Introduction section, the data from the remaining 15 drivers could not be used for a variety of reasons such as truck failure, data collection system failure, and driver non-compliance.

Of the remaining 41 drivers, some data may have been missing for a variety of reasons. For example, a driver may have chosen not to complete the surveys or wear the Nightcap. Alternatively, the SafeTRAC camera may have malfunctioned. The result is that there may have been one or two data variables missing for the subject, but there were dozens of other usable data variables. All usable data was incorporated for each analysis. Table 10 shows which drivers and data sources were included for each research objective.

**Table 10. Drivers and data sources included in each research objective.**

| | **Data Source*** | | | | | **Driver** | |
|---|---|---|---|---|---|---|---|
| **Objective** | **.dat** | **.rem** | **.slp** | **Survey** | **Video** | **Single** | **Team** |
| 1 | | X | | X | | 12 | 9 |
| 2 | | X | X | | | 7 | 9 |
| 3 | X | | | | X | 13 | 14 |
| 4* | X | | | X | X | 15 | 11 |
| 4* | X | X | | | X | 12 | 6 |
| 5 | X | | | | X | 13 | 14 |
| 6 | X | X | | X | X | 16 | 13 |
| 7 | X | | | | X | 13 | 7 |

* There were two data sets used for this objective.

## DRIVER DEMOGRAPHIC DESCRIPTIONS

As in most studies, there were wide variations in the demographic characteristics of the single and team drivers. In this project, certain objectives required analysis by Driver Type (single vs. team). When such analyses showed differences, the analyst often looked back to the driver characteristics to help explain this variability. The driver characteristics are presented and analyzed here so that the reader will become familiar with the characteristics of the subject population before reading the more detailed objective-by-objective analyses. The driver characteristics considered in this section include Driver Type, Age, Gender, and Years of Driving Experience. Tables 11 and 12 present these characteristics in tabular form, along with supplemental graphs. Discussions of these characteristics will also be repeated throughout the report when deemed appropriate for the analysis at hand. It should be noted that some demographic data were missing for three drivers (Age, Years of Experience, and Gender).

### Driver Type

Of the 41 drivers whose data were used for this study, 23 were single drivers and 18 were team drivers during the time of their participation in the study. Of the team drivers, the mean Years of Experience of driving as part of a team was 3.4 years (*SD* = 5.3 years). The team drivers averaged 1.5 years of experience of driving with their *current* partner (*SD* = 2.3 years). Three of the teams were composed of married couples. Table 11 presents the Driver Type demographics.

**Table 11. Demographics of single and team drivers.**

| **Driver Type** | **Single** | **Team** |
|---|---:|---:|
| Number | 23 | 18 |
| Mean years of team experience (*SD*) | N/A | 3.4 (5.3) |
| Mean years w/ current partner (*SD*) | N/A | 1.5 (2.3) |
| Married teams | N/A | 3 |

### Driver Age

The mean Age across all drivers was 42.6 years, with a standard deviation of 9.9 years. The drivers ranged in age from 28 to 63 years, and over 40 percent of the drivers were in the 36 to 45-age category, as seen in Figure 18. The mean Age of the team drivers was 40.1 (*SD* = 8.3), while the mean Age of the single drivers was 44.9 (*SD* = 10.8), as shown in Figure 19. A t-test for differences in the single vs. team drivers' age showed no significant difference ($t_{36} = 1.514$; $p > .05$). Table 12 presents these driver Age demographics.

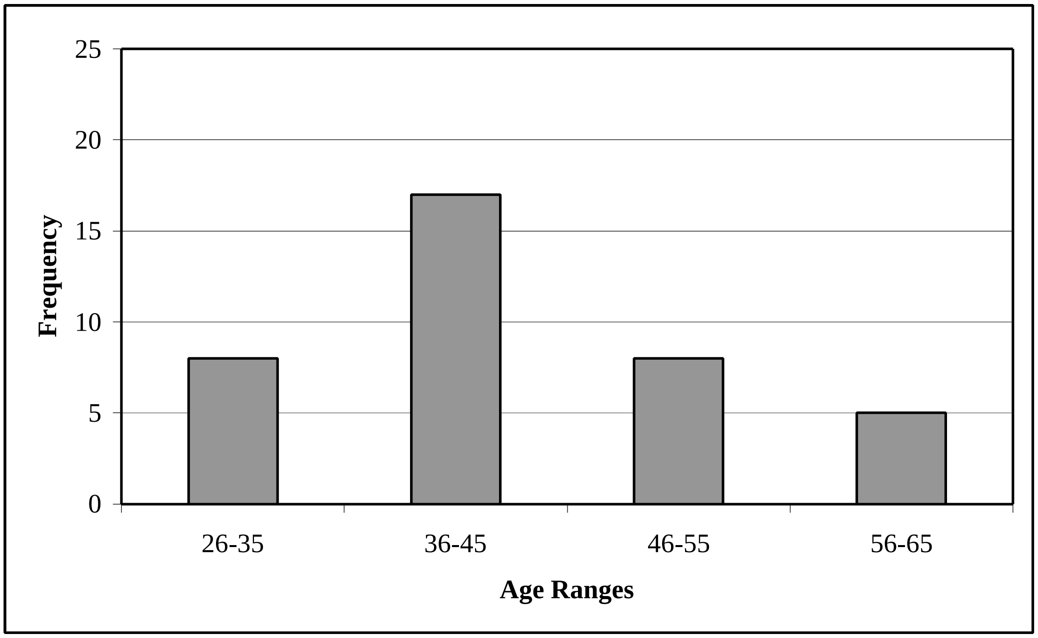


**Figure 18. Distribution of Ages for all drivers.**

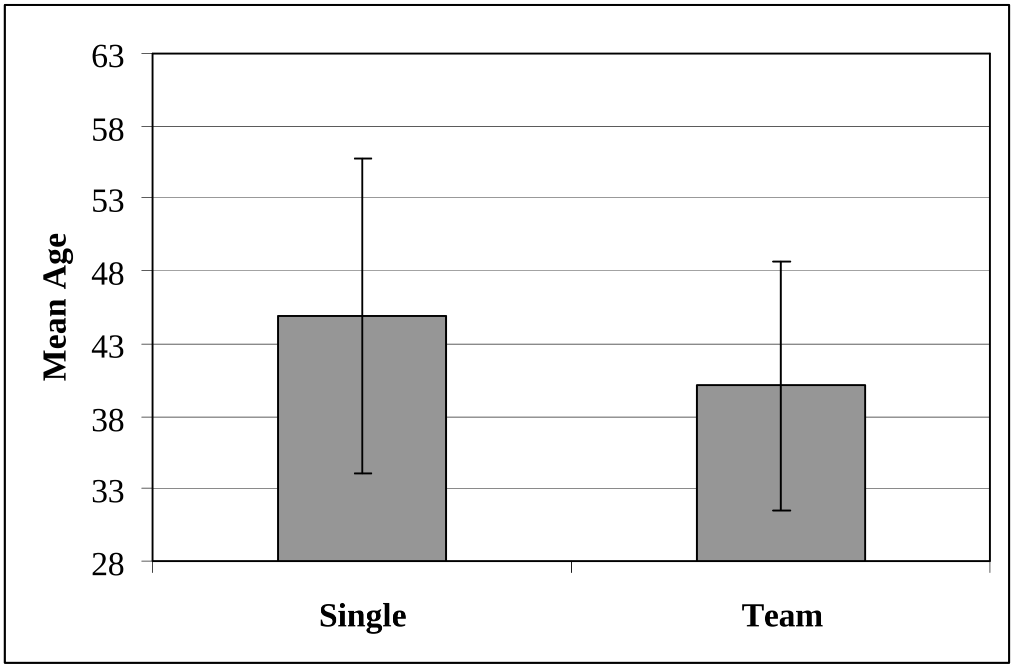


**Figure 19. Mean Age by Driver Type. Note that the difference in driver age was not significant at an a = 0.05 level.**

**Table 12. Driver Age demographics.**

| | **Mean** | *SD* |
|---|---:|---:|
| All drivers | 42.6 | 9.9 |
| Single drivers | 44.9 | 10.8 |
| Team drivers | 40.1 | 8.3 |

### Driver Gender

There were 34 male drivers and 7 female drivers. Of the female drivers, 6 drove as part of a team, and in three cases were part of a married team. The set of male drivers consisted of 22 single drivers and 12 team drivers. The mean Ages of the male and female drivers is shown in Figure 20, while Table 13 presents driver Gender demographic attributes. As can be seen in both Figure 20 and Table 13, the mean Ages of the male and female drivers were quite close, and a t-test revealed no significant age differences by Gender ($t_{36} = 0.1009$; $p > .05$).

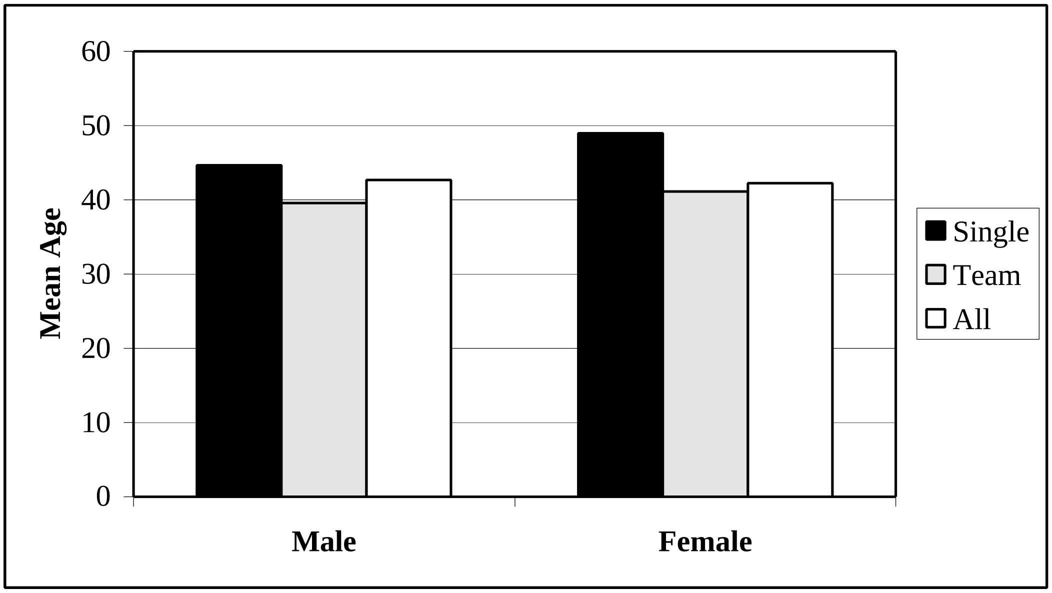


**Figure 20. Mean Ages of male and female drivers by Driver Type.**

**Table 13. Driver Age by Gender and Driver Type.**

| Gender | Single | Team | All Drivers |
|---|---|---|---|
| Male, age in years, mean | 44.7 | 39.6 | 42.7 |
| *SD* | 11.1 | 9.1 | 10.5 |
| Female, age in years, mean | 49.0 | 41.2 | 42.3 |
| *SD* | NA | 7.1 | 7.1 |
| All drivers, age in years, mean | 44.9 | 40.1 | 42.6 |
| *SD* | 10.8 | 8.3 | 9.9 |

### Years of Commercial Driving Experience

Overall, subjects averaged 12.8 years of commercial driving experience (*SD* = 9.8 years). The least experienced driver had only 0.3 years, while the most experienced driver had 42 years. The distribution of Years of Experience is shown in Figure 21.

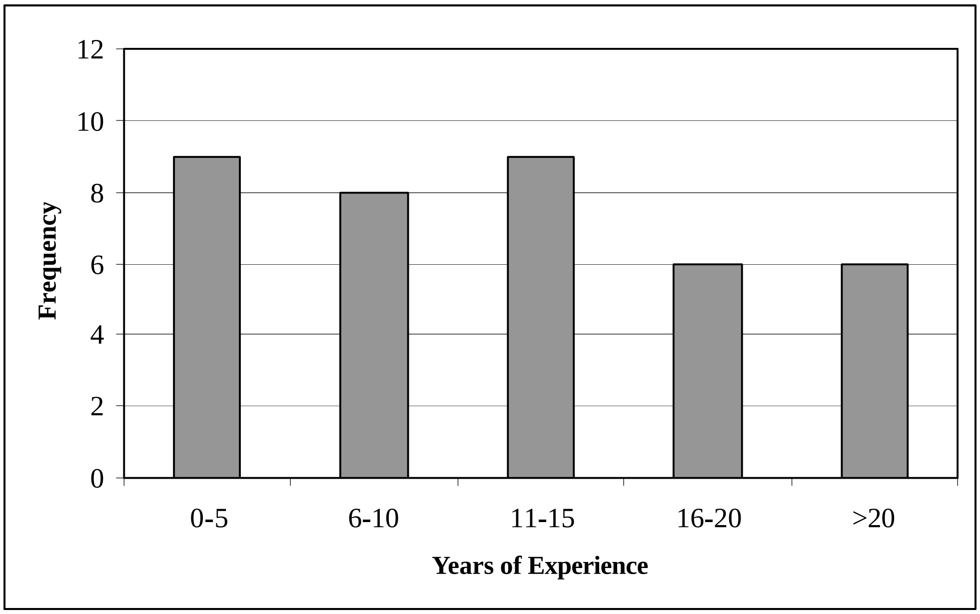


**Figure 21. Distribution of Years of Experience for all drivers.**

The next analysis considers Years of Experience for Driver Type (single vs. team). As shown in Figure 22 and Table 14, single drivers average over 5 more Years of Experience than the team drivers. However, a t-test showed that this difference was not significant ($t_{36} = 1.6577$; $p > .05$).

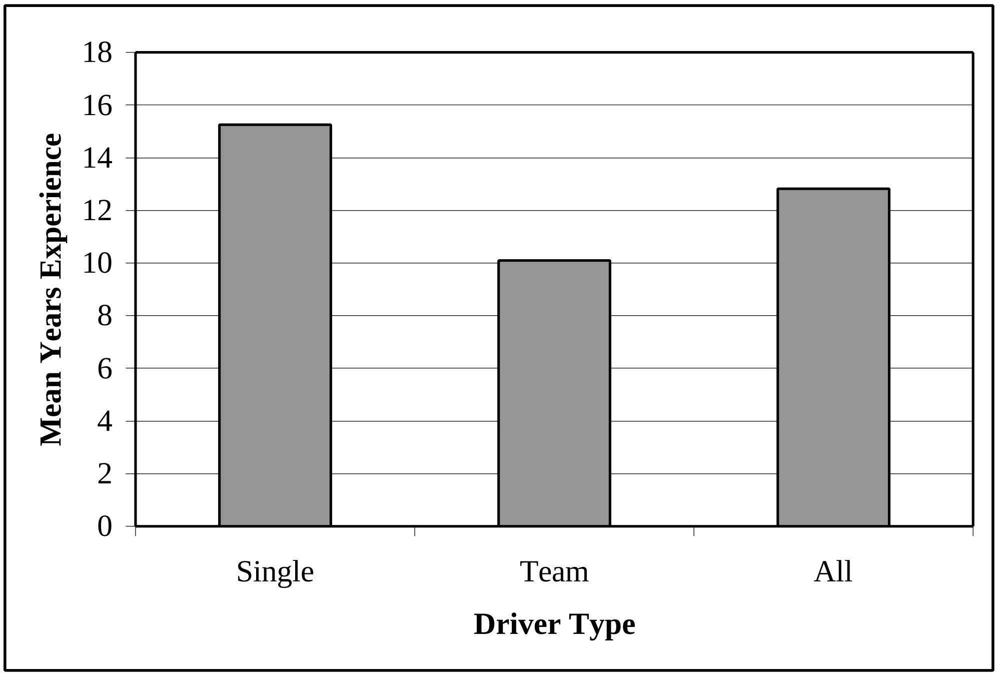


**Figure 22. Mean Years of Experience for single and team drivers.**

**Table 14. Driver Experience demographics for Driver Type.**

| | **Mean** | *SD* | **Minimum** | **Maximum** |
|---|---|---|---|---|
| Single | 15.2 | 9.3 | 1.7 | 42.0 |
| Team | 10.1 | 9.9 | 0.3 | 40.0 |
| All | 12.8 | 9.8 | 0.3 | 42.0 |

The relationship between Gender and Years of Experience is explored in the next analysis. As can be seen in Figure 23 and Table 15, male drivers averaged 14.7 Years of Experience, compared with 4.6 years for female drivers. A t-test revealed that this difference was significant ($t_{36} = 2.6446$; $p = .012$). This result should not be considered surprising because the commercial driving field has traditionally been male-dominated, and only recently have females taken up this profession in large numbers.

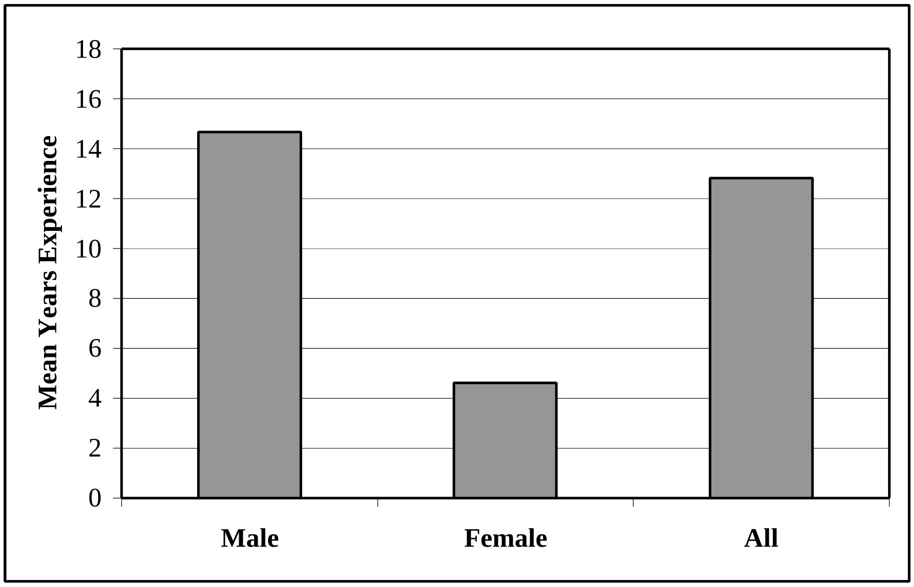


**Figure 23. Mean Years of Experience for male and female drivers.**

**Table 15. Driver Experience demographics for Gender.**

| | **Mean** | *SD* | **Minimum** | **Maximum** |
|---|---|---|---|---|
| Male | 14.7 | 9.8 | 1.7 | 42.0 |
| Female | 4.6 | 3.9 | 0.3 | 11.0 |
| All | 12.8 | 9.8 | 0.3 | 42.0 |

The final analysis concerns the possible interactions of Driver Type and Gender for Years of Experience. Due to low numbers of data points (particularly the fact that there was only one female single driver), it was not possible to test this relationship statistically. However, it can be seen in Figure 24 and Table 16 that the mean Years of Experience for the female team drivers is much lower than for the other Driver Type/Gender combinations.

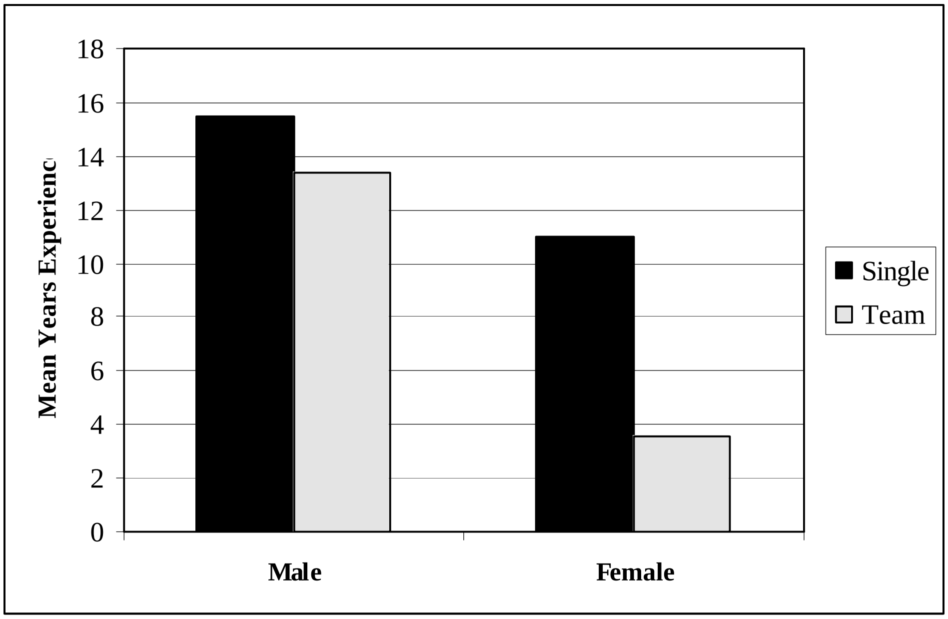


**Figure 24. Mean years of experience for Gender by Driver Type.**

**Table 16. Mean years of driver experience by Gender and Driver Type.**

| | **Single** | **Team** | **All Drivers** |
|---|---:|---:|---:|
| Male, mean | 15.5 | 13.4 | 14.7 |
| *N* | 19 | 12 | 31 |
| Female, mean | 11.0 | 3.6 | 4.6 |
| *N* | 1 | 6 | 7 |
| All drivers, mean | 15.2 | 10.1 | 12.8 |
| *N* | 20 | 18 | 38 |

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## OBJECTIVE 1: DETERMINE THE QUANTITY AND QUALITY OF SLEEP THAT TRUCK DRIVERS GET IN BOTH A STATIONARY AND MOVING SLEEPER BERTH RELATIVE TO HOME SLEEP

### Data Analysis Overview

This objective examines survey and Nightcap data sources to determine the quantity and quality of sleep that single and team drivers obtained at home as compared to on the road (OTR) during the study. For each data source, the dependent variables shown in Table 17 were examined.

**Table 17. Wake-up Survey and Nightcap Dependent Variables for Objective 1.**

| Wake-up Survey Dependent Variables | Nightcap Dependent Variables |
|---|---|
| Subjective Sleep Time (Question 7) | *Total Sleep Time |
| Quality of Sleep (Question 8) | REM Percent of Total Sleep Time |
| Number of Awakenings (Question 6) | Number of Awakenings |
| Sleep Latency (Question 14) | Sleep Onset Latency |
| Depth of Sleep (Question 5) | (No corresponding Nightcap measure) |
| Clearheaded on Awakening (Question 10) | (No corresponding Nightcap measure) |
| Satisfaction (Question 11) | (No corresponding Nightcap measure) |
| Terminal Insomnia (Question 12) | (No corresponding Nightcap measure) |
| (No corresponding survey measure) | Sleep Efficiency |

* Due to missing sleep bouts data, Total Sleep Time could not be accurately calculated using the Nightcap.

When feasible, the Nightcap and Survey results were compared. In addition to these analyses, the quality and quantity of sleep that team drivers obtained when the truck was moving versus when the truck was stationary was also examined.

Unless specifically noted, a 2 (Driver Type) X 2 (Sleep Location: home, OTR) mixed-factor ANOVA was conducted for each dependent variable. In some instances, data was analyzed by day using a 2 (Driver Type) X 12 (Day) mixed-factor ANOVA. The 12 days represented three days of home sleep and nine days of OTR sleep.

#### *Driver Data Included in the Analyses*

For this objective, data were included for 12 single and 9 team drivers. Driver data were included if there were survey data for both home and OTR and if there were Nightcap data for both home and OTR. Occasionally a driver would skip a day in completing a survey or wearing the Nightcap, which would result in a lost data point for that day.

Some difficulties were encountered during the reduction of the Nightcap data. There were several cases where the number of sleep bouts for the Nightcap data did not equal the number of bouts reported in the sleep surveys. In many of these cases, the drivers apparently did not don the system. Consequently, the Nightcap data were not used for a Total Sleep Time calculation.

## Results

### *Subjective Sleep Time*

Subjective Sleep Time data were collected with Question 7 from the Wake-up Survey. The question, "How much sleep did you have?" was asked. Drivers reported this in hours and minutes, but when this was compared to the reported falling asleep and waking up times, several arithmetic errors were noted. As a result, this metric was calculated using the driver reported times for falling asleep and waking up.

When the amount of sleep was collapsed across days, an ANOVA showed that Driver Type was significant, $F_{1,19} = 5.12$; $p = .035$ (see Appendix B, Table B-1 for the complete ANOVA). As shown in Figure 25, single drivers reported less sleep than team drivers. Note that single drivers, on average, reported over one hour less sleep per day while on the road.

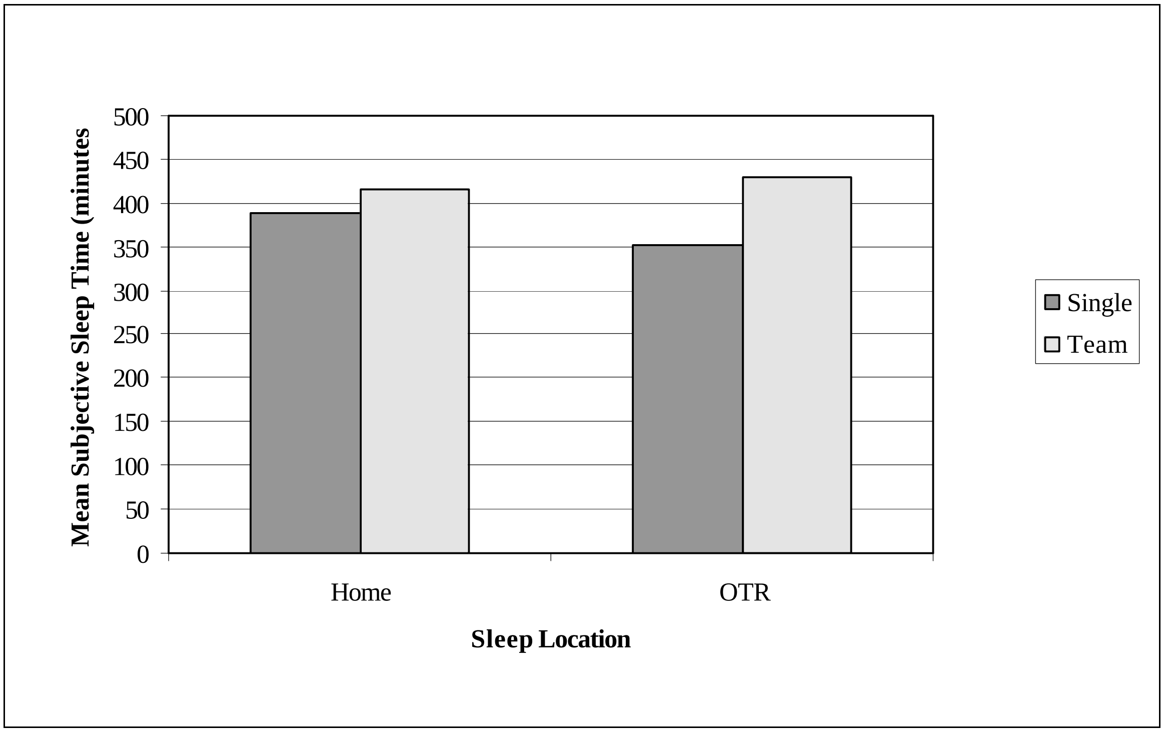

**Figure 25. Mean Subjective Sleep Time by Sleep Location for single and team drivers.**

As can be seen in Figure 26, team drivers reported more sleep time than did single drivers for almost every day of driving, whether at home (H1-H3) or on the road (D1-D9). For this analysis, Location and Day were combined into one within-subjects independent variable, while Driver Type was a between-subjects independent variable. An ANOVA for these factors showed that Driver Type was the only significant factor, $F_{1,19} = 6.55$; $p = .028$ (Appendix B Table B-2).

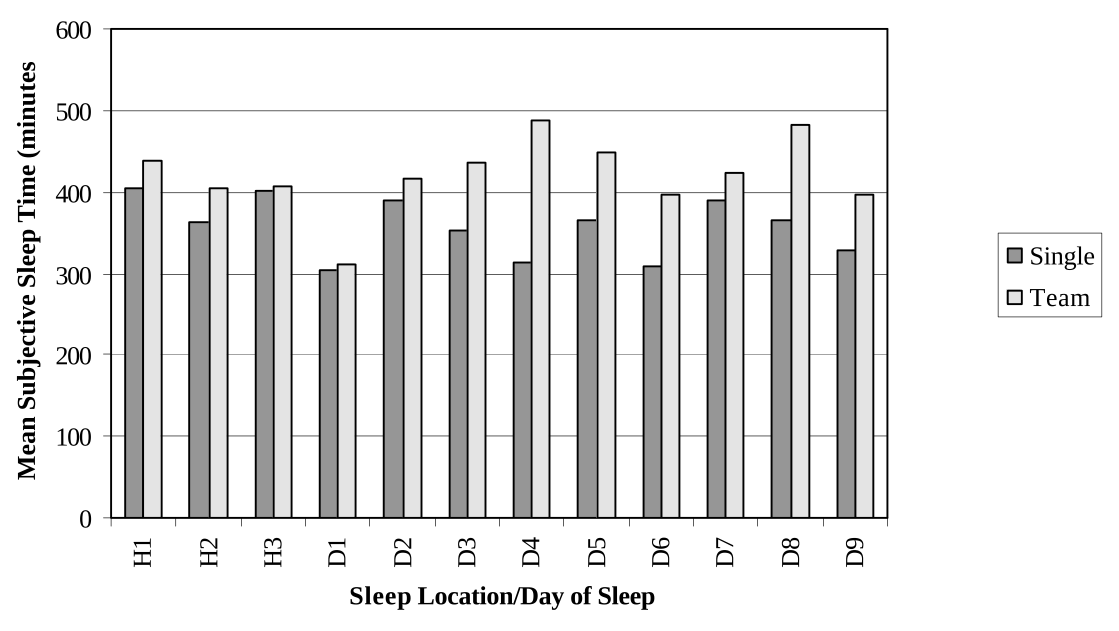

**Figure 26. Mean Subjective Sleep Time by Sleep Location and Day of Sleep for single and team drivers.**

*Quality of Sleep/REM Percent of Total Sleep Time*
An analysis of REM Percent of Total Sleep Time from the Nightcap data revealed a significant main effect of Sleep Location, $F_{1,14} = 9.48$; $p = .0082$ (Appendix B, Table B-3). Single drivers got roughly the same percentage of REM sleep whether at home or on the road (Figure 27). In contrast, team drivers apparently got much less REM sleep on the road compared to their home sleep.

It should be noted that the Nightcap data were scored, with some difficulty, by experts at the Harvard Medical School. The data contained noise not usually seen in laboratory environments, forcing the Harvard experts to hand-score each sleep file (see related material in the *Method* section). This noise may have affected the results in that the noise was greatest while the truck was moving. Thus, even though the data are believed to be accurate, the reader is advised to use some caution when interpreting the Nightcap results.

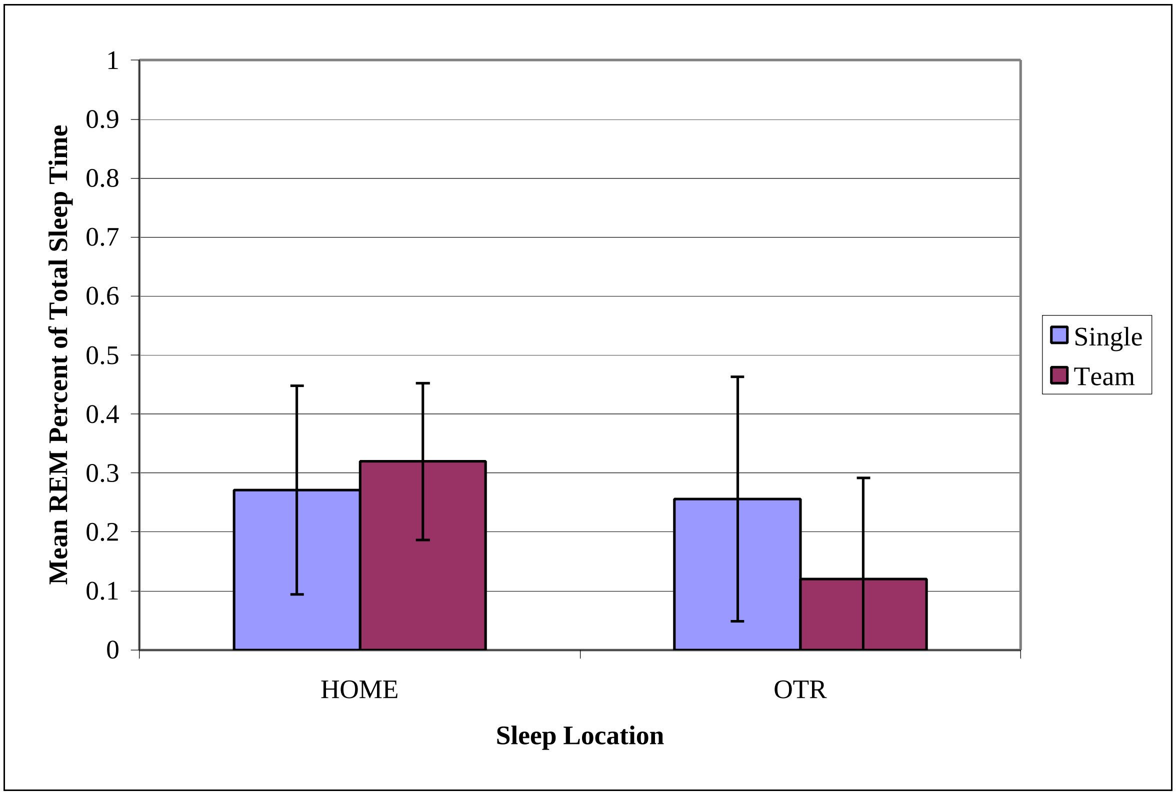

**Figure 27. Mean REM Percent of Total Sleep Time by Sleep Location for single and team drivers.**

In the Wake-up Survey, Question 8 asked, “How well did you sleep?” A 6-point scale was used:

1. Very badly
2. Badly
3. Fairly badly
4. Fairly well
5. Well
6. Very well

The general trend, as shown in Figure 28, was that home sleep was reported as being higher quality than road sleep. An ANOVA revealed that Location was a significant main effect for sleep quality, $F_{1,19} = 4.46$; $p = .0481$ (Appendix B, Table B-4). Note that all of the average ratings were in the range of “fairly well” to “well” with respect to subjective sleep quality.

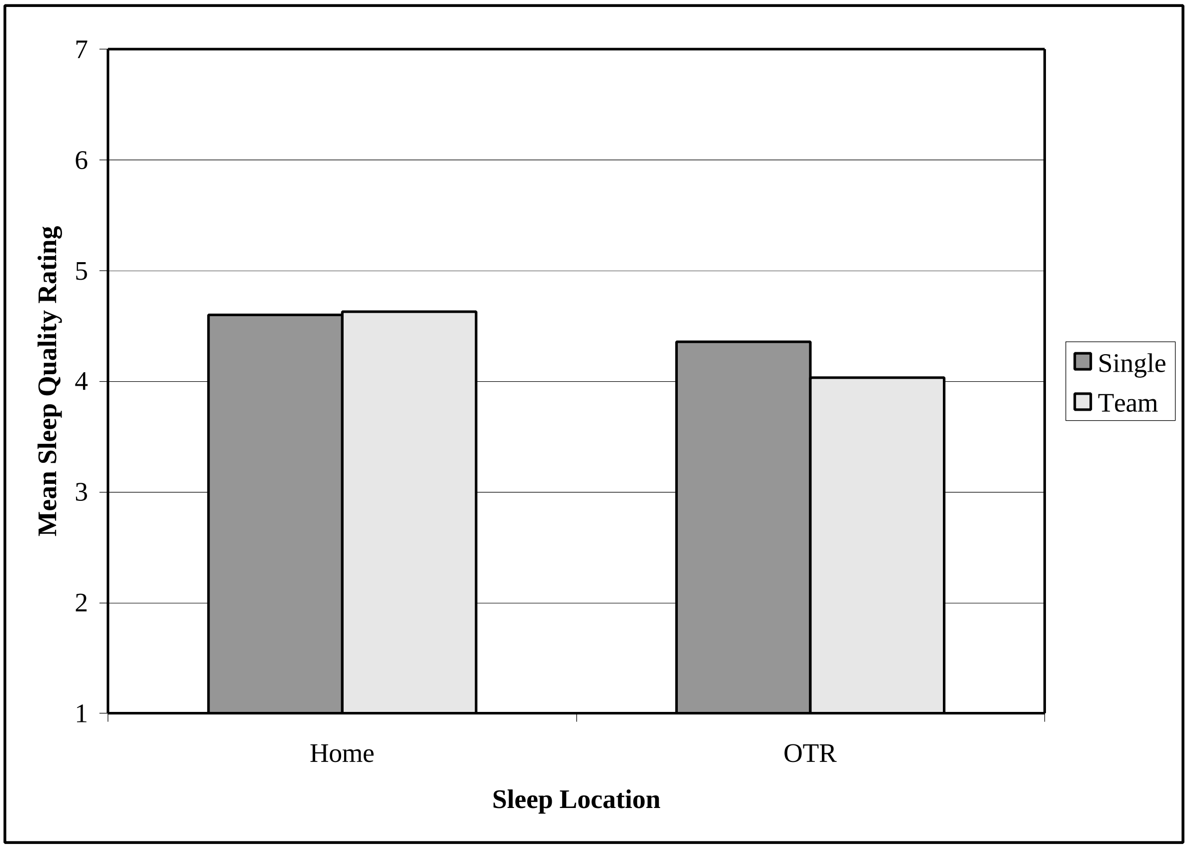

**Figure 28. Mean Sleep Quality ratings by Sleep Location for single and team drivers.**

The day-by-day analysis, for the Question 8 Quality of Sleep variable, revealed no significant main effects or interactions (Appendix B, Table B-5). As shown in Figure 29, the lowest average rating for Quality of Sleep was present for both single drivers and team drivers on the first day of a trip. This result, though non-significant, is interesting in that it may indicate that drivers take a couple of days to fully adapt to the "new" OTR sleep location when they first go out on the road.

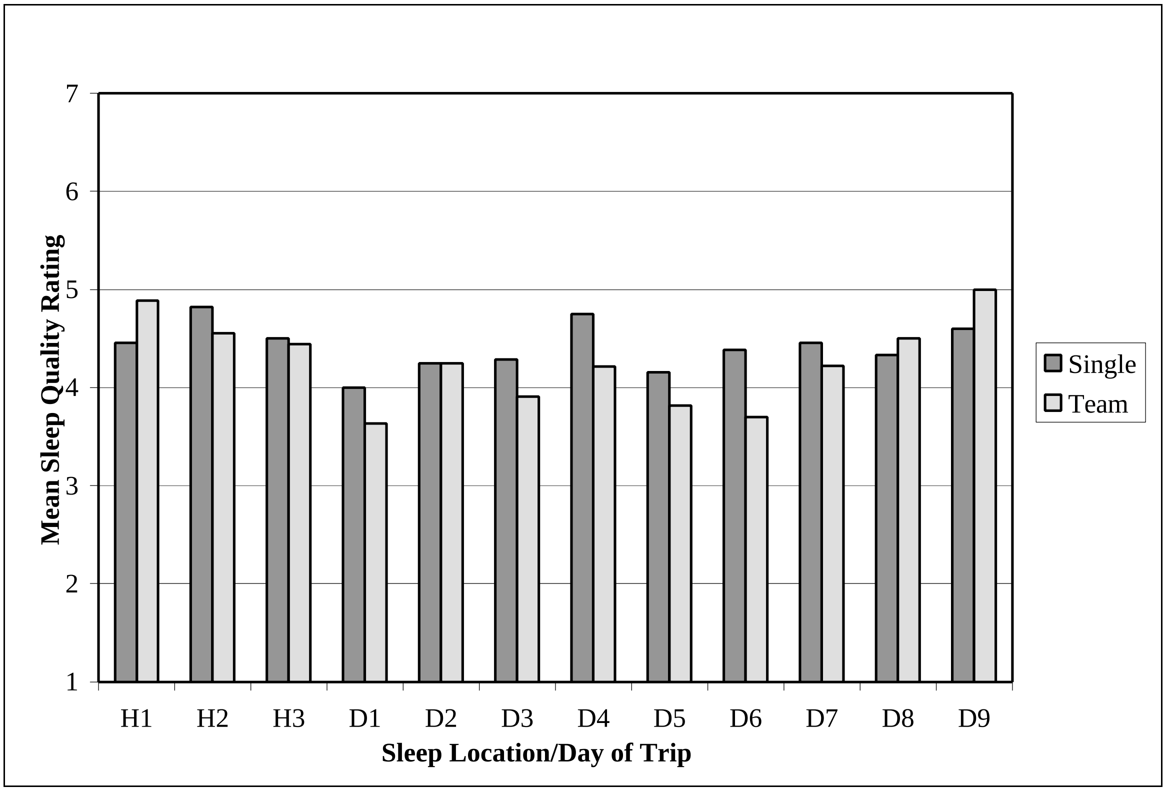

**Figure 29. Mean Sleep Quality ratings by Sleep Location and Day of Trip for single and team drivers.**

*Number of Awakenings*

An analysis of the number of awakenings occurring per sleep bout from the Nightcap data source revealed a significant Driver Type by Sleep Location interaction, $F_{1,8} = 13.99$; $p = .0057$. There was also a significant main effect of Driver Type, $F_{1,19} = 5.86$; $p = .0257$ (Appendix B, Table B-6). Drivers averaged about 2.5 awakenings per sleep bout while at home, Figure 30. In contrast, single drivers had fewer awakenings while OTR (1.1 on average), and team drivers had more while OTR (4.6 on average).

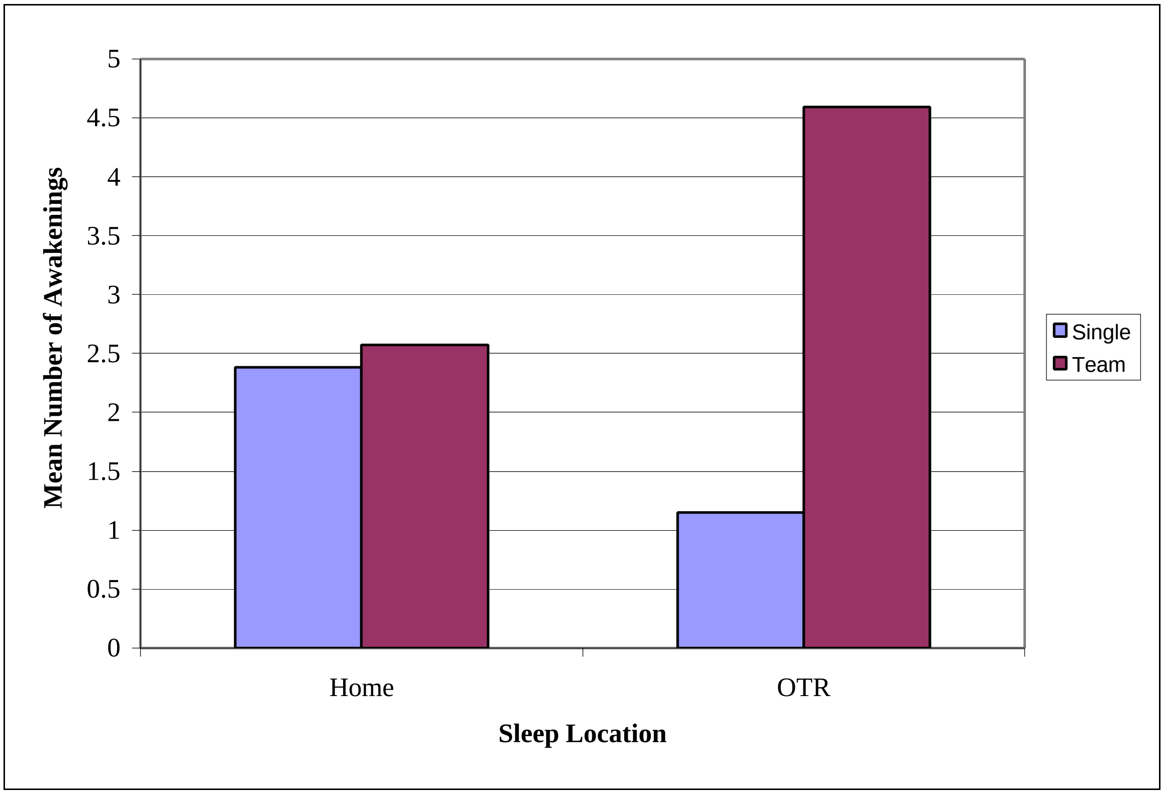

**Figure 30. Mean Number of Awakenings by Sleep Location for single and team drivers as determined by the Nightcap.**

An analysis to examine the mean number of awakenings relative to the length of the sleep bout revealed a significant Driver Type by Sleep Location interaction, $F_{1,8} = 25.94$; $p = .0009$, a significant main effect of Sleep Location, $F_{1,8} = 17.75$; $p = .0029$, and a significant main effect of Driver Type, $F_{1,19} = 6.58$; $p = .0190$ (Appendix B, Table B-7). Figure 31 depicts this relationship. As can be seen, team drivers had a much higher mean number of awakenings on the road relative to both their home sleep and single drivers in either location.

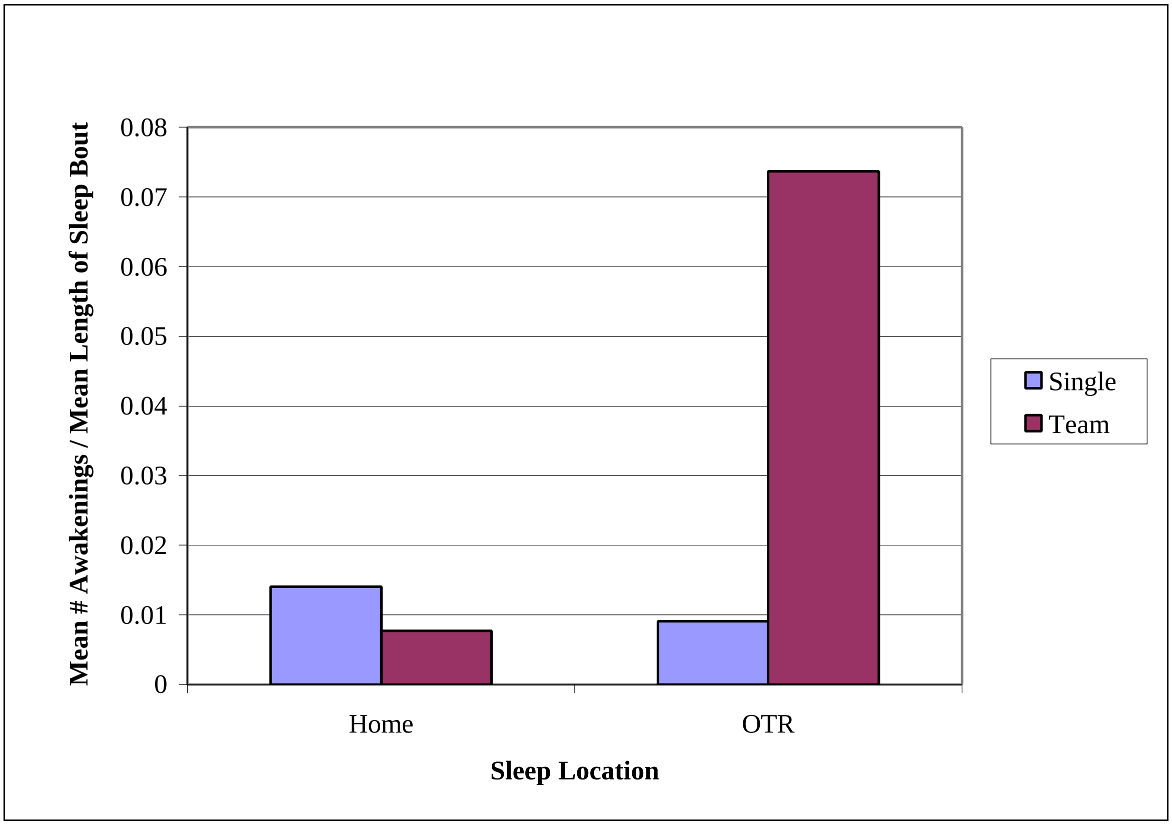

**Figure 31. Mean Number of Awakenings per Mean Length of Sleep Bout by Sleep Location for single and team drivers as determined by the Nightcap.**

For the subjective analysis of awakenings, survey Question 6 was analyzed: "How many times did you wake up?"

0. Not at all
1. Once
2. Twice
3. Three times
4. Four times
5. Five times
6. Six times
7. More than six times

No significance was found in the two-way ANOVA (Appendix B, Table B-8). A descriptive look at the data is shown in Figure 32. In general, the number of self-reported awakenings was lower than that indicated by the Nightcap, particularly in the case of the team drivers OTR. Single drivers reported being woken more often at home, while team drivers reported being woken more often on the road. However, this trend failed to reach significance.

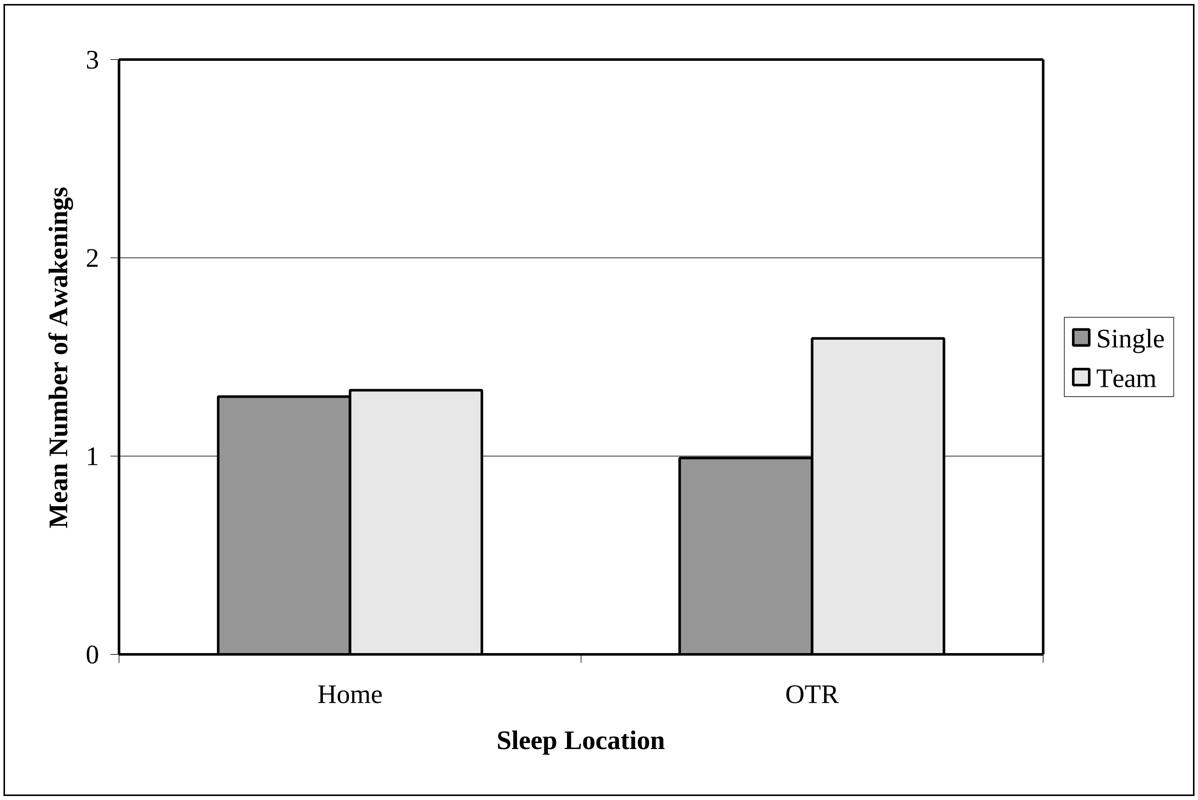

**Figure 32. Mean Number of Awakenings by Sleep Location for single and team drivers as determined from the survey data.**

To assess the frequency of sleep disruption, the total number of awakenings per sleep bout was divided by the minutes of sleep in that bout. An ANOVA was performed for this metric, analyzed by Driver Type and Location of Sleep. The interaction failed to reach significance, $F_{1,19} = 2.64$; $p = .121$, as did the main effects (Appendix B, Table B-9). As seen in Figure 33, the trend for team drivers reporting more sleep disruptions on the road is still present when exposure was accounted for; however, the trend was still not statistically significant.

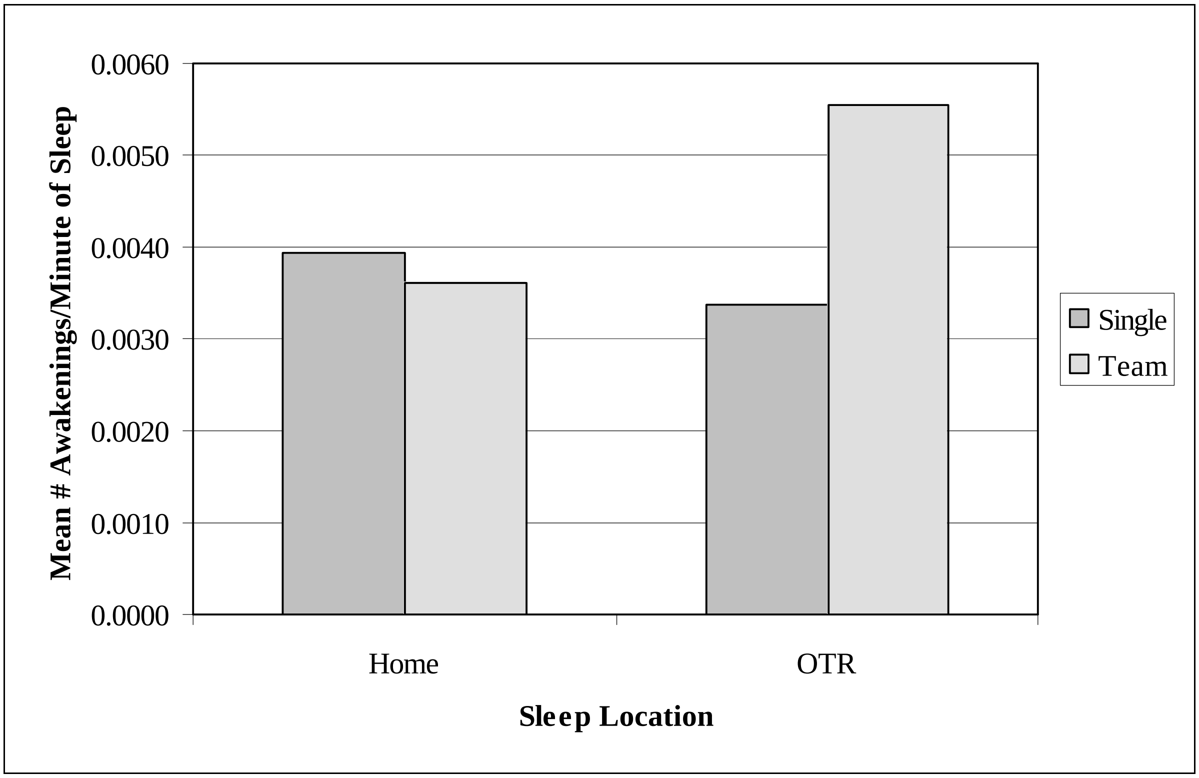

**Figure 33. Mean Number of Awakenings per Mean Minute of Sleep by Sleep Location for single and team drivers as determined from survey data.**

Figure 34 shows the day-by-day trend for the self-reported number of times awakened. An ANOVA revealed a significant interaction of Driver Type and Location/Day, $F_{11,179} = 1.96$; $p = .035$ (Appendix B, Table B-10). The interaction most likely results from the first three days of driving: on days 1 and 3, the team drivers were awakened more often, while on day 2, single drivers were awakened more often. After day 3, the team drivers generally reported being awakened more often than the single drivers, but the differences were not as large.

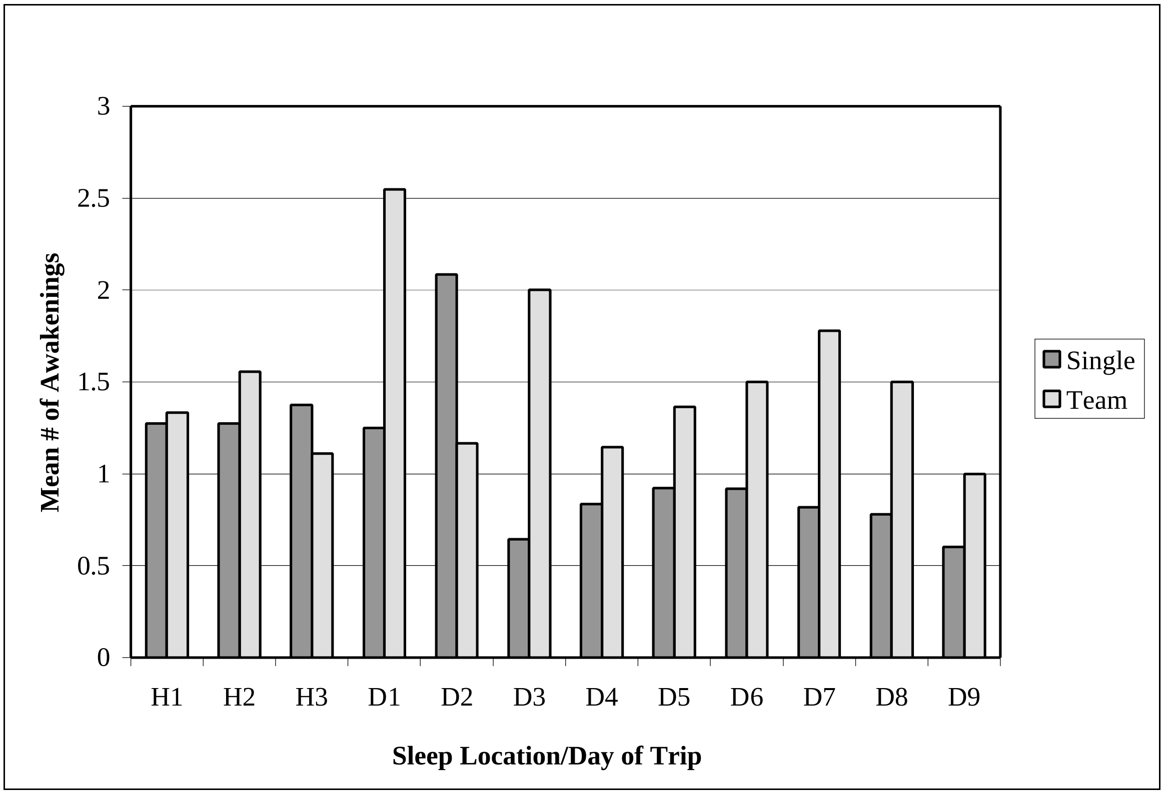

**Figure 34. Mean Number of Awakenings for Sleep Location and Day of Trip for single and team drivers as determined from the survey data.**

*Sleep Latency*
An analysis of the dependent variable Sleep Latency generated from the Nightcap data revealed no significant outcomes (Appendix B, Table B-11).

Question 14 on the Wake-up Survey asked drivers how long it took them to fall asleep. Drivers answered this question in hours and minutes, and the results were converted to minutes. As seen in Figure 35, drivers seemed to fall asleep more quickly at home than on the road. An ANOVA (Appendix B, Table B-12) showed that location was indeed significant for time to fall asleep, $F_{1,19} = 7.81$; $p = .012$.

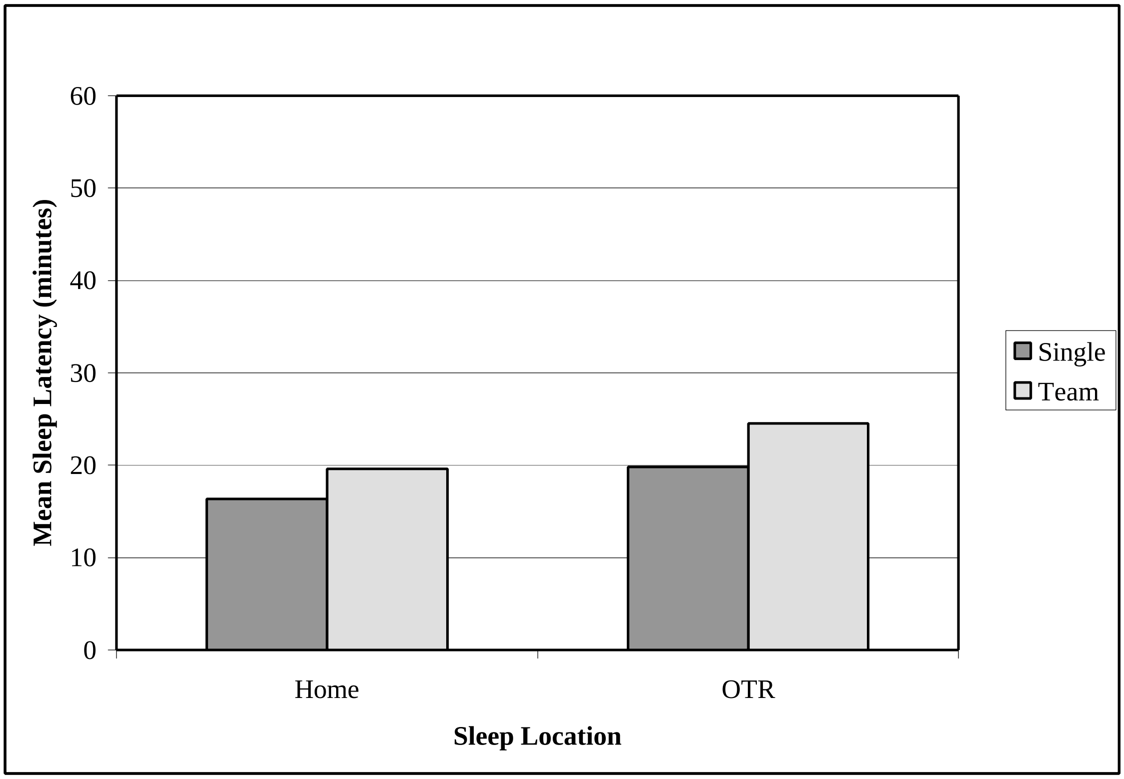

**Figure 35. Mean Sleep Latency by Sleep Location for single and team drivers.**

As shown in Figure 36, there were two days for which team drivers reported taking quite a bit of time to fall asleep, days 1 and 9. This resulted in a significant Location/Day main effect, $F_{11,180} = 2.01$; $p = .030$. A complete ANOVA is shown in Appendix B, Table B-13. The day 1 result could be attributed to difficulty sleeping in a moving truck unless some level of adaptation and/or some greater level of fatigue is present. However, there does not seem to be a general trend of falling asleep more quickly over the duration of the trip. Such a trend might indicate the presence of cumulative fatigue.

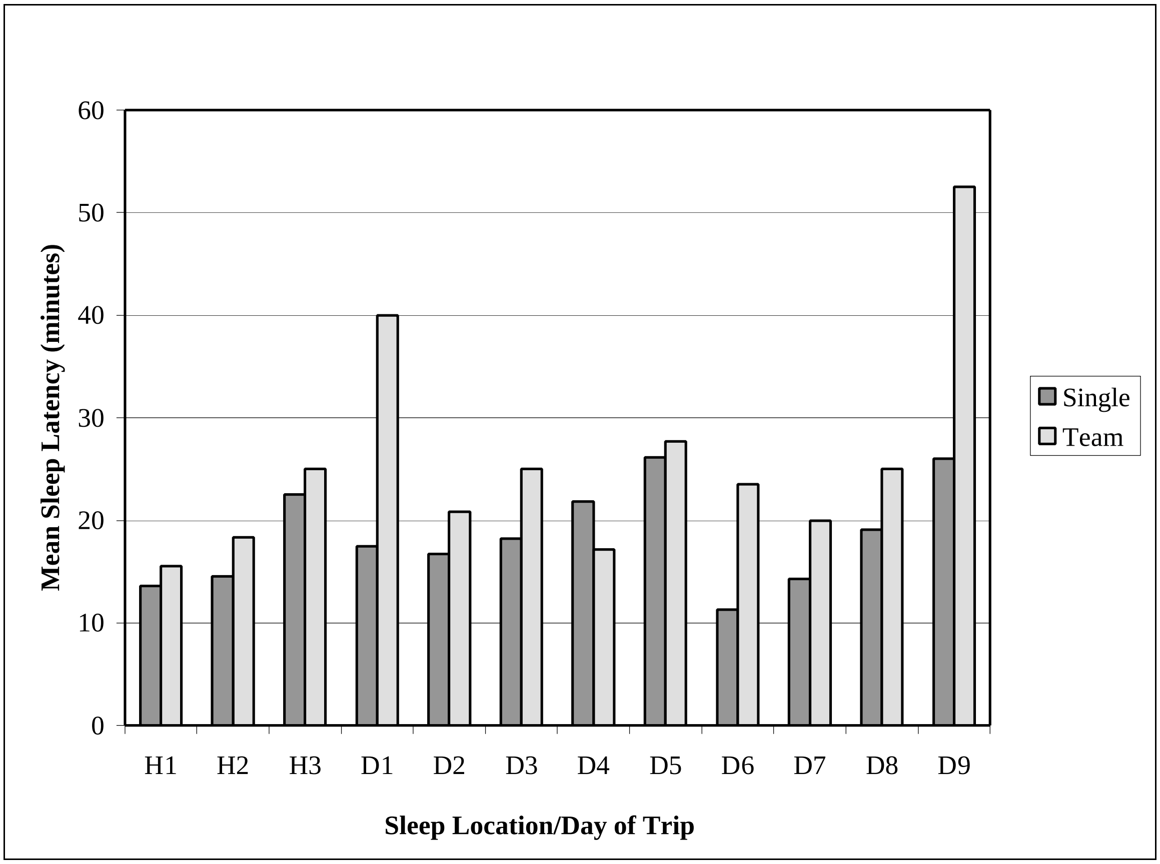

**Figure 36. Mean Sleep Latency by Sleep Location and Day of Trip for single and team drivers.**

*Depth of Sleep*
Depth of Sleep was assessed via the Wake-up Survey. The question asked, “Was your sleep”:

1. Very light
2. Light
3. Fairly light
4. Deep average
5. Fairly deep
6. Deep
7. Very deep

The two-way ANOVA revealed no significant main effects or interactions for Driver Type or Location of Sleep (Appendix B, Table B-14). The mean ratings are shown in Figure 37. As shown, all of the average ratings on the survey were in the range of “deep average” to “fairly deep.”

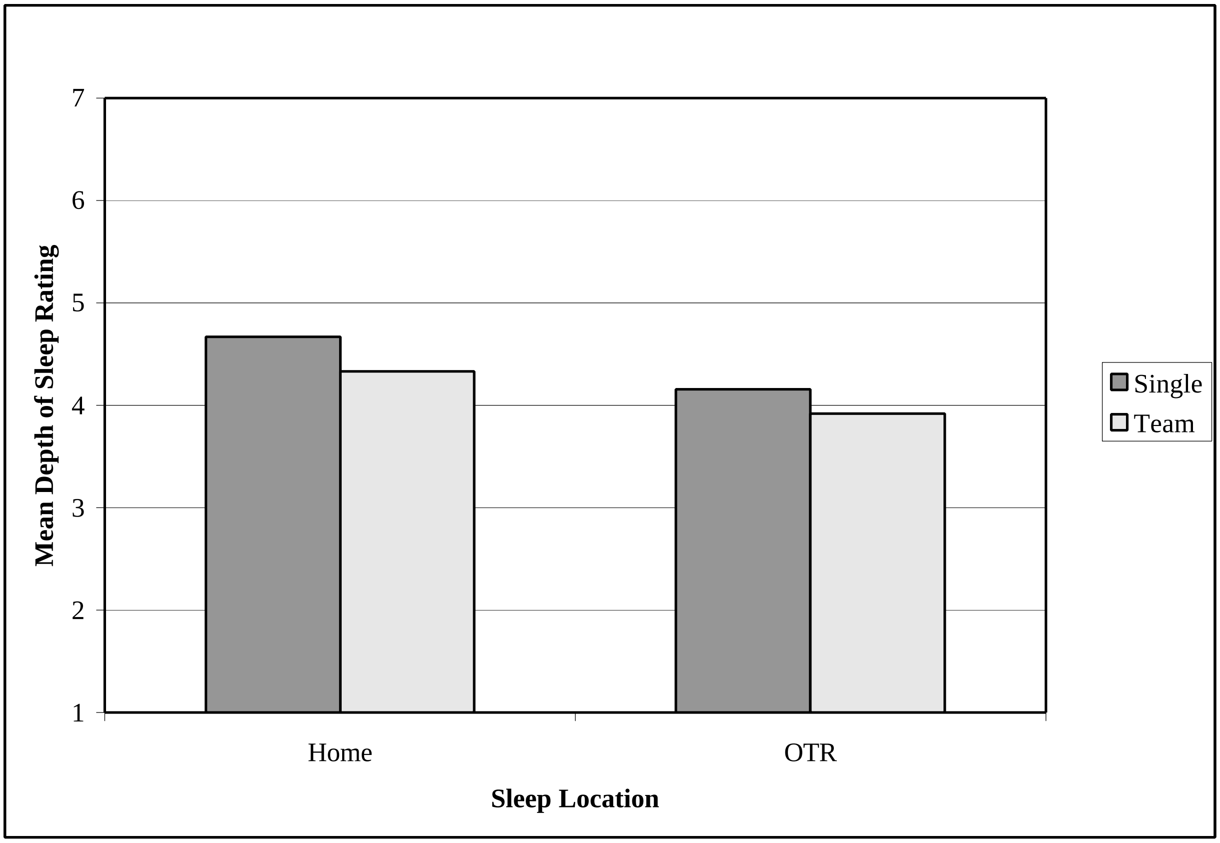

**Figure 37. Mean Depth of Sleep Rating by Sleep Location for single and team drivers.**

An analysis of the Depth of Sleep broken down by individual Day of Trip revealed a main effect of Location, $F_{11,19} = 2.00$; $p = .031$ (Appendix B, Table B-15). There appears to be a Location/Day trend, as seen in Figure 38. The general trend was that both single and team drivers reported sleeping more deeply as the trip progressed, while home sleep was fairly stable for both groups. This finding may be indicative of some level of cumulative fatigue, with increasing deeper sleep to help compensate for these cumulative effects.

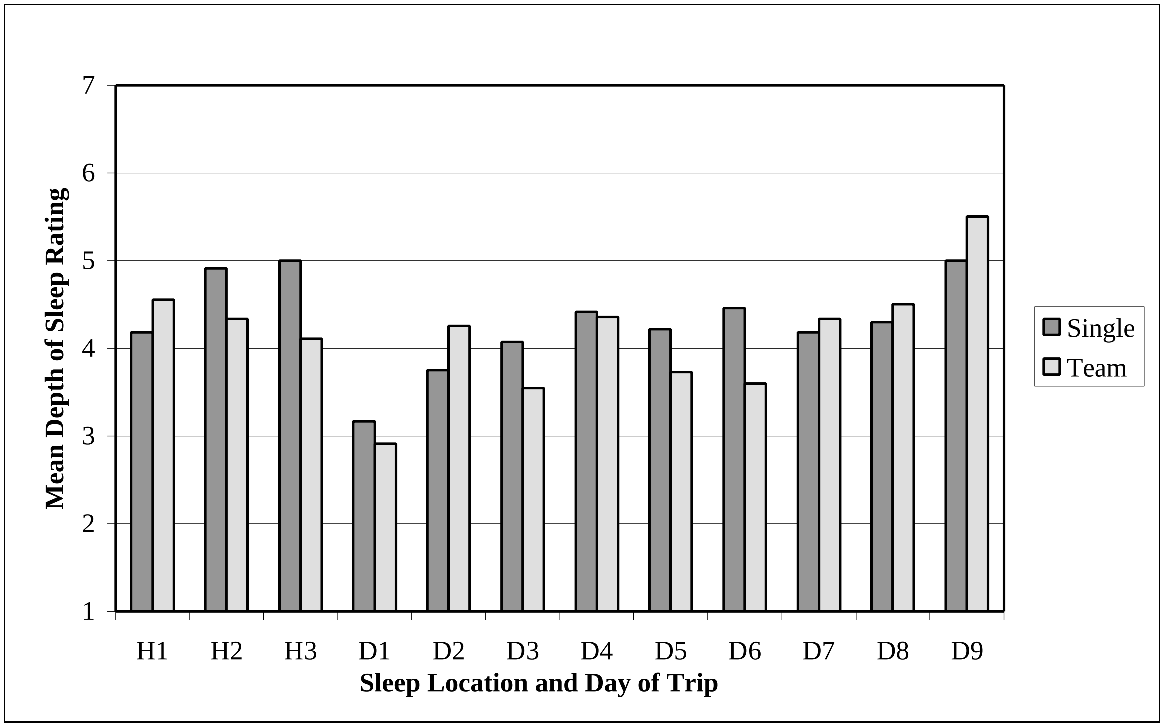

**Figure 38. Mean Depth of Sleep by Sleep Location and Day of Trip for single and team drivers.**

*Clearheaded Upon Awakening*

The degree to which drivers felt "clearheaded" upon awakening was assessed with the following Wake-up Survey question: "How clearheaded did you feel after getting up?"

1. Still very drowsy
2. Still moderately drowsy
3. Still slightly drowsy
4. Fairly clear headed
5. Alert
6. Very alert

As seen in Figure 39, the alertness ratings were fairly consistent across Driver Type and Location, and an ANOVA failed to find significance for this variable (Appendix B, Table B-16). In general, both single and team drivers felt "fairly clear headed," on average, during a trip.

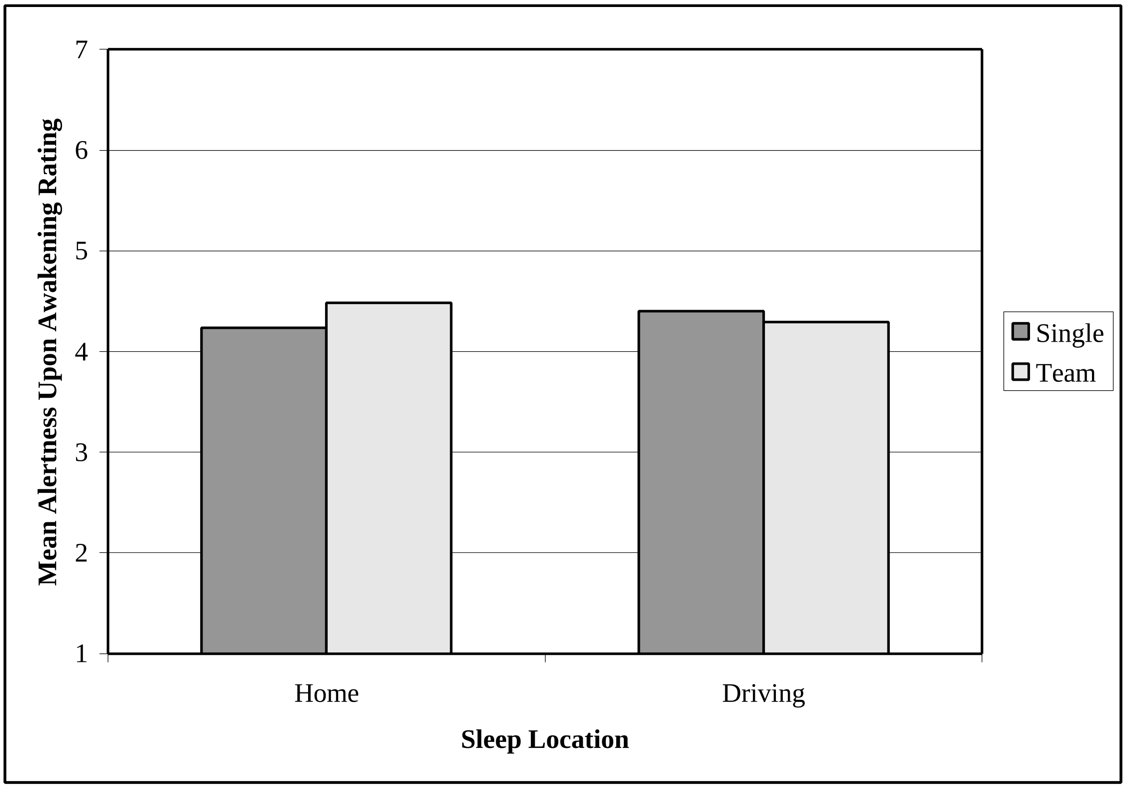

**Figure 39. Mean Alertness Upon Awakening by Sleep Location for single and team drivers.**

The “clearheaded” ratings were also remarkably consistent across days, as shown in Figure 40. An ANOVA failed to find significance for any main effects or interactions for this question (Appendix B, Table B-17). There was very little variation, on average, in the alertness level that drivers reported across Day of Drive.

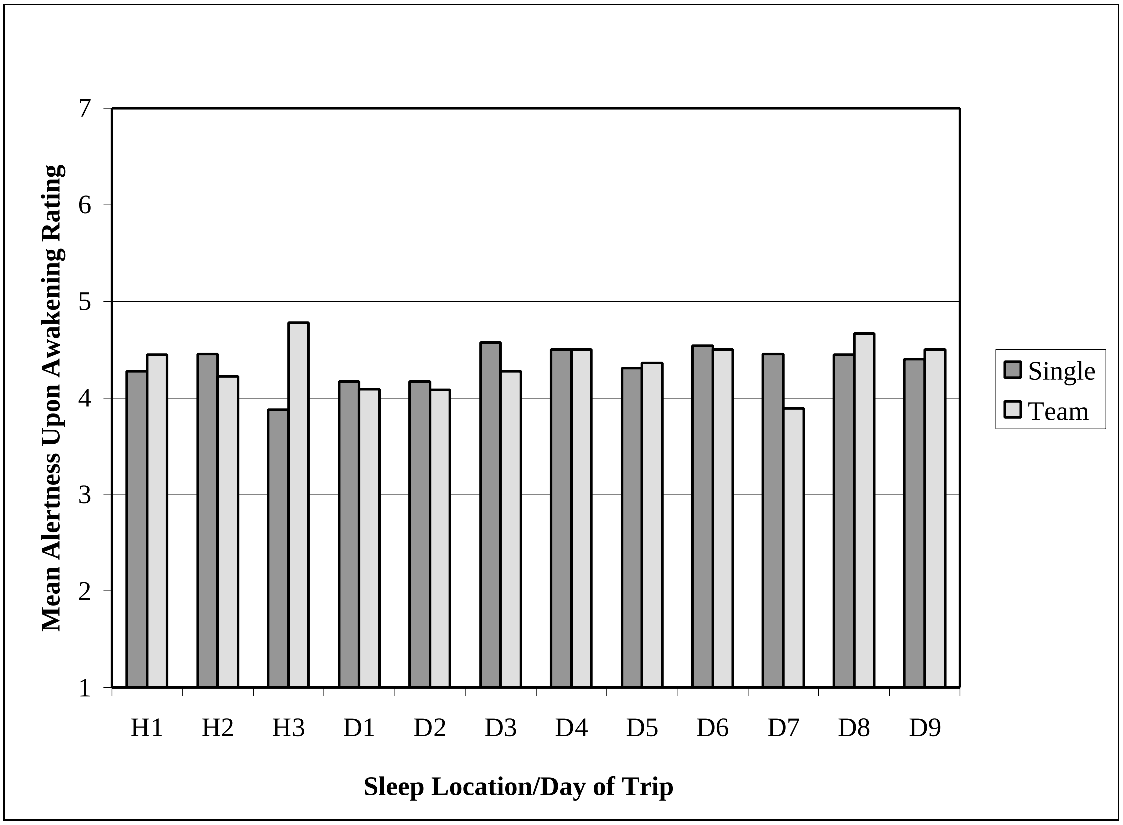

**Figure 40. Mean Alertness Upon Awakening by Sleep Location and Day of Trip for single and team drivers.**

*Satisfaction*

The Wake-up Survey included a question regarding sleep satisfaction: “How satisfied were you with the sleep you just had?”

1. Very unsatisfied
2. Moderately unsatisfied
3. Slightly unsatisfied
4. Fairly satisfied
5. Completely satisfied

The sleep satisfaction ratings were generally consistent across Driver Type and Location both day-by-day and collapsed across days (Figure 41). ANOVAs (Appendix B, Table B-18 and Table B-19) revealed no significant main effects or interactions for this analysis of sleep satisfaction. In general, the driver ratings for this question averaged about 3.7. This rating is between “fairly satisfied” and “slightly unsatisfied.”

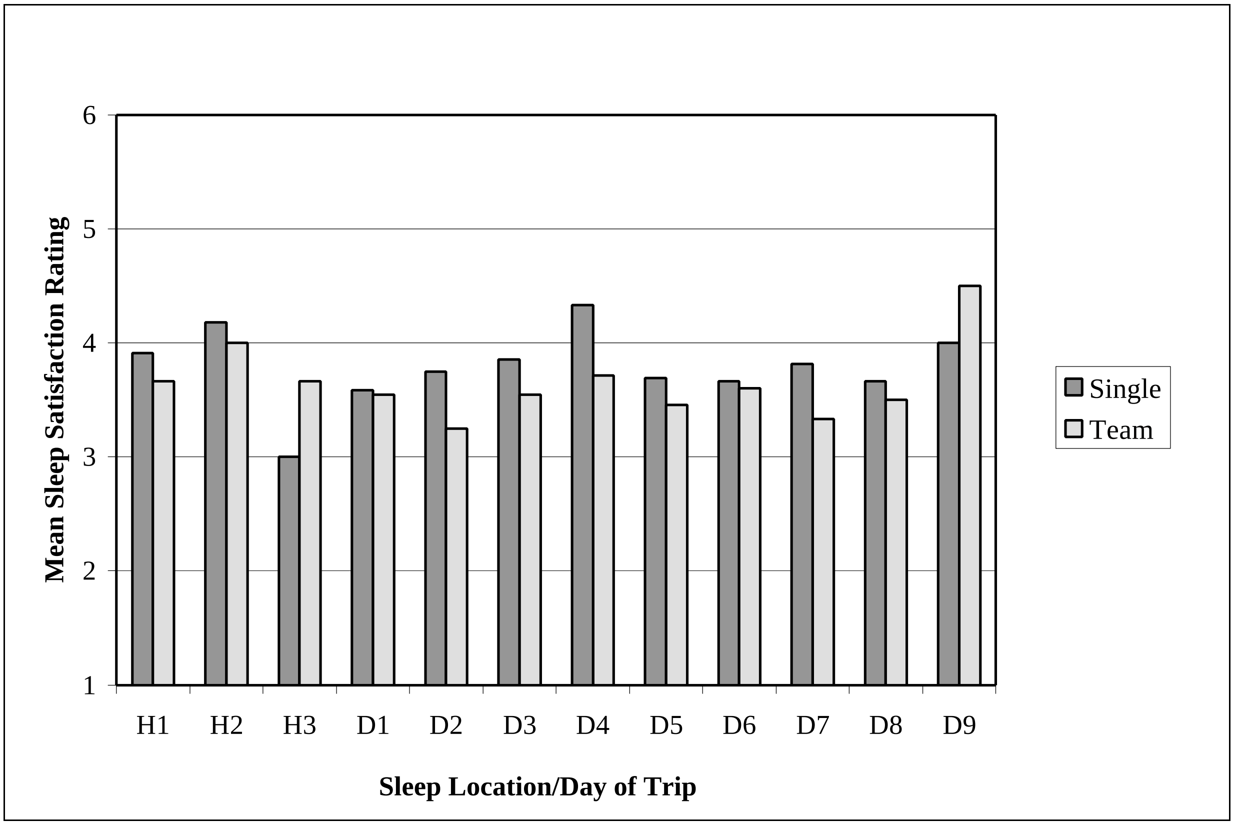

**Figure 41. Mean Sleep Satisfaction by Sleep Location and Day of Trip for single and team drivers.**

*Terminal Insomnia*
The Wake-up Survey question addressing premature awakening asked, “Were you troubled by waking prematurely, being unable to get off to sleep again?”

1. Yes
2. No

Since these data were in the form of yes/no answers, a chi-square test was used instead of an ANOVA. In looking at Figure 42, Driver Type by Location collapsed across days, it appears that the team drivers were awakened prematurely more often than the single drivers. A one-way chi-square test showed that Driver Type was significant ($X^2_1 = 4.445$; $p = .035$). Location does not appear to be as important as Driver Type in the figure, and this was confirmed by a one-way chi-square showing that Location was not significant. A two-way chi-square test also failed to reveal significance for any particular Driver Type/Location combination.

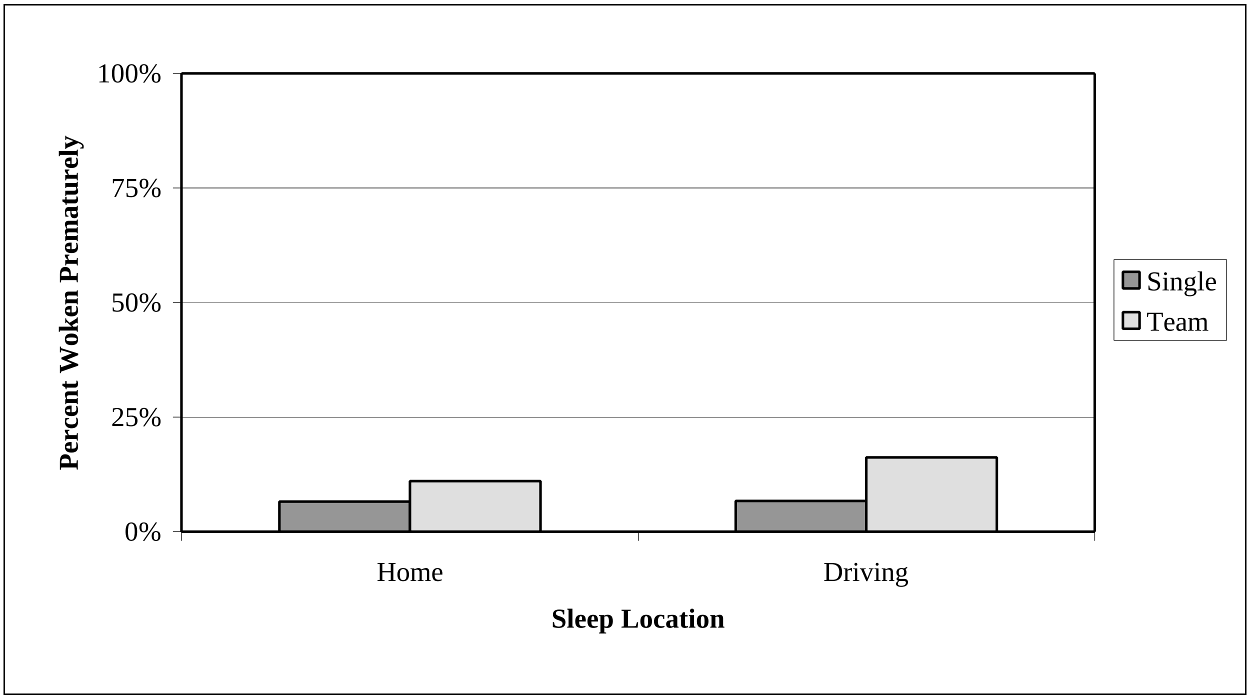

**Figure 42. Percent Woken Prematurely by Sleep Location for single and team drivers.**

An examination of the data on a day-by-day basis reveals that there were many days for which no drivers reported being woken prematurely. On Day 6, however, 50 percent of the team drivers reported being woken prematurely, while none of the single drivers reported being woken prematurely on that day (Figure 43).

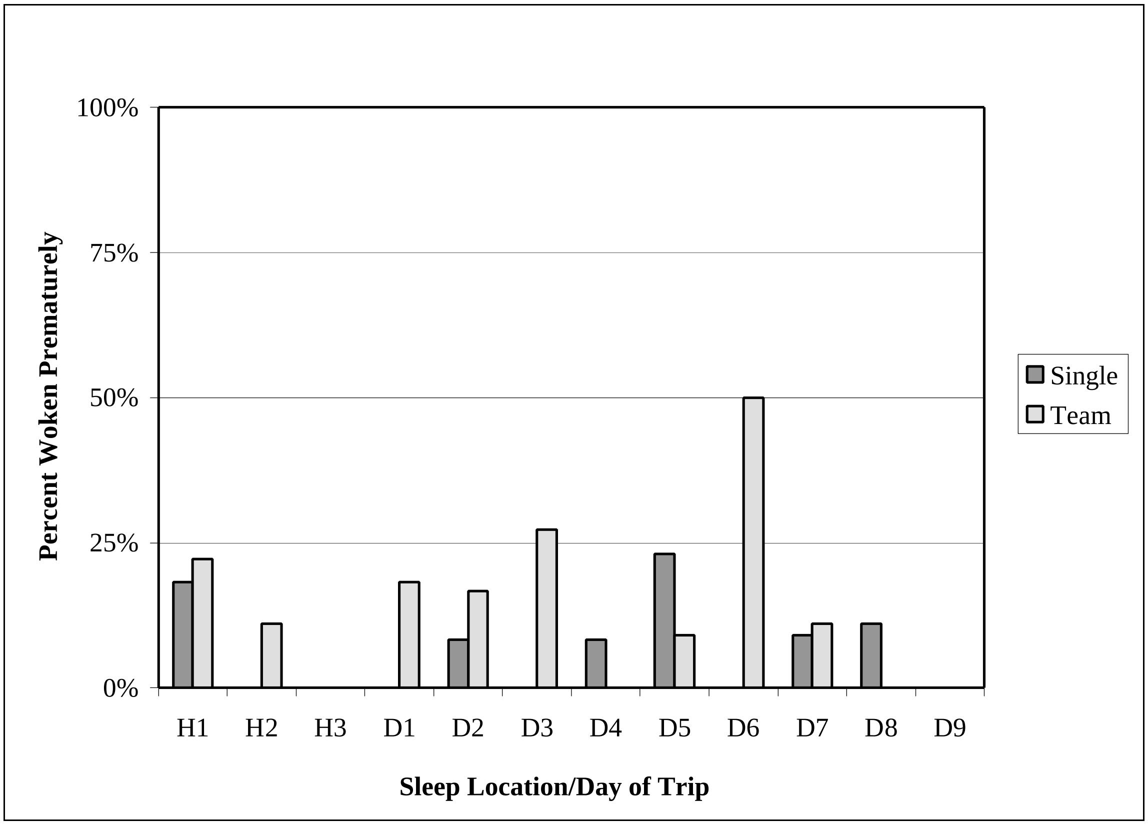

**Figure 43. Percent Woken Prematurely by Sleep Location and Day of Trip for single and team drivers.**

*Sleep Efficiency*

An analysis of Sleep Efficiency from the Nightcap data source was also conducted. There was a significant Driver Type by Sleep Location Interaction, $F_{1,13} = 6.41$; $p = .0250$ (Appendix B, Table B-20), and a significant main effect of Sleep Location, $F_{1,13} = 6.85$; $p = .0213$ (Appendix B, Table B-20). There was not a significant main effect of Driver Type, $F_{1,19} = 0.67$; $p = .4238$ (Appendix B, Table B-19). Sleep efficiency for team drivers was considerably lower when sleeping in a moving vehicle as compared to sleeping at home, as shown in Figure 44.

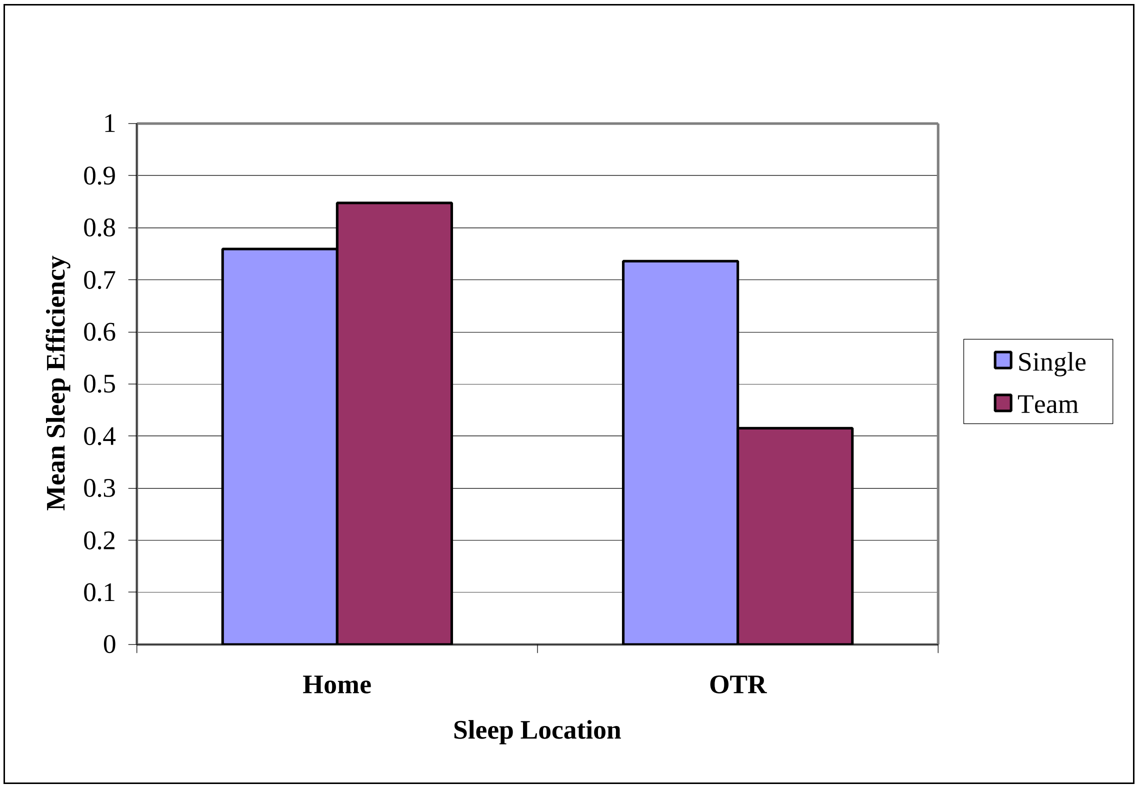

**Figure 44. Mean Sleep Efficiency by Sleep Location for single and team drivers.**

## Discussion

The analysis of this objective revealed several important findings. Across each day of an OTR trip, team drivers consistently reported getting more sleep than did single drivers. The difference was over one hour per day on average, with single drivers reporting six hours of sleep per 24-hour period and team drivers reporting just over seven hours per 24-hour period. There was much less of a pronounced difference between home sleep and OTR sleep, with drivers reporting roughly the same amount of sleep, on average, between the two locations. There were a number of measures, both objective and subjective, that indicated that the quality and depth of sleep was worse on the road, particularly for team drivers. Specifically:

- Team drivers got substantially less REM sleep while OTR.
- Both team and single drivers rated their sleep quality as lower OTR.

- Team drivers suffered from more awakenings while OTR, although single drivers had fewer awakenings OTR relative to home sleep. Team drivers had more awakenings per hour of sleep bout than did single drivers OTR.
- Both team and single drivers reported greater difficulty falling asleep OTR.
- Both types of drivers reported sleeping more deeply as a trip progressed, perhaps indicating the presence of a cumulative sleep deficit.
- Team drivers reported being prematurely awakened and had difficulty falling back asleep more often than did single drivers. Although this was most pronounced OTR, this same trend was also present for home sleep.
- Team drivers' sleep efficiency OTR is approximately one-half of that at home.

These results clearly show that the sleep that drivers get while on the road does not compare favorably to their normal home sleep. The overall sleep quality appears to be the worst in a moving truck; however, even the single drivers' sleep quality suffered while on the road.

## OBJECTIVE 2: DETERMINE IF ANY ENVIRONMENTAL VARIABLES APPEAR TO DISRUPT SLEEP

### Data Analysis Overview

The drivers who participated in this study were on the road between two and nine days at a time and slept in the tractors' sleeper berths during off hours. One of the primary objectives of this research was to determine if there are any environmental variables that impact drivers' sleep quantity or quality. In examining this objective, two sources of data were considered: (i) sleep data collected from the Nightcap, and (ii) environmental data collected from sensors instrumented on the trucks.

As indicated in Objective 1, drivers who participated in this research were asked to wear a Nightcap device each time they slept. The Nightcap collected a variety of measures related to the quantity and quality of sleep that a driver received. A list of the Nightcap measures is presented in Table 18. For each sleep bout (i.e., each instance the driver went to sleep), the Nightcap device provided an estimate of: (i) the time that the Nightcap was on, (ii) the number of times the driver awoke, (iii) the number of awakenings divided by the number of hours that the Nightcap was on, and (iv) the number of awakenings divided by the hours of sleep.

**Table 18. List and description of measures collected by the Nightcap.**

| Nightcap Measure | Measure Description |
|---|---|
| Nightcap On Time | Measured in minutes, the amount of time that the Nightcap was on the driver's head. |
| Number of Awakenings | Frequency count of the number of times that the Nightcap indicated that the driver woke up from sleep. |
| Number of Awakenings/Nightcap On Time | Summary statistic of the number of awakenings divided by the amount of time (in hours) that the Nightcap was worn. |
| Number of Awakenings/Nightcap Sleep Time | Summary statistic of the number of awakenings divided by the estimate sleep time (in hours). |

In addition to the Nightcap data, the second source of data that is relevant for this objective is the potential environmental factors. The environmental factors were collected via sensors that were instrumented on the trucks. Four environmental factors were recorded: (i) vibration, (ii) sound pressure level (SPL), (iii) illumination, and (iv) temperature. Table 19 highlights these factors and the sensors used to collect this data.

**Table 19. Environmental variables collected in this study.**

| Factor | Description | Sensor |
|---|---|---|
| Vibration | A measure of "whole-body" vibration, transmitted to the body as a whole through the supporting surfaces of the body while lying on a mattress in a sleeper berth. | Triaxial piezoelectric accelerometers embedded in the mattress. |
| SPL (sound, pressure, level) | A measure of Leq sound pressure level recorded by microphones that are located in the trucks' sleeper berths inside acoustically transparent enclosures. | Larson-Davis 824 real-time spectrum analyzer installed in the truck. |
| Illumination | A measure of illumination in the sleeper compartment. | Ambient illumination sensor using a photosensitive transducer. |
| Temperature | A measure of the "dry-bulb" ambient air temperature in the sleeper berth. | Solid state temperature sensor measuring "dry-bulb" ambient air temperature. |

To investigate this objective, data from 7 single drivers and 9 team drivers (16 drivers total) were used. Because of occasional problems with the Nightcap device and the environmental sensors, not all data from all drivers were valid. As such, only the data determined to be valid were used to explore this issue. Note that because of the reliance on differing sensors, subjects, and therefore the data, for this objective are somewhat different than the data used for Objective 1.

## Results

Two sets of analyses were conducted in support of this objective. The first analysis focused on the Nightcap data, while the second analysis examined the environmental factors as a function of the awakenings measured by the Nightcap devices. The following sections highlight the findings from each analysis.

### *Sleep Period Length and Number of Awakenings*

Table 20 presents a summary of the Nightcap data for each subject. These data were analyzed using the Mann-Whitney test (sometimes referred to as the Wilcoxon- Mann-Whitney test), a non-parametric alternative to the t-test. Each measure is considered individually in Figures 45 to 48.

**Table 20. Summary of awakening data for all 16 subjects.**

| Driver Category | Subject No. | Average Time Nightcap On (minutes) | Average No. Awakenings per Sleep Bout | Average Awak./Hr. (Nightcap On) | Average Awak./Hr. (Sleep Time) |
|---|---|---|---|---|---|
| Single | 7 | 261.7 | 3.3 | 0.8 | 1.7 |
| Single | 10 | 357.0 | 2.0 | 0.3 | 0.4 |
| Single | 12 | 333.6 | 1.6 | 0.4 | 0.4 |
| Single | 13 | 285.3 | 1.3 | 0.3 | 0.3 |
| Single | 22 | 168.4 | 2.0 | 0.8 | 1.1 |
| Single | 26 | 260.8 | 1.8 | 0.4 | 0.5 |
| Single | 201 | 78.0 | 3.0 | 2.3 | 3.7 |
| **Single Avg.** | | **249.26** | **2.14** | **0.76** | **1.16** |
| Team | 103 | 311.0 | 7.3 | 1.5 | 2.4 |
| Team | 104 | 469.4 | 4.7 | 0.9 | 2.0 |
| Team | 107 | 210.4 | 3.6 | 1.0 | 5.2 |
| Team | 108 | 165.4 | 3.6 | 1.3 | 6.2 |
| Team | 111 | 101.6 | 1.0 | 0.7 | 1.4 |
| Team | 112 | 139.8 | 2.0 | 1.0 | 5.3 |
| Team | 203 | 524.0 | 4.0 | 0.5 | 0.5 |
| Team | 205 | 158.5 | 3.0 | 1.2 | 2.9 |
| Team | 209 | 199.0 | 3.4 | 1.2 | 7.2 |
| **Team Avg.** | | **253.23** | **3.62** | **1.03** | **3.68** |

In Figure 45, the average time that the Nightcap was on is plotted as a function of the driver number/category. As can be seen, the average time that the Nightcap was on was approximately the same for single drivers (*M* = 249.26 min.) as for team drivers (*M* = 253.23). Accordingly, the Mann-Whitney test was not significant, *p* > .05.

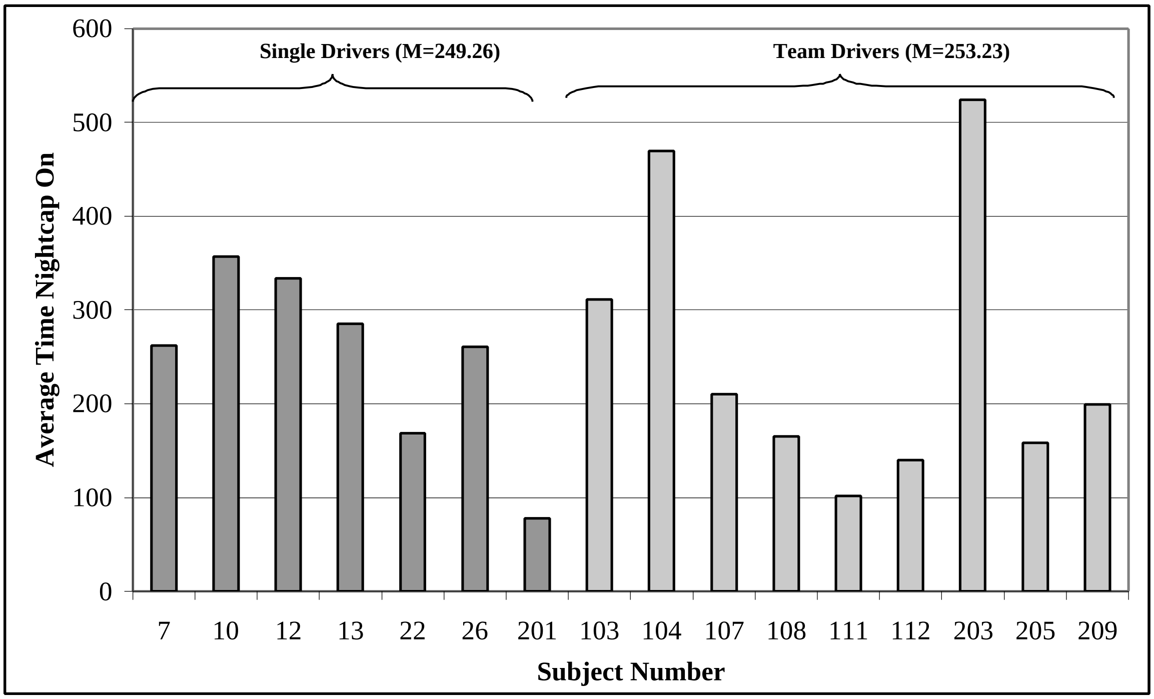

**Figure 45. Average time that the Nightcap was on for each driver.**

Figure 46 shows the average number of awakenings per sleep bout. This measure is directed at answering the question: How many times, on average, did the driver wake up from his/her sleep? The average number of awakenings for single drivers was 2.14 and for team drivers it was 3.62. Though the numerical difference was again large, the Mann-Whitney test was not significant, *p* > .05.

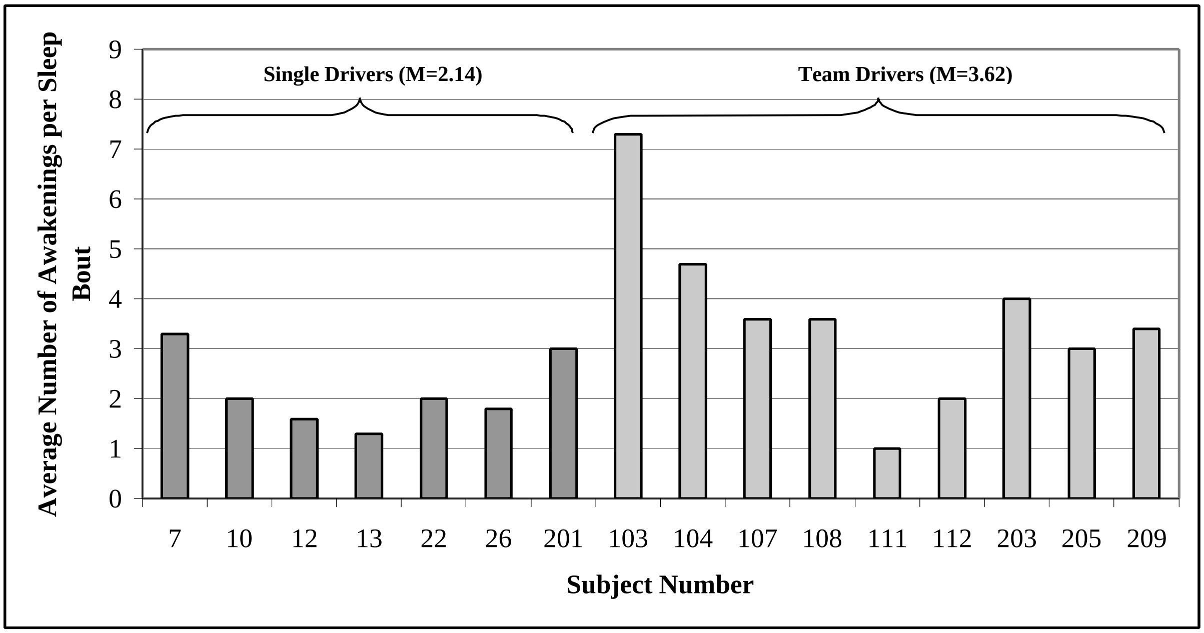

**Figure 46. Average number of awakenings per sleep bout for each driver.**

Figure 47 shows the average number of awakenings divided by the number of hours that the Nightcap was on. The average awakenings per hour were 0.76 for single drivers and 1.03 for team drivers. The Mann-Whitney test proved significant, *p* <.05. Figure 48 shows the average number of awakenings divided by the number of hours of sleep time. The average was 1.16 for single drivers and 3.68 for team drivers. Again, the difference proved to be statistically significant, *p* < .05. Taken together, the results shown in Figures 47 and 48 indicate that team drivers are awakened (for whatever reason) more frequently than are single drivers.

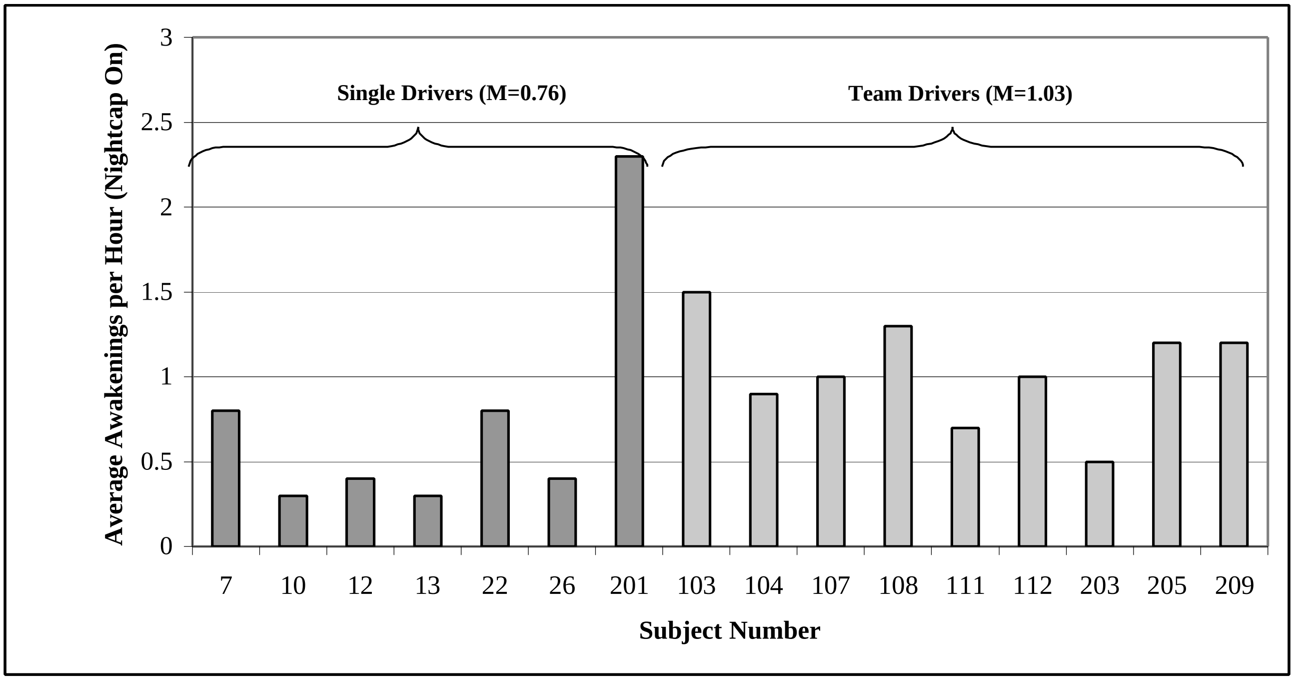

**Figure 47. Average number of awakenings per hour that Nightcap is on for each driver.**

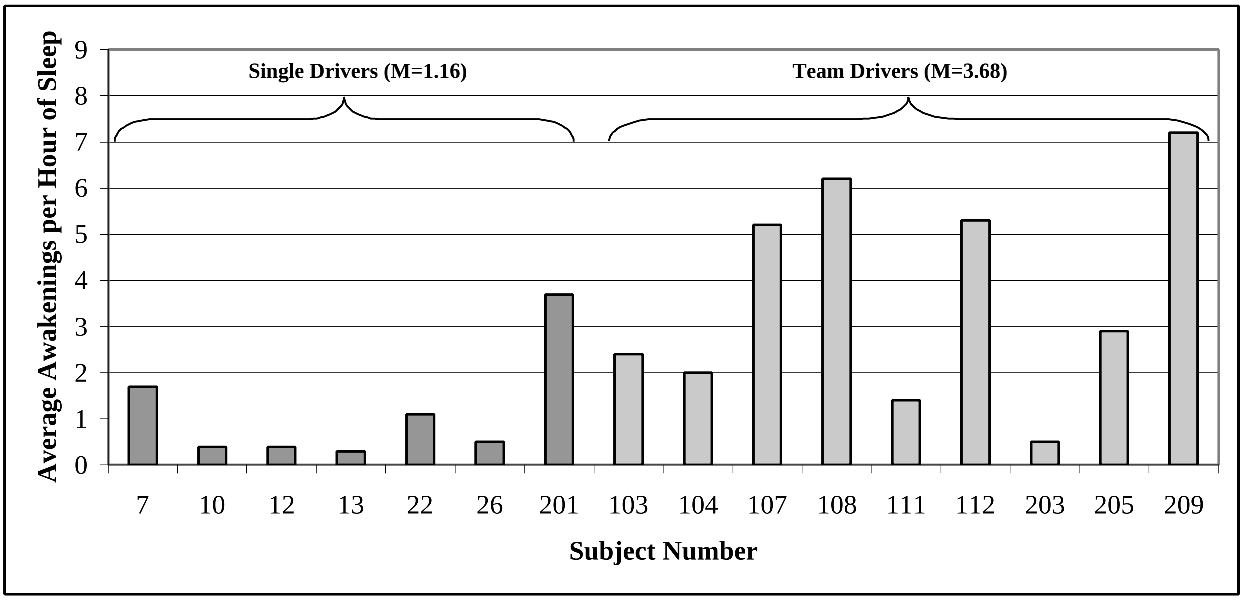

**Figure 48. Average number of awakenings per hour of sleep for each driver.**

*Assessment of Environmental Factors in the Occurrence of Awakenings*

Table 21 presents a summary of the environmental data for each subject. As can be seen, there are 7 measures for each subject. The first measure, number of sleep bouts, refers to the number of times that the driver went to sleep. The number of awakenings refers to the number of times during the recorded sleep bouts that the driver had a sleep disturbance. The remaining five measures in the table are the factors that are attributed to the awakening. These include the four environmental factors described previously, along with an "indeterminable" measure that indicated that the cause of the awakening could not be determined and did not appear to be related to the environmental factors.

Note the high number of vibrations that occurred for team drivers 103, 104, 107, and 108. At first glance one might suspect differences in the truck suspension; however, drivers 103, 104, 107, 108, 111, and 112 drove the Volvo and drivers 203, 205, and 207 drove the Peterbilt. Data indicate that these team drivers were sleeping in a moving vehicle most of the time; therefore, the road surface condition would be a likely reason for the instances of high vibration.

**Table 21. Summary of potential environmental factors affecting all subjects.**

| Subject Number | No. Sleep Bouts | No. Awakenings | No. Vibration | No. SPL | No. Illumination | No. Temperature | No. Indeterminable |
|---|---|---|---|---|---|---|---|
| 7 | 7 | 23 | 0 | 0 | 0 | 0 | 23 |
| 10 | 6 | 12 | 0 | 2 | 0 | 0 | 10 |
| 12 | 8 | 13 | 0 | 1 | 0 | 0 | 12 |
| 13 | 3 | 4 | 0 | 0 | 1 | 0 | 3 |
| 22 | 7 | 14 | 0 | 5 | 0 | 1 | 8 |
| 26 | 4 | 7 | 2 | 0 | 0 | 0 | 5 |
| 201 | 1 | 3 | 0 | 0 | 0 | 0 | 3 |
| **Single Average** | **5.14** | **10.86** | **0.29** | **1.14** | **0.14** | **0.14** | **9.14** |
| 103 | 6 | 44 | 33 | 3 | 0 | 1 | 11 |
| 104 | 7 | 33 | 26 | 1 | 0 | 4 | 6 |
| 107 | 7 | 26 | 19 | 1 | 0 | 1 | 7 |
| 108 | 8 | 32 | 24 | 0 | 0 | 0 | 8 |
| 111 | 5 | 5 | 5 | 0 | 0 | 1 | 0 |
| 112 | 5 | 10 | 5 | 0 | 0 | 0 | 5 |
| 203 | 2 | 8 | 1 | 1 | 0 | 2 | 5 |
| 205 | 2 | 6 | 4 | 5 | 0 | 0 | 0 |
| 209 | 5 | 17 | 0 | 10 | 0 | 1 | 7 |
| **Team Average** | **5.22** | **20.11** | **13.0** | **2.33** | **0** | **1.11** | **5.44** |

Figure 49 shows a histogram of the total number of recorded sleep bouts for each driver. The average for the two groups of drivers was similar; for single drivers, the average was 5.14 sleep bouts while for team drivers it was 5.22 sleep bouts.

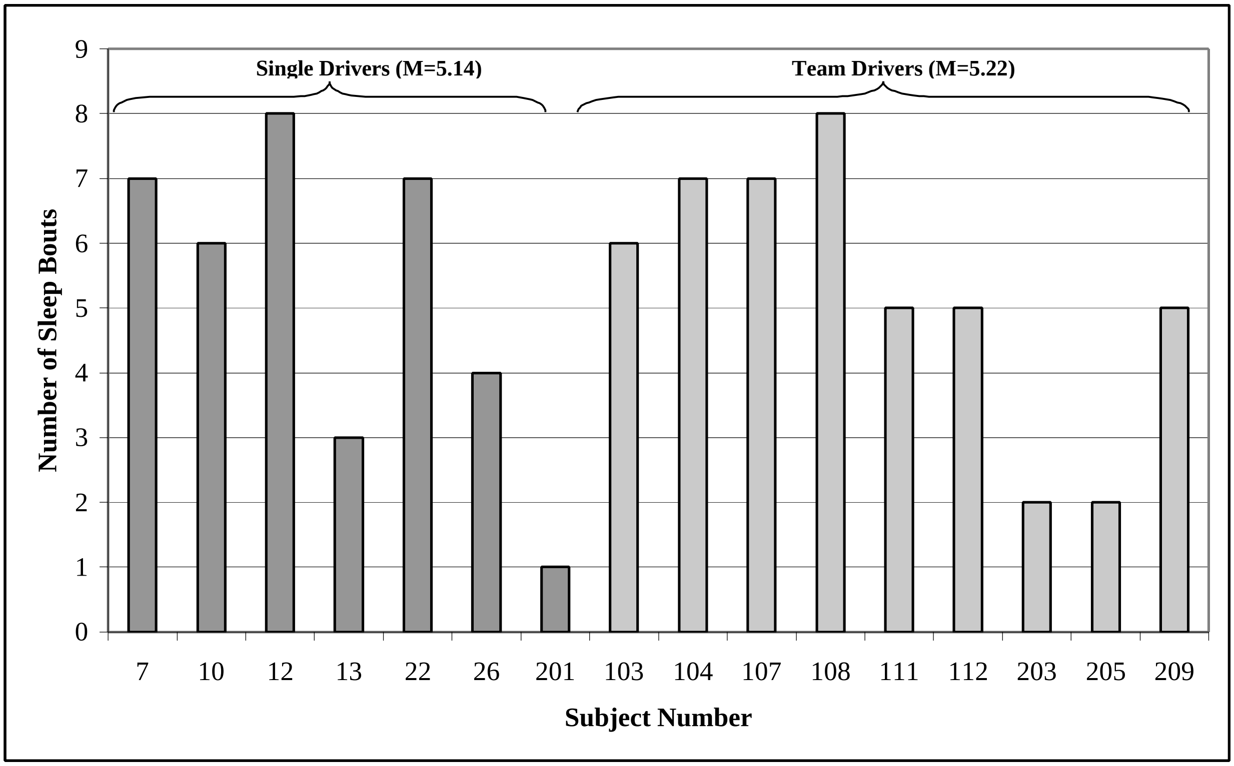

**Figure 49. Number of sleep bouts for each driver.**

The total number of awakenings for the two groups of drivers is shown in Figure 50. A large difference was found in the number of awakenings for team drivers (*M* = 20.11) as compared to single drivers (*M* = 10.86). That is, team drivers were found on average to be awakened from their sleep twice as often as single drivers.

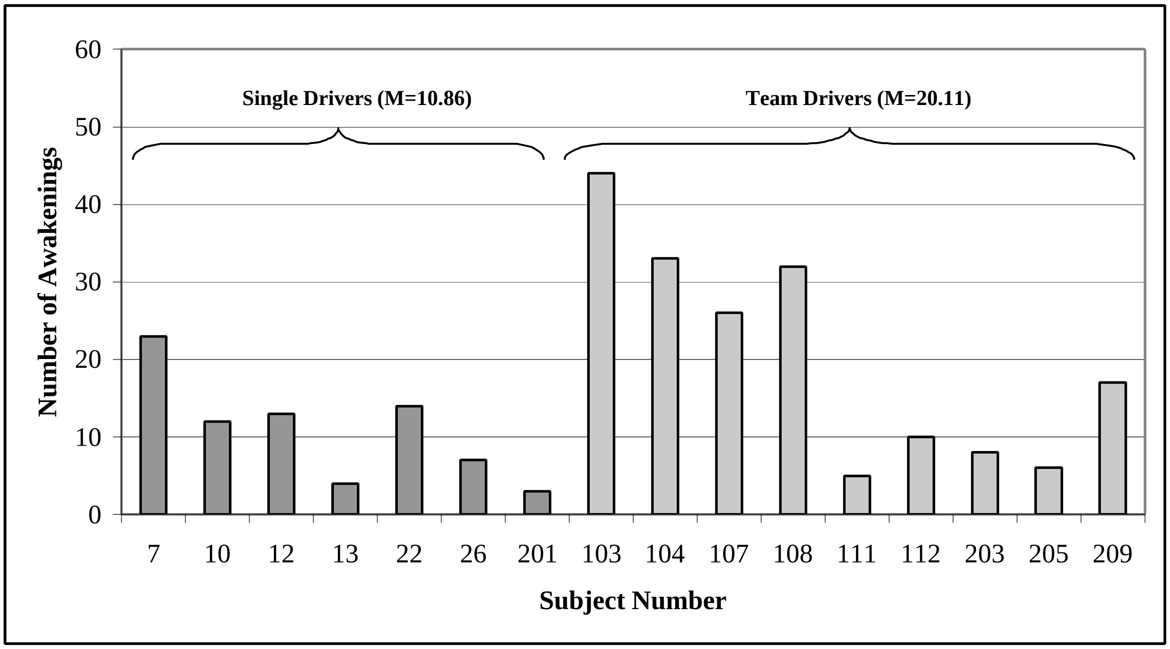

**Figure 50. Number of awakenings for each driver.**

As mentioned previously, four environmental factors were considered: vibration, sound pressure level (i.e., noise), illumination, and temperature. For each awakening that was recorded, the environmental data for a period of five minutes prior to the occurrence of the disturbance (the five-minute period ended at the time given for the occurrence of the awakening) was highlighted, examined to determine if a change in the environment might be responsible for the disturbance, and the average magnitude (in the case of the noise levels, the Leq) of each environmental variable for the five-minute period calculated. The environmental data for each awakening was then examined to determine if the awakening could be attributed to one or more environmental factors. In this process, the five minutes of data preceding the awakening was examined for variability. If variation was found, the data recorded during the preceding 10-15 minutes (preceding the beginning of the five minute period before the awakening) was examined to determine if a change in the pattern of the fluctuations in the environmental variable might have been responsible for the awakening. Where changes in one or more of the environmental variables were thought to be possible causes of the awakening, the factors were so noted. The awakening was labeled as "indeterminate” when no possible cause was discernible. In some instances, multiple environmental factors were possible causes of the awakening. In such cases, each possible factor was noted. The process of assessing the environmental factors associated with an awakening was subjective. As such, the attribution of an environmental factor to a sleep disturbance should only be considered a “potential” environmental factor and not the definitive reason for the awakening.

Figure 51 shows the number of times that a factor was attributed to a sleep disturbance for each of the environmental factors and for the indeterminable factor. Looking at each factor individually, it can be seen that for vibration, the average frequency that this factor was attributed to single drivers was 0.29, while for team drivers it was 13.0. This very large difference is likely due to the fact that, while a driver is sleeping, the vehicle is in motion during the team operation but standing still for the single operation. As such, one would expect that vibration would be less of an issue for the sleep of single drivers as compared to team drivers.

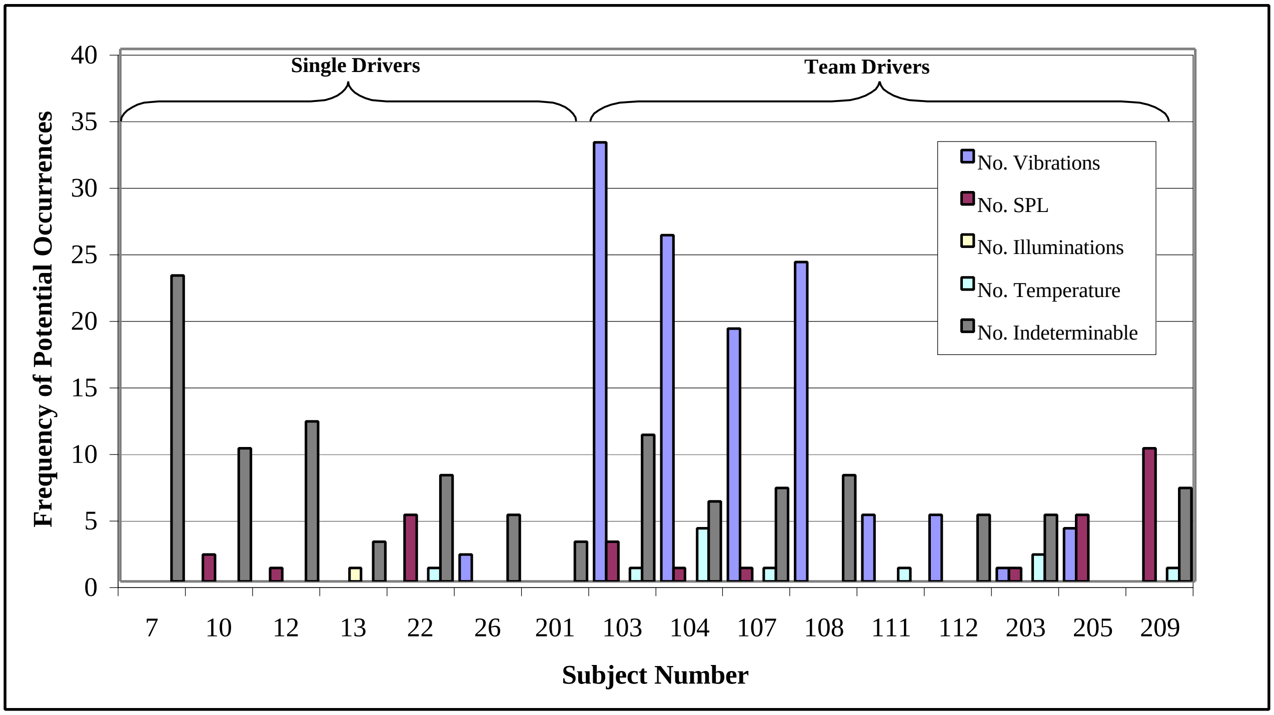

**Figure 51. Frequency of potential occurrence for the environmental factors for each driver.**

Looking at the noise level (SPL) for the two groups of drivers, the average number of times that SPL was attributed to a sleep disturbance for single drivers was 1.14, and for team drivers it was 2.33. As with vibration, this large discrepancy may have been due to the fact that the vehicle was in motion when team drivers slept, and it was parked when single drivers slept. In regards to illumination, across all drivers, both single and team, only one sleep disturbance was attributed to this factor. As such, it is believed that this has little impact on the drivers' ability to sleep. A large average difference was found in regard to temperature. For single drivers, there was only one instance of an awakening being attributed to a large temperature change (*M* = 0.14). However, there were 10 instances of a temperature change being attributed to team driver sleep disturbances (*M* = 1.11). This finding has implications for the design of sleeper berths in that insulation, and the minimizing of temperature changes in the sleeper berth, should be of concern to designers. The category with the largest frequency of attributions was "Indeterminable." That is, for most cases, the cause of the sleep disturbance could not be easily identified.

**Discussion**

There were a number of interesting findings from the analysis on sleep disturbances and the environmental factors that may impact drivers' sleep. With regard to the Nightcap data, it was found that the average number of times that a team driver was awakened was significantly higher than for single drivers. The average awakenings divided by the time that the Nightcap was on indicated that team drivers have significantly more sleep disturbances than do single drivers. One explanation for this finding is that, because the truck is in motion when the team driver is trying to sleep, the quality of sleep (in terms of sleep disturbances) is much less for team drivers.

When the environmental factors were considered, it was found that many of the sleep disturbances that occurred for single drivers could not be attributed to an environmental factor. For team drivers, who sleep while the vehicle is in motion, factors such as vibration and noise would be expected to impact drivers' sleep. This was indeed the case. This finding suggests that while the vehicle was in motion, the sleeper berths used in the study were not impervious to the effects of vibration and noise and this, in turn, potentially degraded the drivers' sleep. This finding has design implications for sleeper berths and indicates that, when the truck is in motion, greater attention should be paid to reducing the amount of vibration and noise that invades the sleeper berth.

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## OBJECTIVE 3: DETERMINE THE LEVEL OF ALERTNESS FOR SINGLE VERSUS TEAM TRIPS, LENGTH OF TRIP, TIME OF DAY, AND LENGTH OF SHIFT

### Data Analysis Overview

#### *Alertness Measures*

For this objective, two alertness measures were used to evaluate possible differences in the Driver Type (single vs. team), Length of Trip, Time of Day, and Length of Shift. The two alertness measures used in this analysis were the Observer Rating of Drowsiness scale and the Karolinska scale. The Observer Rating of Drowsiness (ORD) scale was used by trained data reduction analysts during the video reduction procedure. The analysts watched from 3 to 12 minutes of continuous videotape and rated each driver's drowsiness level for every minute of the continuous video segment. The ORD scale is a continuous scale from 0 to 100. For some of the following analyses, the scale was separated into 5 categories:

1. Not Drowsy (rating of 0-12.49)
2. Slightly Drowsy (rating of 12.5 – 37.49)
3. Moderately Drowsy (rating of 37.5 – 62.49)
4. Very Drowsy (rating of 62.5 – 87.49)
5. Extremely Drowsy (rating of 87.5- 100)

In a separate analysis, the ORD rating for the second minute of each segment of data was averaged across hour, shift, and day to obtain an average ORD/hour, ORD/shift, and ORD/day.

Drivers used the Karolinska scale to rate their own drowsiness levels. The Karolinska scale is a scale with discrete rankings from 1 to 9. Drivers were asked to rate their drowsiness levels at pseudo-random intervals varying between 45 and 75 minutes (every hour plus or minus 15 minutes) while they were driving. For several analyses, the nine categories were collapsed into three categories to analyze the data. This was necessary to provide an adequate number of data points as the data were parsed to address the issues in question. A Karolinska rating from 1 to 3 was categorized as "not drowsy," 4 to 6 was categorized as "somewhat drowsy," and 7 to 9 was categorized as "very drowsy."

#### *Driver Data Included in the Analyses*

Thirteen single subjects and 14 team drivers were chosen from the entire data set of 30 single subjects and 13 teams. These subjects were chosen based upon the number of days that data were available. When there were less than three days of data collected (due to truck failure, hardware system failure, or other extenuating circumstances), the driver was not included in the subject pool.

Since the goal of this objective was to determine the level of driver alertness for the variables of interest (i.e., Driver Type, Time of Day, Length of Shift, and Length of Trip for each analysis), the critical incident triggers were excluded and only the timed triggers from the data were used.

Data were used for the first eight days of the trip. Few of the drivers had data for days 9 and 10 since most trips were shorter than 9 days in duration. There were only six subjects' data for day 9, resulting in 49 data points, and only one subject's data for day 10, resulting in eight data points. Therefore, data for days 9 and 10 were not used for analyses for Objective 3.

## Results

The analyses that were conducted to meet Objective 3 are described in detail below.

### *Correlation Between Observer Rating of Drowsiness and Karolinska Ratings*

First, a determination of the relationship between the ORD and the Karolinska drowsiness ratings was necessary to interpret all other analyses using these two drowsiness measures. This is required because if the correlations were very high, for all practical purposes, the measures would be redundant and should not be interpreted independently.

The Spearman Rank Order Correlation Coefficient was used for all correlation analyses for Objective 3. The scale data for this analysis were used in their raw form and were not collapsed into categories. The overall correlation between the ORD and Karolinska ratings for all data points was $r_s = .20$; $p < .01$. Somewhat weak correlations were also found when single and team drivers were examined separately. For single drivers across all days of driving, there was a weak level of correlation, $r_s = .19$; $p < .01$. Similarly, the team driver data across all days of driving revealed a weak level of correlation, $r_s = .21$; $p < .01$. A review of the data revealed that there were very few cases where either the drivers or the trained observers rated fatigue above "somewhat drowsy" on the respective scales. Individual differences in driver ratings, coupled with the relatively small range of the vast majority of these data, are likely the cause for the relatively low correlations between measures. As will be discussed in greater detail in later sections, an important finding of this research is that there were very few instances where drivers were having difficulty with greater than moderate levels of fatigue.

In order to reduce the random variability in the correlation, an additional correlation analysis was conducted with the data collapsed across Hour of Day. The correlation of the mean ORD and Karolinska values averaged for Hour of Day indicated a high and significant correlation, $r_s = .75$; $p < .01$. For single drivers exclusively, the correlation was $r_s = .68$; $p < .01$. For team drivers, the correlation was $r_s = .77$; $p < .01$. This shows that while there is variability between the raw data points in the two drowsiness measures, they generally do correlate when looking at overall trends in the data.

As expected, these results indicate that the two measures are related but not identical. Therefore, it is important to look at the results from both scales for each of the subsequent analyses.

### *ORD and Karolinska Rating Values for Single and Team Drivers by Length of Trip and Hour of Day*

#### Application of Analysis of Variance Procedure

In order to examine interactions, the original experimental design called for conducting a 2 Driver Type (Single, Team) X 8 (Length of Trip) X 24 (Hour of Day) mixed-factor ANOVA for the ORD ratings and the Karolinska ratings. Since missing data were present, the General Linear

Model procedure was used. These analyses used the rating data in their raw form; that is, the ORD scale was 100 points and the Karolinska scale was 1 to 9. (See Appendix C: Objective 3 ANOVAs for complete ANOVA tables.)

Only the Hour of Day main effect was significant (or approached significance) for ORD, $F_{23,59}$ = 4.57; $p < .01$. For the Karolinska ratings, a main effect of Hour of Day was also revealed, $F_{23,292}$ = 3.40; $p < .01$ (Appendix C, Tables C-1 and C-2). The finding is not surprising since the nature of fatigue is such that it varies greatly across the time of day due to circadian rhythms, meals, naturally occurring short bouts of drowsiness, and other causes. However, these natural variations that occur within each day may be masking other important effects.

As shown in Figure 52, the average ratings for both scales across Hour of Day were, on average, fairly low. All of the values shown, regardless of the time of day, represent values that vary only between the “alert” or “not drowsy” values and the “somewhat drowsy” values of the respective scales. The ratings for both scales have what appears to be a sinusoidal pattern. The highest ORD ratings occurred from approximately midnight to 5:00 am. In contrast, the highest Karolinska ratings occurred between about 4:00 am and 7:00 am. For both scales, the lowest ratings occurred between approximately 10:00 am and 3:00 pm.

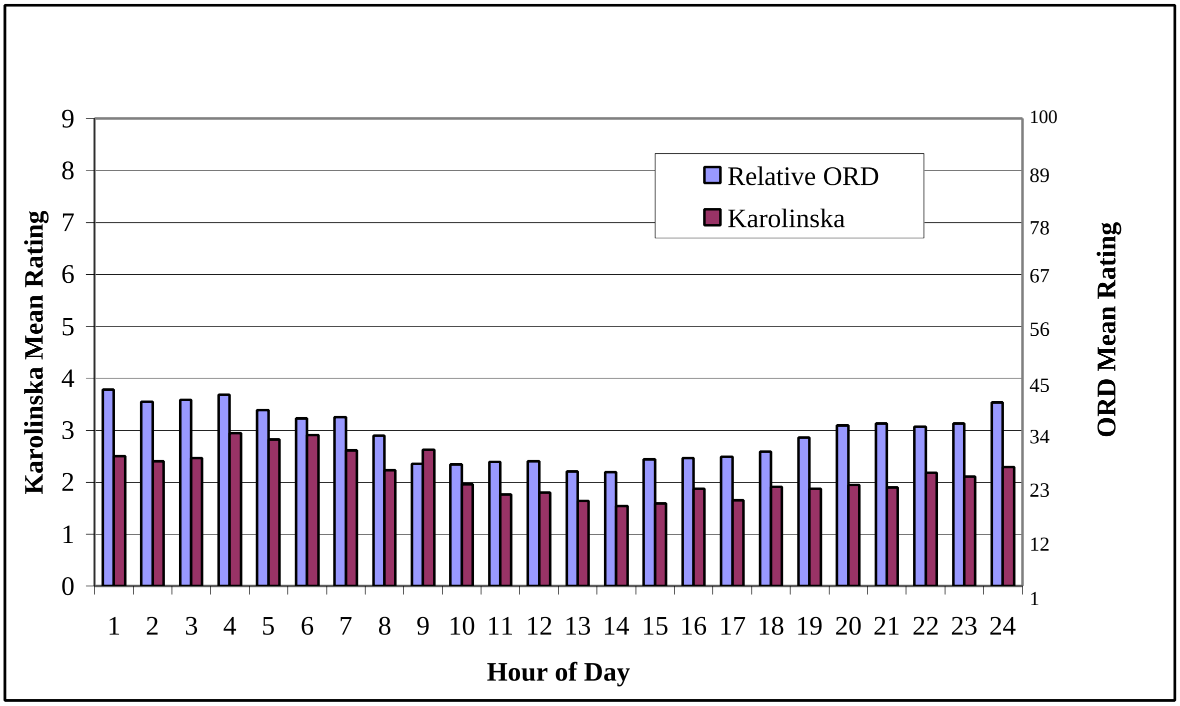

**Figure 52. Mean Karolinska and Mean Relative ORD Ratings by Hour of Day.**

Figures 53 and 54 depict the ORD and Karolinska ratings, respectively, for Hour of Day for single and team drivers separately. A significant main effect of Driver Type for the Karolinska ratings was found, $F_{1,25} = 5.42$; $p < .05$ suggesting the presence of an important trend (Appendix C, Table C-2). Specifically, the team drivers consistently rate themselves as more drowsy compared to the single drivers in Figure 54, while no such trend appears based upon the observer ratings of drowsiness (ORD) in Figure 53. The Driver Type by Hour interaction was not significant for the Karolinska ratings, $F_{23,438} = 1.14$; $p = .30$

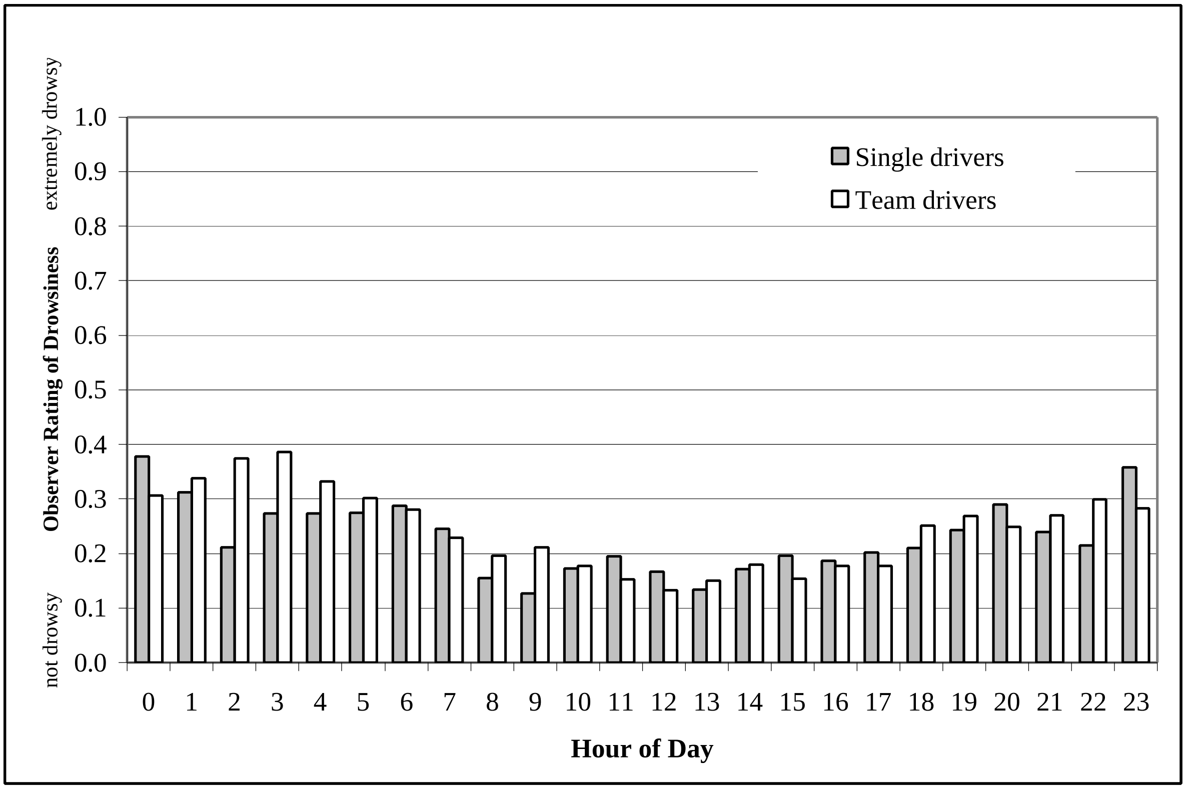

**Figure 53. Mean Observer Rating of Drowsiness per Hour of Day for single and team drivers.**

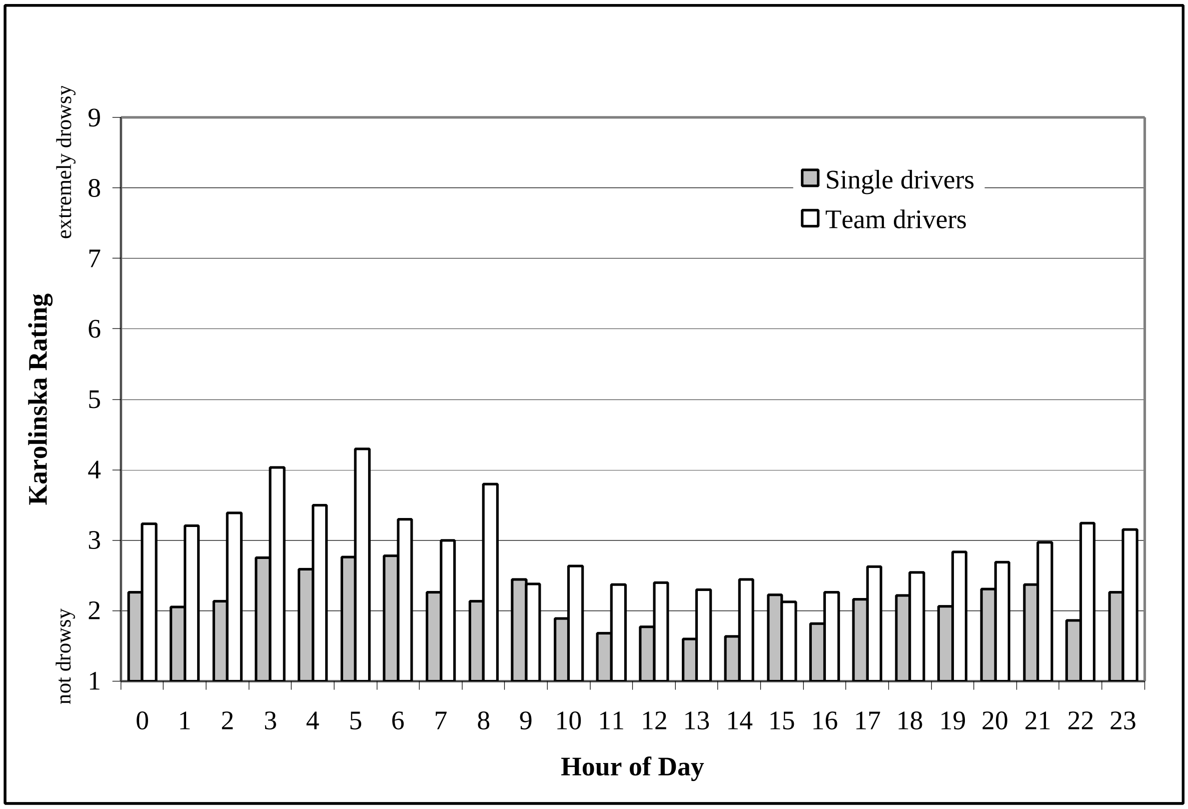

**Figure 54. Mean Karolinska Ratings per Hour of Day for single and team drivers**

It is important to note from the Tables in C-1 and C-2 in Appendix C that no effects were found based upon Length of Trip. A primary hypothesis associated with this study was that the effects of cumulative sleep loss from multi-day trips might adversely affect driver alertness for one or both groups. As shown by the mean Karolinska ratings and ORD ratings for days 1 to 8 for all drivers (Figure 55), no such trend was present, at least at this top level of analysis.

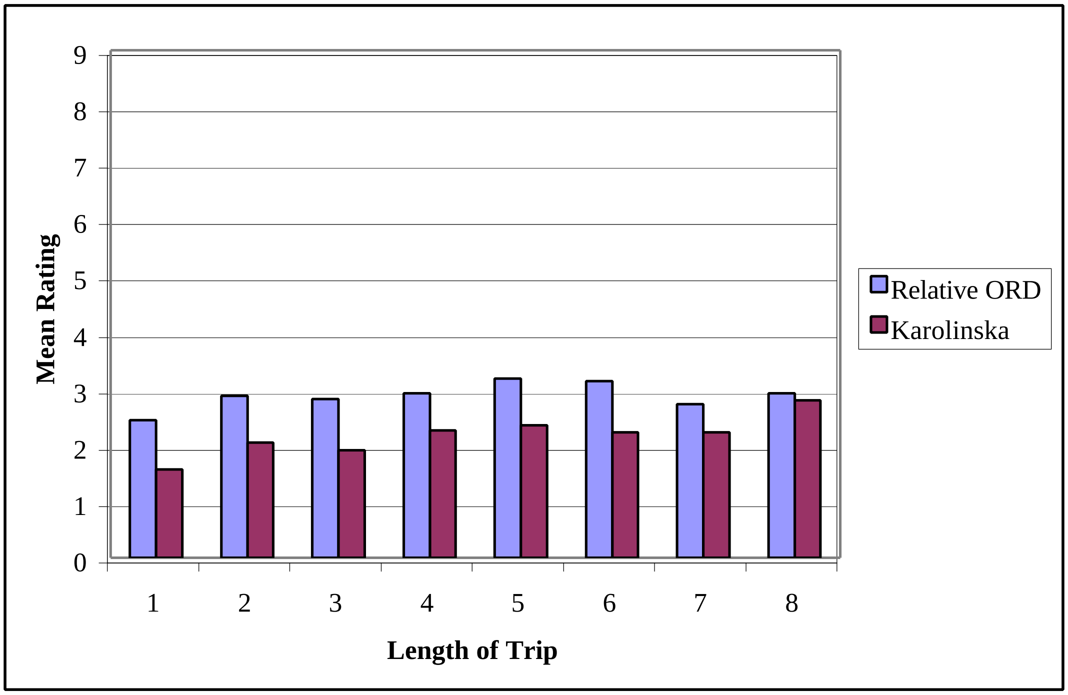

**Figure 55. Mean Karolinska and mean relative ORD Ratings by Length of Trip.**

Given the variability in the data both between-driver and across-hour as illustrated in Figures 53 and 54, it is important to focus the analysis on those relatively few cases of reported moderate-to-severe fatigue to see if any patterns emerge. Thus, chi-squared tests were conducted to study the frequencies of occurrences for these events across driver type and across day of drive.

Application of the Chi-Square Test

Chi-square tests were conducted to determine if there were differences in the frequency of ORD ratings for single and team drivers. The results are listed in Table 22. As shown, the frequency of drivers rated in categories 1 (Not Drowsy) and 4 (Very Drowsy) is significantly higher for single drivers than for team drivers.

**Table 22. Results of the Chi-Square Tests of frequency of ratings to ORD categories 1 to 5 for single and team drivers.**

| Category | $X^2$ | DF | Single Frequency | Team Frequency | Probability |
|---|---|---|---|---|---|
| **1 – Not Drowsy** | **11.6235** | **1** | **93** | **49** | **.0007** |
| 2 – Slightly Drowsy | 2.0775 | 1 | 290 | 311 | .1495 |
| 3 – Moderately Drowsy | 2.3968 | 1 | 52 | 66 | .1216 |
| **4 – Very Drowsy** | **5.8582** | **1** | **15** | **4** | **.0155** |
| 5 – Extremely Drowsy | – | – | 1 | 0 | – |

Chi-square tests were also conducted to determine if there were differences in the frequency of Karolinska ratings assigned to categories 1 through 3 for single and team drivers. Table 23 shows the results of the Karolinska ratings. As shown, team drivers more frequently rated themselves in the middle category, which corresponds to being "somewhat drowsy" as operationally defined. Note that more single drivers did not rate themselves as "very drowsy" when self-reporting their fatigue level using the Karolinska scale.

**Table 23. Results of the Chi-Square Tests of frequency of ratings to Karolinska categories 1 to 3 for single and team drivers.**

| Category | $X^2$ | DF | Single Frequency | Team Frequency | Probability |
|---|---|---|---|---|---|
| 1 – Alert | 2.5367 | 1 | 599 | 526 | .1112 |
| **2 – Somewhat Drowsy** | **17.4388** | **1** | **44** | **90** | **.0001** |
| 3 – Very Drowsy | .4163 | 1 | 29 | 33 | .5188 |

Controlling for Length of Trip

Additional chi-square tests were conducted to determine if there were differences in the frequency of the ORD and Karolinska ratings for single and team drivers when examining Length of Trip. Table 24 shows the results of the chi-square tests for the ORD data. Note that the ORD categories 3, 4, and 5 were collapsed together for this analysis so that the frequencies were large enough to run the chi-squared analysis. Even when collapsing these categories, there were cases where the cell frequencies were low relative to chi-squared assumptions. Results were significant for days 1, 2, 4, and 8. An examination of the frequency for those days shows that single drivers were more frequently rated as "moderately to extremely drowsy" on day 1 than were team drivers. Single drivers were more frequently rated as "not drowsy" on day 2 and day 4 than were team drivers. On day 8, single drivers were more frequently rated as "slightly drowsy" than were team drivers, and team drivers were more frequently rated as "moderately to very drowsy" than were single drivers.

**Table 24. Results of the Chi-Square Tests of frequency of ratings to collapsed ORD for single and team drivers.**

| Category | $X^2$ | DF | Single Frequency | Team Frequency | Probability |
|---|---|---|---|---|---|
| **DAY 1** | | | | | |
| **1 – Not Drowsy** | **8.1629** | **2** | **27** | **19** | **.0169** |
| **2 – Slightly Drowsy** | | | **25** | **37** | |
| **3-5 – Moderately Drowsy to Extremely Drowsy** | | | **11** | **3** | |
| **DAY 2** | | | | | |
| **1 – Not Drowsy** | **10.3237** | **2** | **23** | **5** | **.0057** |
| **2 – Slightly Drowsy** | | | **51** | **53** | |
| **3-5 – Moderately Drowsy to Very Drowsy** | | | **13** | **14** | |
| **DAY 3** | | | | | |
| 1 – Not Drowsy | 3.1812 | 2 | 19 | 8 | .2038 |
| 2 – Slightly Drowsy | | | 52 | 46 | |
| 3-5 – Moderately Drowsy to Extremely Drowsy | | | 10 | 11 | |
| **DAY 4** | | | | | |
| **1 – Not Drowsy** | **16.7873** | **2** | **18** | **4** | **.0002** |
| **2 – Slightly Drowsy** | | | **34** | **64** | |
| **3-5 – Moderately Drowsy to Extremely Drowsy** | | | **15** | **14** | |
| **DAY 5** | | | | | |
| 1 – Not Drowsy | 1.2706 | 2 | 2 | 5 | .5298 |
| 2 – Slightly Drowsy | | | 26 | 30 | |
| 3-5 – Moderately Drowsy to Extremely Drowsy | | | 6 | 11 | |
| **DAY 6** | | | | | |
| 1 – Not Drowsy | N/A | | 0 | 3 | Low Cell Frequencies |
| 2 – Slightly Drowsy | | | 29 | 38 | |
| 3-5 – Moderately Drowsy to Extremely Drowsy | | | 7 | 4 | |
| **DAY 7** | | | | | |
| 1 – Not Drowsy | N/A | | 1 | 3 | Low Cell Frequencies |
| 2 – Slightly Drowsy | | | 40 | 31 | |
| 3-5 – Moderately Drowsy to Extremely Drowsy | | | 2 | 3 | |
| **DAY 8** | | | | | |
| **1 – Not Drowsy** | **9.1429** | **2** | **3** | **2** | **.0103** |
| **2 – Slightly Drowsy** | | | **33** | **12** | |
| **3-5 – Moderately Drowsy to Extremely Drowsy** | | | **4** | **10** | |

Notice that alertness ratings in the “not drowsy” category occurred more frequently at the beginning of the trip than toward the end of the trip. Specifically, looking at the “not drowsy” numbers for days 5 through 8, there were very few cases where drivers were rated in this category. It is also important to note that the analysts were significantly rating team drivers as "moderately to extremely drowsy" on day 8 more so than they were rating single drivers. This trend only occurred on day 8 and with relatively few data points; however, this finding may be important.

Table 25 shows the results of the chi-square tests for the Karolinska data. Results were significant for days 2, 5, 6, and 8. An examination of the frequency for those days shows that team drivers more frequently rated themselves as "somewhat drowsy" or "very drowsy" than did single drivers on day 2. On days 5 and 6, team drivers more frequently rated themselves at the middle and drowsy end of the Karolinska scale when compared to single drivers. On day 8, team drivers more frequently rated themselves in the middle of the Karolinska scale and single drivers more frequently rated themselves either "alert" or "very drowsy."

**Table 25. Results of the Chi-Square Tests of frequency of ratings to Re-scaled Karolinska categories 1 to 3 for single and team drivers.**

| Category | $X^2$ | DF | Single Frequency | Team Frequency | Probability |
|---|---|---|---|---|---|
| **DAY 1** | | | | | |
| 1 – Alert | N/A | | 61 | 58 | Low Cell Frequencies |
| 2 – Somewhat Drowsy | | | 7 | 6 | |
| 3 – Very Drowsy | | | 2 | 0 | |
| **DAY 2** | | | | | |
| **1 – Alert** | **8.6230** | **2** | **108** | **83** | **.0134** |
| **2 – Somewhat Drowsy** | | | **8** | **18** | |
| **3 – Very Drowsy** | | | **4** | **9** | |
| **DAY 3** | | | | | |
| 1 – Alert | 1.8177 | 2 | 110 | 76 | .4030 |
| 2 – Somewhat Drowsy | | | 10 | 9 | |
| 3 – Very Drowsy | | | 2 | 4 | |
| **DAY 4** | | | | | |
| 1 – Alert | 1.5861 | 2 | 69 | 106 | .4525 |
| 2 – Somewhat Drowsy | | | 7 | 15 | |
| 3 – Very Drowsy | | | 6 | 5 | |
| **DAY 5** | | | | | |
| **1 – Alert** | **10.0812** | **2** | **68** | **68** | **.0065** |
| **2 – Somewhat Drowsy** | | | **1** | **12** | |
| **3 – Very Drowsy** | | | **3** | **8** | |
| **DAY 6** | | | | | |
| **1 – Alert** | **19.3319** | **2** | **88** | **54** | **<.0001** |
| **2 – Somewhat Drowsy** | | | **1** | **13** | |
| **3 – Very Drowsy** | | | **1** | **5** | |
| **DAY 7** | | | | | |
| 1 – Alert | .6644 | 2 | 54 | 57 | .7173 |
| 2 – Somewhat Drowsy | | | 9 | 7 | |
| 3 – Very Drowsy | | | 2 | 1 | |
| **DAY 8** | | | | | |
| **1 – Alert** | **15.7792** | **2** | **41** | **24** | **.0004** |
| **2 –** Somewhat Drowsy | | | **1** | **10** | |
| **3 – Very Drowsy** | | | **9** | **1** | |

*Analysis of Driving Shifts*

Analyses were conducted to determine if there were any differences in driver alertness by shift. A shift was operationally defined by the following:

- A driving period of any length separated by a break of at least 20 minutes.
- The first shift of the day was defined as the first driving period that occurred after midnight.
- The last driving shift of the day was the one that started closest to 11:59 pm of the same 24-hour period.
- Exception: If a shift started before 11:59 pm but ran past midnight, it was still counted as a shift for the day in which it started.
- Note that a shift consists of hours of consecutive driving and does not account for on-duty non-driving time.

It is important to note that shifts were much more regular and easily defined for single drivers as opposed to team drivers. Single drivers typically slept late at night (approximately 12:30AM through 6:00 AM) so that the definition of the first shift occurring after midnight was accurate relative to their sleep patterns. However, since teams traded-off periodically and the truck was often moving almost non-stop for several days, the first shift criterion was somewhat arbitrary. However, it does allow direct comparisons between the two groups based upon Time of Day, so the criterion was held constant for teams.

The number of observations for each shift is shown in Figure 56. As shown, there were no cases where there were more than four shifts in a day for teams. In addition, there were only eight cases where there were five shifts in a day for singles. Since there were so few of these cases (27), the data were not included in this analysis.

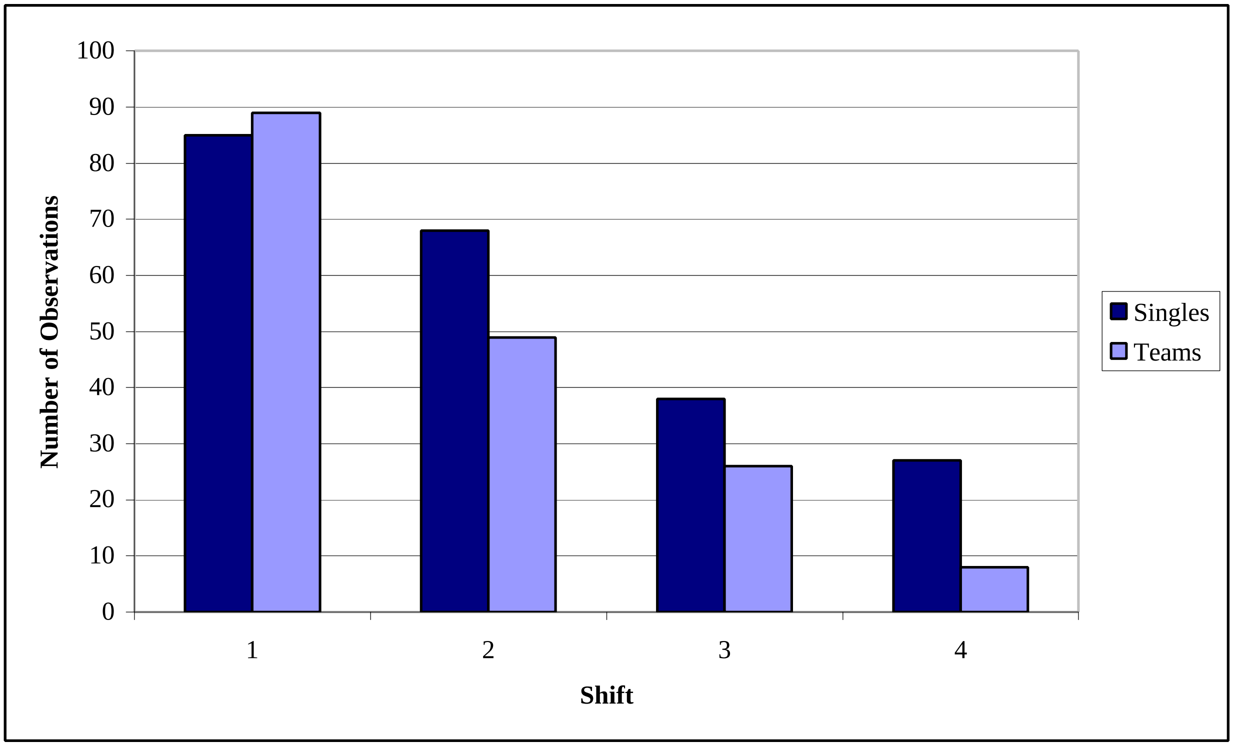

**Figure 56. Number of observations per Shift.**

It is interesting to note that in roughly 40 percent of the cases, team drivers only drove one shift per day and drove one or two shifts per day in 74 percent of the cases.

Application of the Analysis of Variance Test

As was illustrated in Figure 56, the number of shifts per day for each driver varied significantly. This resulted in a fairly large number of missing data points when analyzing Shift as a variable, as a driver might have had only one shift one day and four or five the next. Thus, to conduct an Analysis of Variance with this much missing data, the data had to be split into three parts. The first analysis conducted was a mixed factor, two-way ANOVA with Shift and Team as independent variables. The second analysis was also a mixed-factor, two-way analysis with Shift and Day of Drive as independent variables. The dependent variables for each of these two analyses were time Length of Shift, ORD, and Karolinska ratings. The third analysis was a within-subject, two-way ANOVA with Shift and Hour of Shift as independent variables. For this analysis, ORD and Karolinska ratings served as the dependent variables.

The ANOVA summary tables for the Shift by Team analysis are shown in Appendix C (Tables C-3, C-4, and C-5). For the time length analysis, neither of the main effects approached significance. However, the Shift by Team interaction was significant, $F_{3,58} = 2.94$; $p = .04$ (Appendix C, Table C-3). As shown in Figure 57, each shift generally averaged about 200 to 250 minutes for both singles and teams with wide variations in length. As is also shown, there does not appear to be any systematic variation in shift length that would explain this interaction.

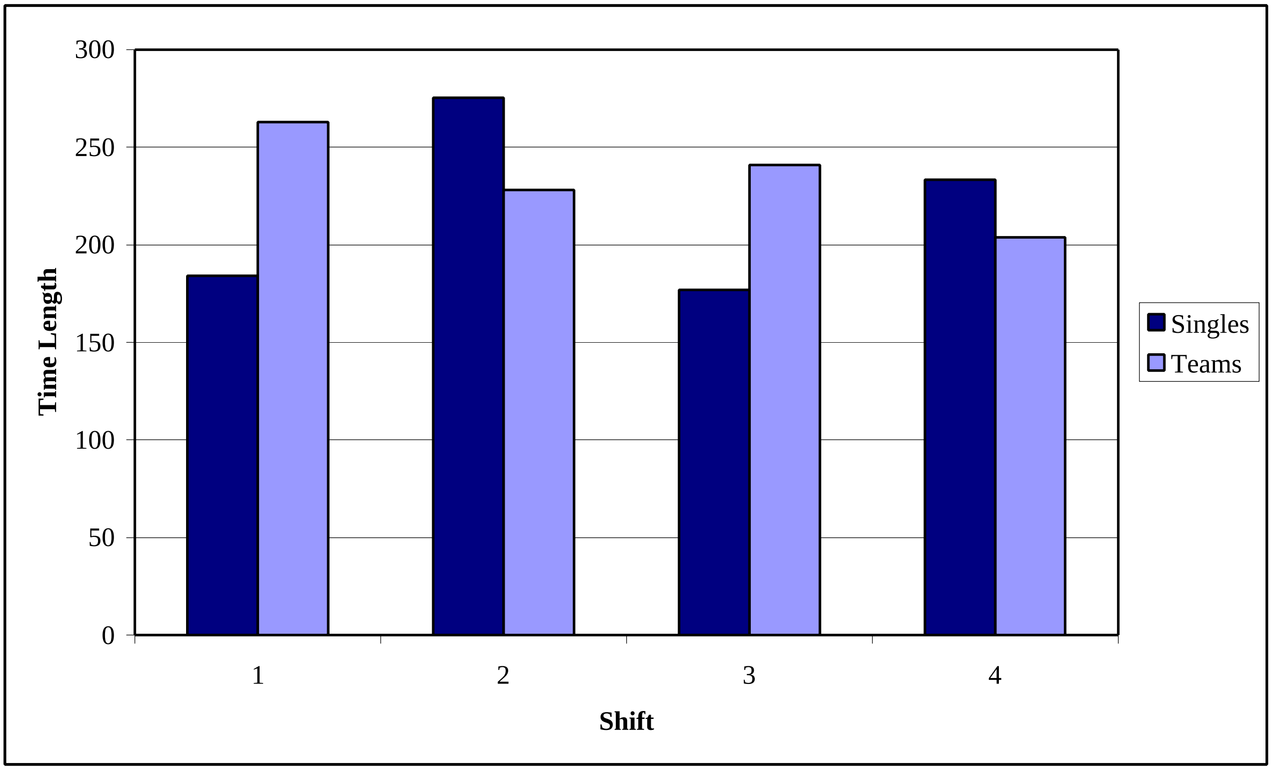

**Figure 57. Mean Time Length per Shift.**

Appendix C, Tables C-4 and C-5 also shows the Shift by Team ANOVA table for the ORD and Karolinska ratings. As shown, none of the variables were significant at the $p < 0.05$ level, and only the Shift main effect approached this level, $F_{3,50} = 2.51$; $p = .07$ (Appendix C, Table C-4). A graph showing the ORD rating by Shift for both teams and singles appears as Figure 58. As shown, the variance in ORD ratings was generally high for each shift. There appears to be a trend toward higher ORD ratings for the later shifts, but in general, all of the average ratings were low and not different to a meaningful degree.

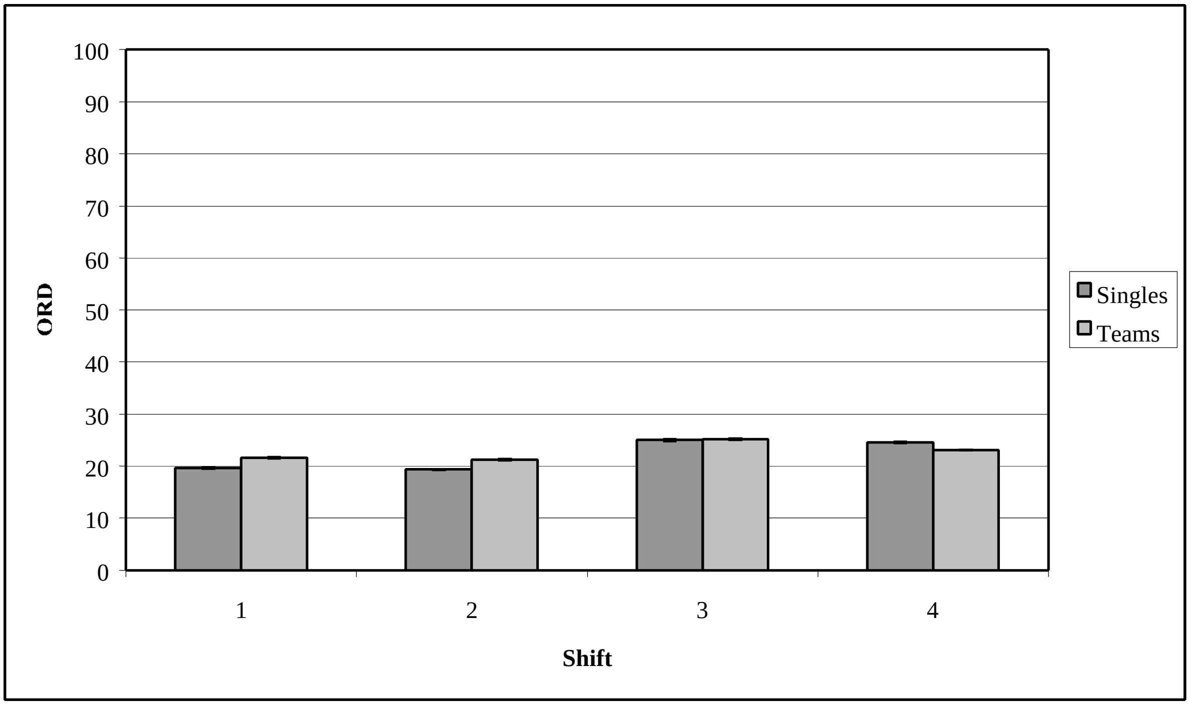

**Figure 58. Mean ORD per Shift.**

The Shift by Length of Trip ANOVA revealed a significant interaction of Shift by Length of Trip for the Karolinska scale rating, $F_{21,87} = 2.19$; $p = .006$ (Appendix C, Table C-8). (Note also that the Shift main effects were significant but since these were discussed above, they will not be addressed again here.) A graph showing this interaction appears as Figure 59. Although the variance between ratings is fairly high across Length of Trip and Shift, the highest ratings were found on day 8 for the second and third shifts. This may be an indication of some degree of cumulative fatigue.

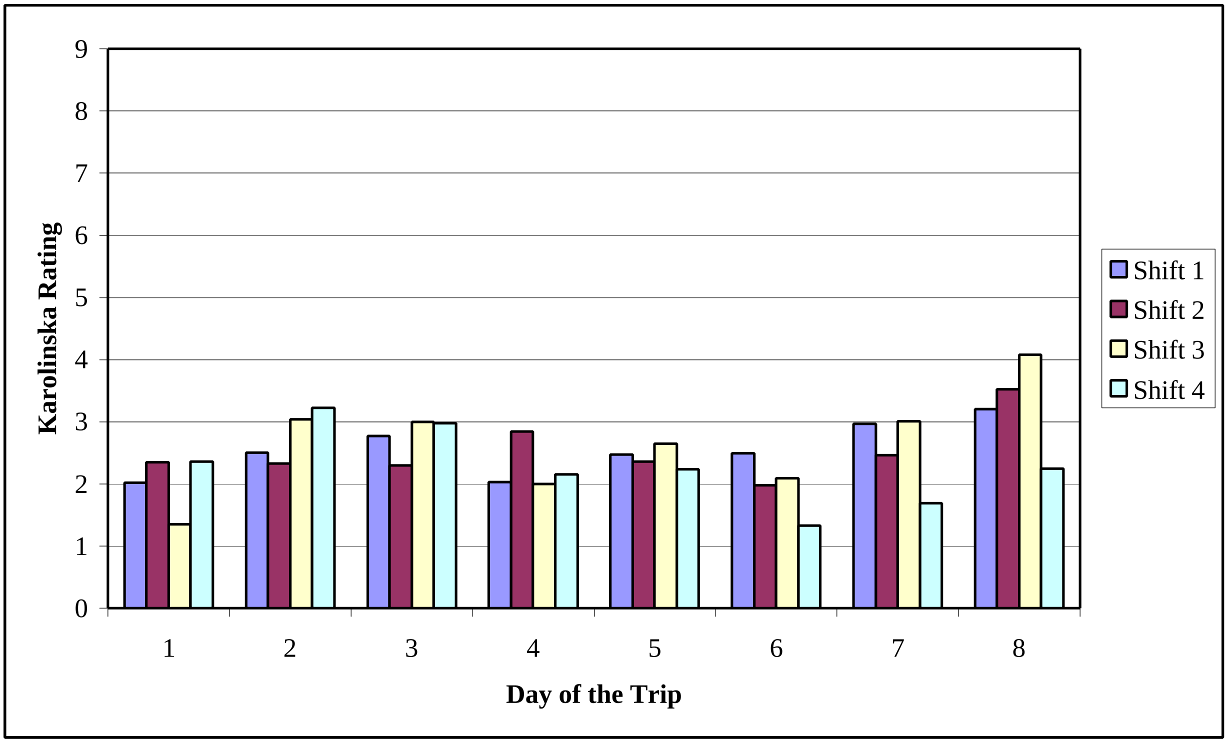

**Figure 59. Karolinska Ratings for Shift by Length of Trip.**

The data analysis for Hour of Shift revealed an interesting overall finding. As shown in Figure 60, although roughly one-half of the shifts observed were four hours or less, there were 63 cases of driving hours that were over 10 consecutive hours. Assuming that all of these cases represented the only shift in a given day, this represents 17 times that the current hours-of-service regulations (i.e., 10 consecutive hours maximum per shift) were violated. As will be discussed later, the actual number is likely somewhat higher.

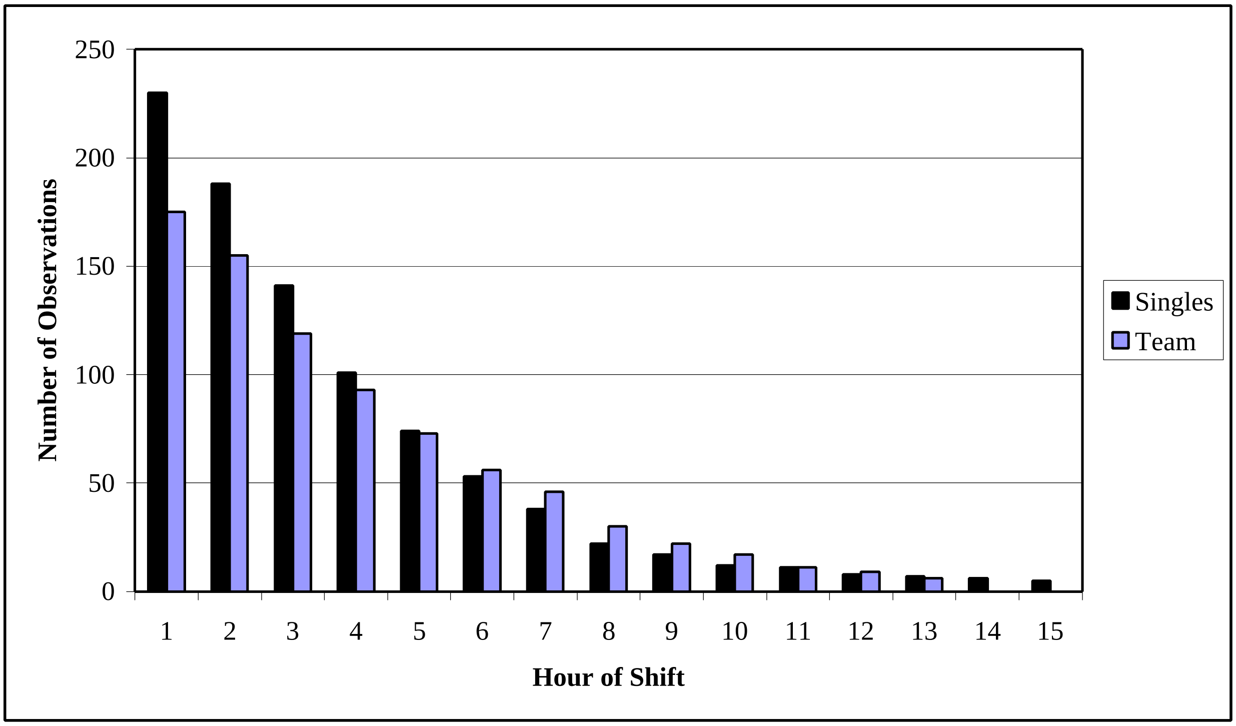

**Figure 60. Number of Observations by Hour of Shift.**

The Shift by Hour of Shift ANOVA showed a number of significant effects. For the ORD, the main effect of Hour of Shift, $F_{15,183} = 2.08$; $p = .013$, and the Shift by Hour of shift interaction, $F_{31,167} = 1.77$; $p = 0.012$, were significant (Appendix C, Table C-9). Figures 61 and 62 show the ORD ratings for each shift by Hour of Shift for singles and teams, respectively. The highest ORD ratings for single drivers occurred late in the second, third, and the fifth shifts of the day. Note that hours 12 and 13 of the second shift of the day represent hours-of-service violations. In addition, hours 6 and 7 of the third shift of the day represent possible hours-of-service violations (reflecting on-duty driving hours only). Note, however, that there were cases of drivers driving up to 16 hours on the first day of the drive with no apparent alertness effects. This indicates that long shift lengths on multiple days (i.e., greater than one) tend to create the most serious alertness problems in drivers.

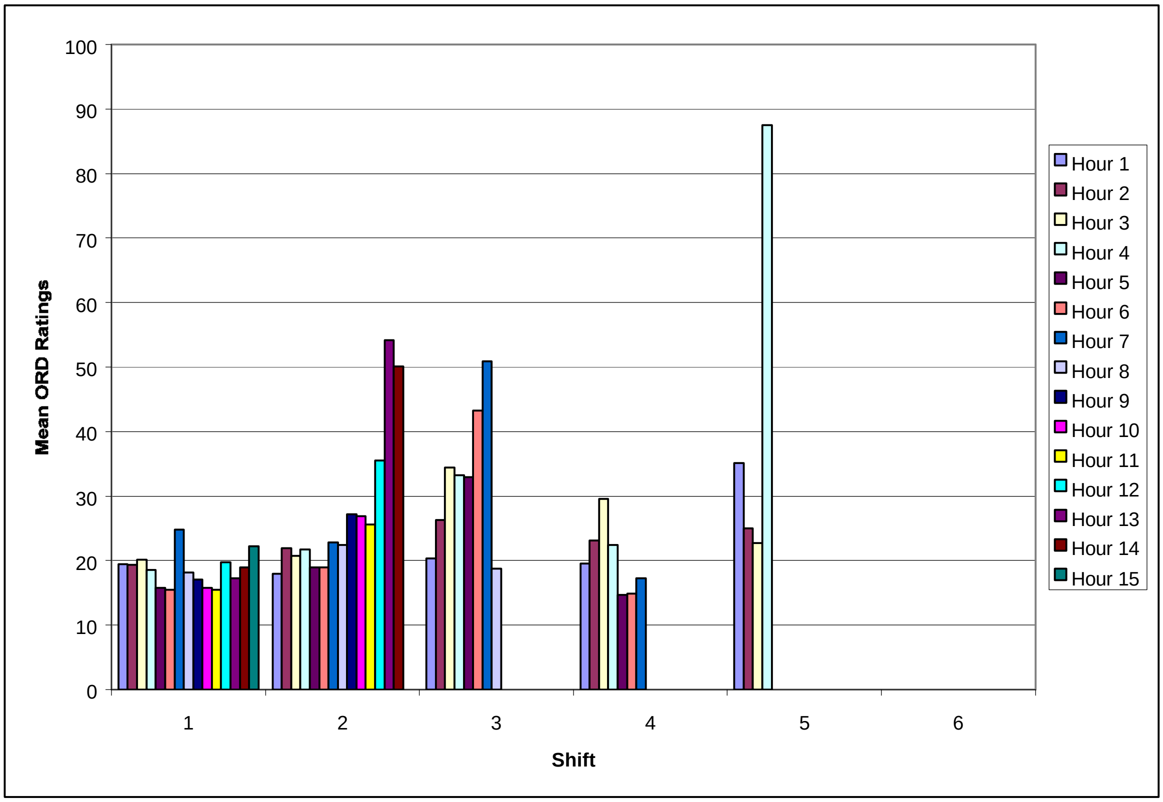

**Figure 61. Mean ORD Ratings for each Hour of each Shift per Day for single drivers.**

Figure 62 shows the same information for team drivers. As shown, the same trend of fatigue late in a shift is present for teams as well as singles, but the magnitude of the apparent fatigue does not reach the same levels. Note that there are cases where team drivers are driving 11, 12, or 13 hours on *the second or third shift of the day*.

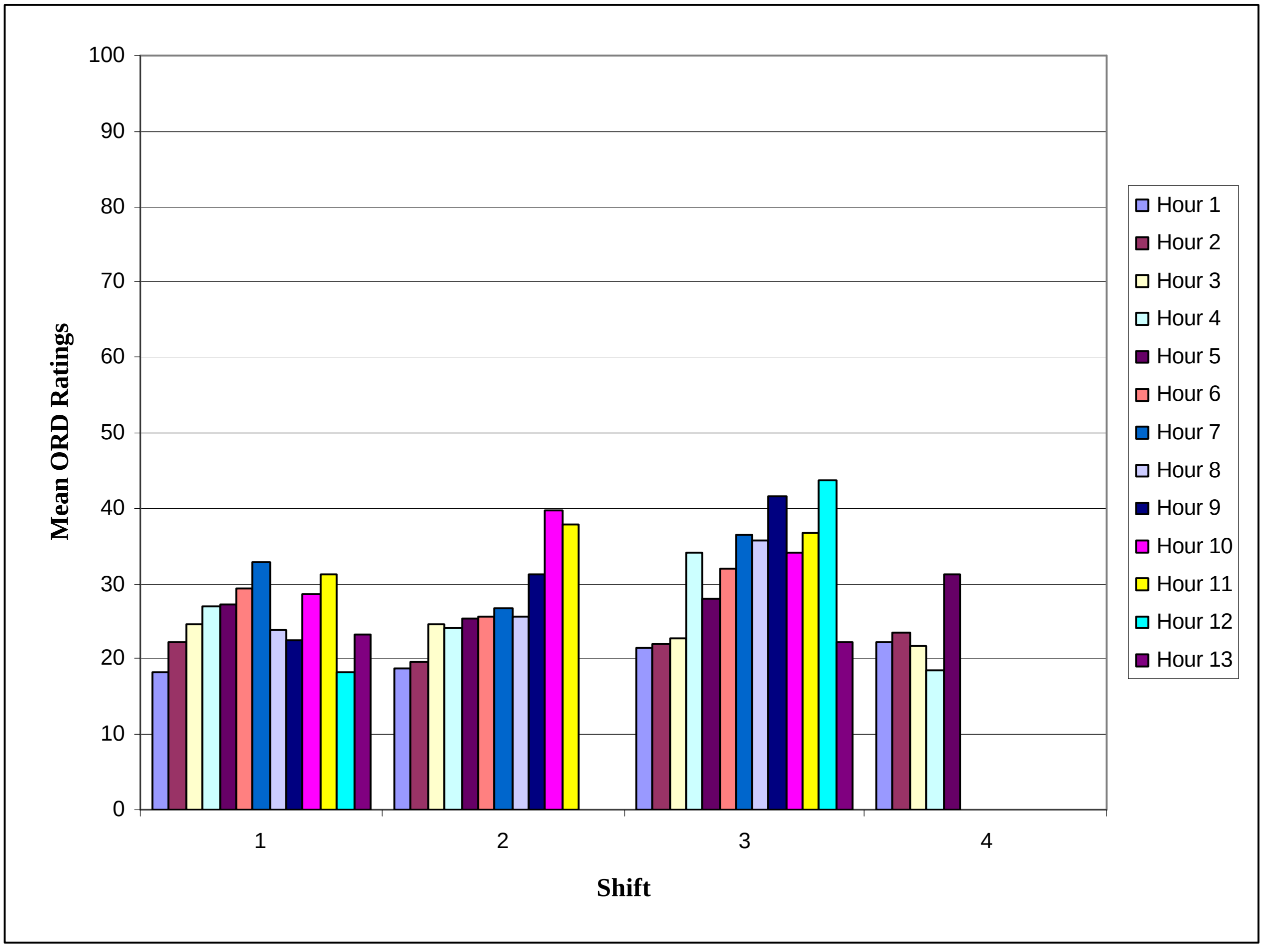

**Figure 62. Mean ORD Ratings for each Hour of each Shift per Day for team drivers.**

The Hour of Shift main effect was also significant for the Karolinska scale ratings, $F_{23,218} = 1.87$; $p = .011$ (Appendix C, Table C-10). As shown in Figure 63, there appears to be a tendency for team drivers to rate themselves as more fatigued, on average, as the shift wears on. This is consistent with the observations of the trained ORD operators. The single drivers, however, did not show the same trend.

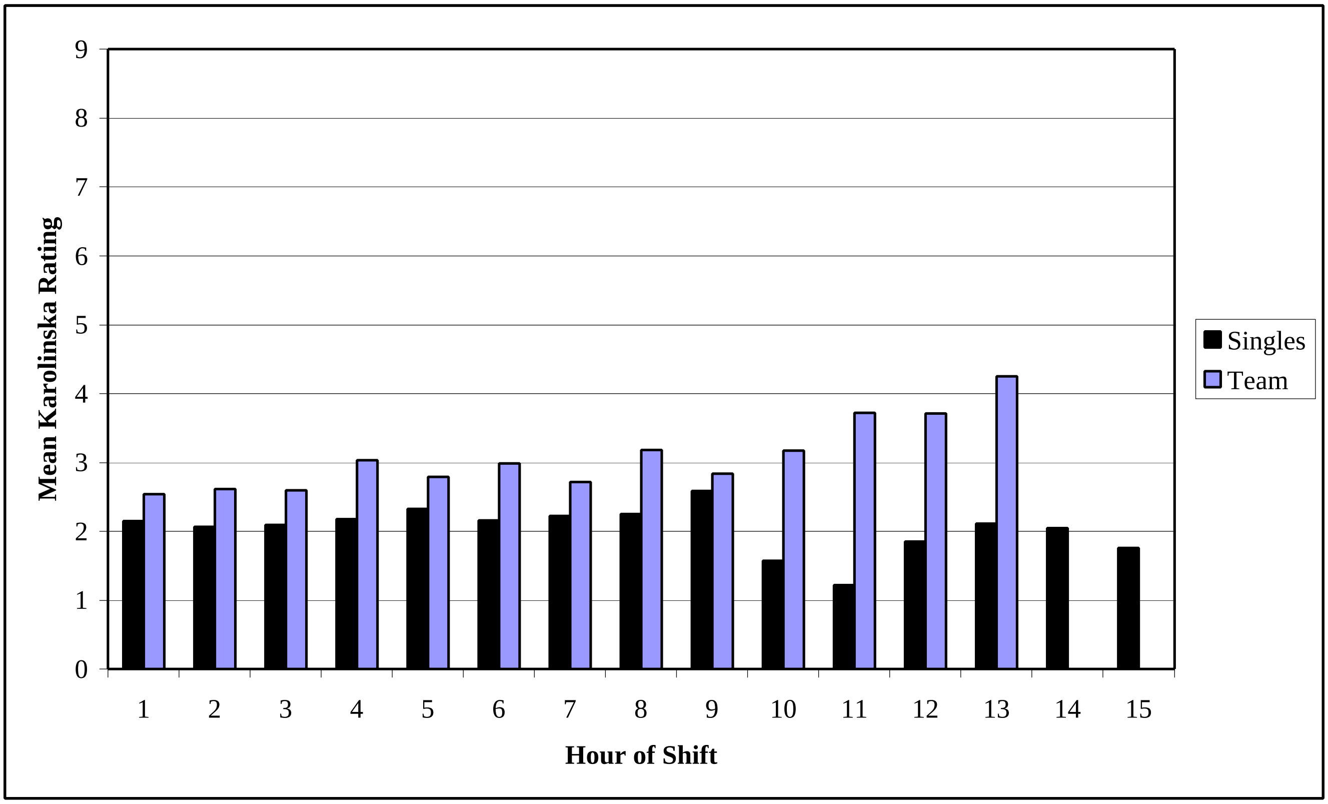

**Figure 63. Mean Karolinska Rating by Hour of Shift.**

*Analysis of Hours-of-Service Violations*

Given the finding that there were a number of cases where drivers violated the hours-of-service regulations, an additional set of descriptive analyses were conducted to determine the absolute and relative alertness of the drivers studied during these cases. Note that on-duty-not-driving time (refer to Table 1) could not be verified by the truck data collection system and often did not match what was recorded in the drivers' logs. For this reason, *all hours of service violations mentioned in the report include only on-duty-driving hours that could be verified by the data collection system.* Any additional hours-of-service violations that may have occurred due to on-duty-not-driving work are not reflected.

Figure 64 shows the frequency of ORD ratings in each alertness category, for both singles and team drivers, for only the cases where drivers exceeded ten consecutive hours of driving in a day. As shown, the data mirror the entire data set in that most of the occurrences for both singles and teams were in the "slightly drowsy" category. Note that, for single drivers, there were nine instances of "very drowsy," but there were no team drivers in this category. There were also no singles or team occurrences in the "extremely drowsy" category.

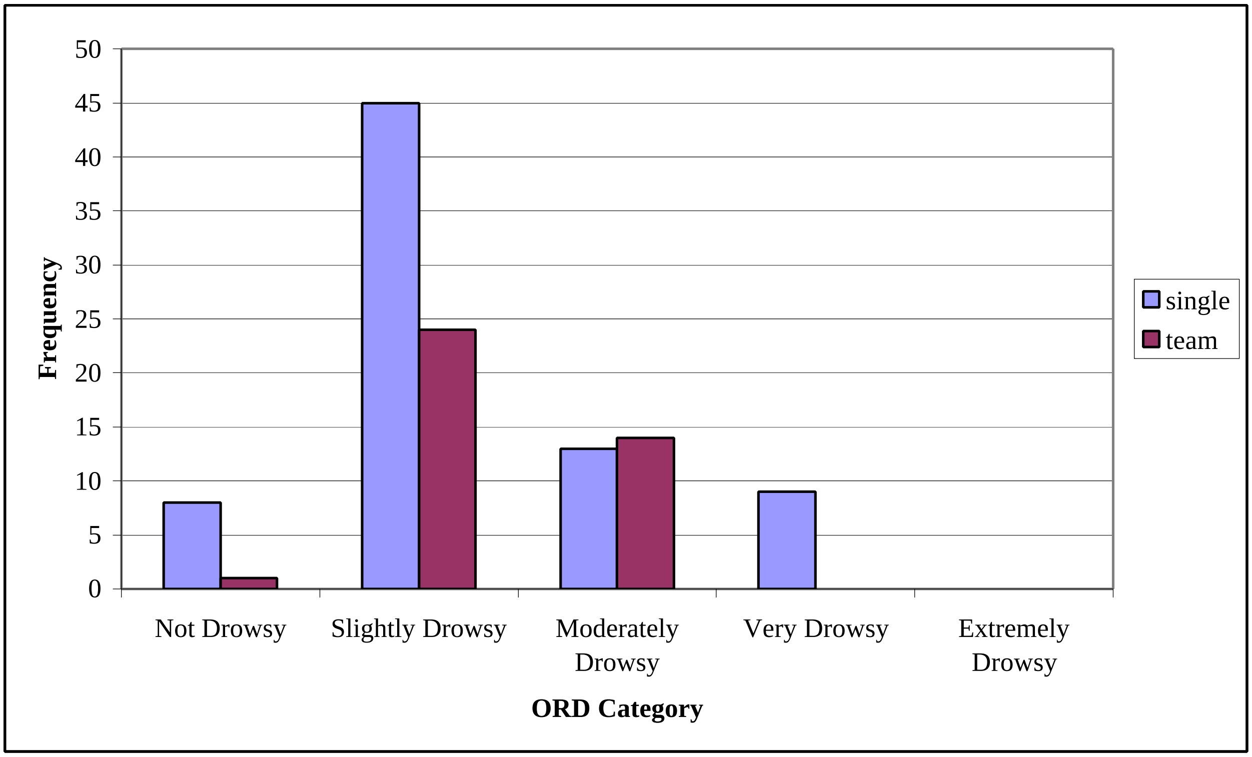

**Figure 64. Number of ORD Ratings per category for all hours driven over 10 hours of service in a 24-hour period.**

Graphs depicting the frequency of ORD categorizations for singles (Figure 65) and teams (Figure 66) for each hour of driving beyond 10 hours are provided below. Note that each hour of driving does not represent an independent sample for both Figures 65 and 66. Figure 65 shows that, as a percentage, the incidents of lower levels of alertness tend to increase for singles, although the frequencies in general are very low. The same is generally true for team drivers (Figure 66), with 12 out of the 19 cases beyond driving hour 12 rated as "moderately drowsy." This is in contrast to hours 10, 11, and 12 where 28 of the 33 cases were rated as either "not drowsy" or "slightly drowsy."

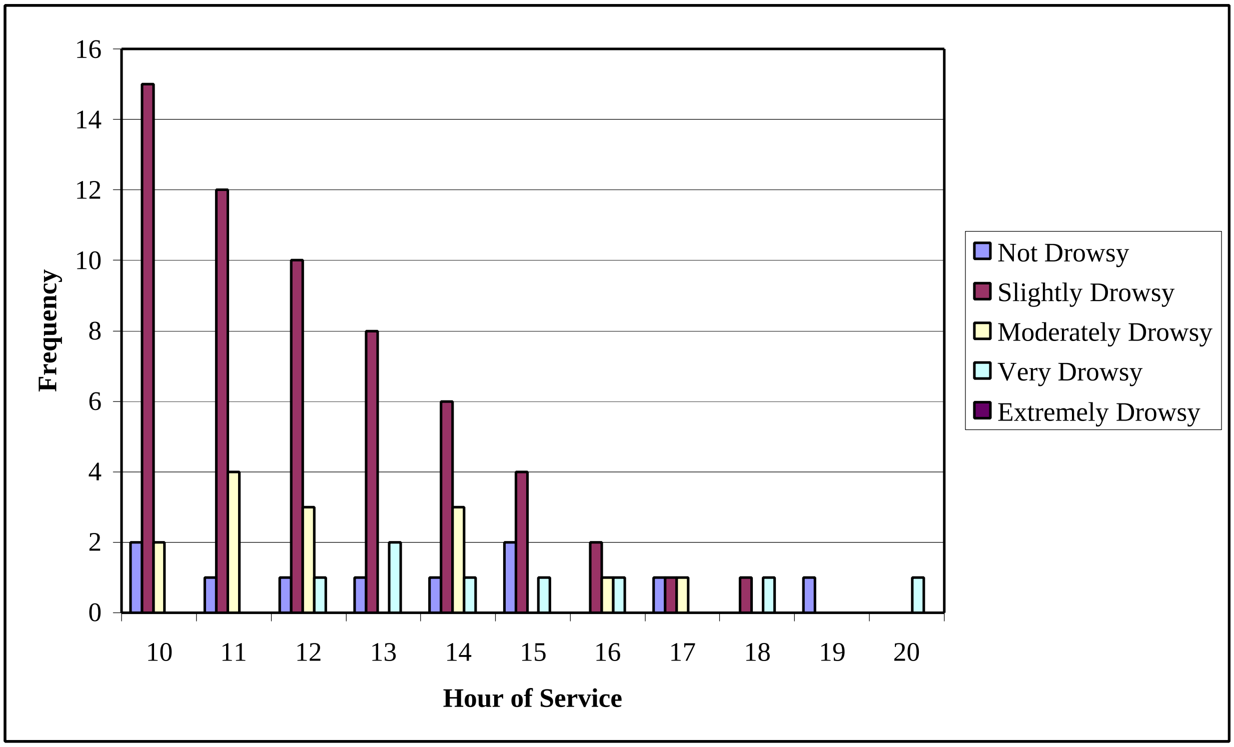

**Figure 65. Number of ORD Ratings for single drivers for hours over 10 hours of service in a 24-hour period.**

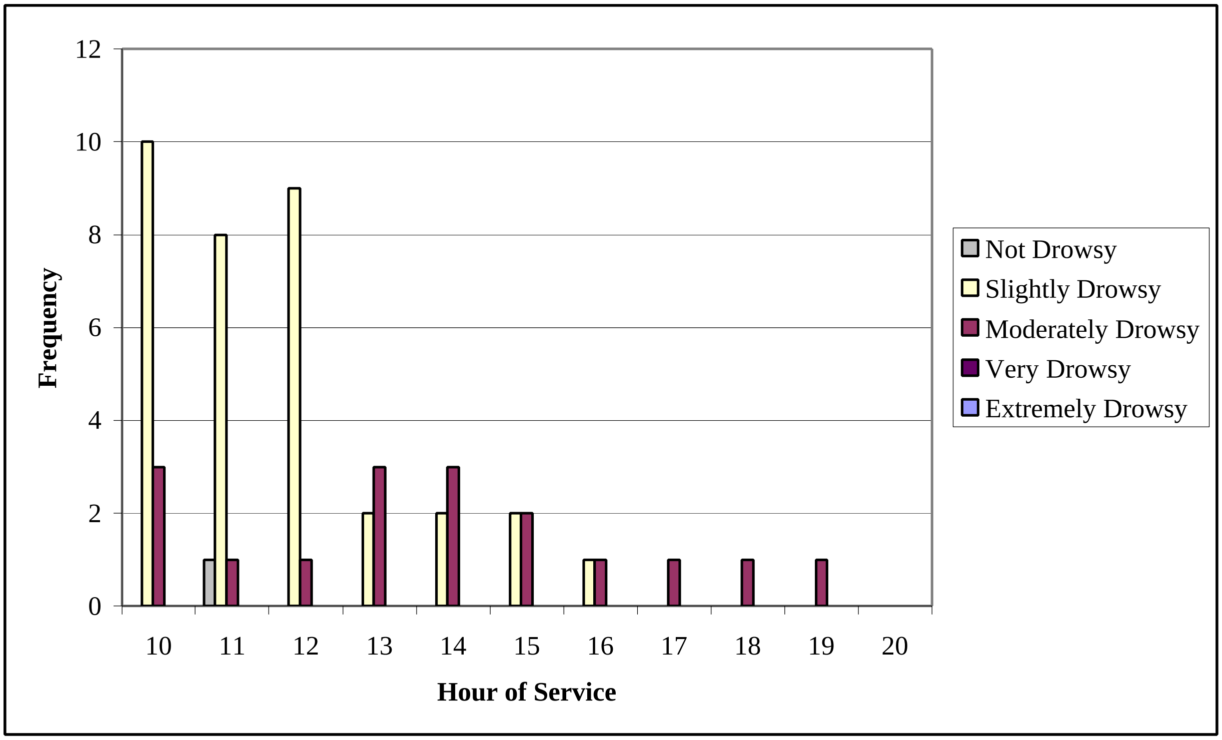

**Figure 66. Number of ORD Ratings for team drivers for hours over 10 hours of service in a 24-hour period.**

**Discussion**

The purpose of the analyses presented in this objective was to examine the level of alertness for single and team drivers as a function of Length of Trip, Time/Hour of Day, and Length of Shift. The primary question being asked was: Does a teaming arrangement, or lack thereof, impact the alertness experienced by drivers, and if so, does alertness vary as a function of the number of days spent on the road for a single trip, the time of day, or the length of their driving shift for a given day? For this particular objective, the presence of critical incidents was not considered as it is presented in Objectives 5, 6, and 7. Rather, of interest were the effects of the trip characteristics on driver alertness. As such, critical incident events were not included in these analyses; rather only the time-triggered “events” (or baseline samples) were used.

ORD and Karolinska drowsiness ratings were the dependent variables by which alertness was measured. The first set of analyses used the ANOVA procedure where the variability of ratings, for the various independent variables of interest, was examined. With regard to Length of Trip, one interesting finding was that team drivers consistently rated themselves (i.e., Karolinska scale) as more drowsy as compared to single drivers; however, ORD ratings did not follow this same pattern. Because of this discrepancy between the two measures, it is unclear what this finding means, if anything. Perhaps, because a relief driver was always present in a team operation, team drivers were more forthright with their self-ratings. That is, team drivers have the “luxury” of admitting when they are tired as they can rely upon their partner to take over the operation. However, single drivers, who do not have a relief driver, may feel compelled to press on and continue to drive under all circumstances (including fatigue). If this is so, what benefit is gained by a single driver admitting to themselves, or the researchers, that they are tired?

A closer look at the frequencies for the ORD and Karolinska ratings was conducted as a function of the driving operation. The results from a chi-square analysis found that single drivers had a greater number of ORD ratings in the "not drowsy" and in the "very drowsy" categories. For the Karolinska ratings, the number of instances in which team drivers indicated they were "somewhat drowsy" was significantly more than single drivers. Based on these results, single drivers were more likely to have an ORD rating near the drowsiness extremes, while team drivers were more likely to have a Karolinska rating that was in the middle of the scale. Based partially on other findings described for this study, it appears likely that single drivers were getting higher quality sleep. This serves as a feasible explanation for why they are "not drowsy" more often. However, as was shown in several analyses, single drivers tend to push themselves harder on occasion, and without a backup driver, they suffer more cases of extreme fatigue.

When Length of Trip was considered for each of the two groups of drivers, it was found that single drivers had a more frequent number of "moderately to extremely drowsy" ORD ratings than did team drivers on day 1. This may have indicated that single drivers were "pushing" themselves more than team drivers, who had the luxury of switching drivers if one became fatigued. On day 8, single drivers were rated "slightly drowsy" more frequently than were team drivers, while team drivers were rated "moderately to very drowsy" more often than single drivers. This may indicate cumulative fatigue effects due to lower sleep quality from team drivers.

ANOVAs were also conducted to determine the impact of the driving shift on driver alertness. When using the Karolinska rating as the drowsiness measure, it was found that the highest ratings (i.e., those ratings that indicated that the driver was most drowsy) across both groups of drivers occurred on the last day of the trip for the second and third shifts of that day. That is, drivers rated themselves as more drowsy when they drove for multiple shifts during the last day of driving. One explanation for this finding is that the fatigue experienced by drivers was cumulative and, by the eighth day of driving, drivers acknowledged through the self-ratings that they were very tired.

One final interesting finding that should be highlighted is in regard to the hours-of-service violations that were recorded. It was indicated that there were 63 driving hours that were in violation of the hours-of-service regulations, with drivers driving between 11 and 15 consecutive hours. Approximately 60 percent of these hours were with single drivers. What impact did these violations have on driver drowsiness? For single drivers, the highest ORD ratings occurred late in the second, third, and fifth shifts of the day. A closer look at these shifts found that each of these involved an hours-of-service violation. Because drivers were found to drive up to 16 hours on the first shift of the trip without any apparent negative effects, it is suggested that these high ORD ratings resulted from drivers driving for long shifts over multiple days. Not surprisingly, it is also suggested that this combination of long shifts for multiple days creates the most significant drowsiness problem for drivers.

## OBJECTIVE 4: DETERMINE THE RELATIONSHIP BETWEEN LEVEL OF SLEEP QUALITY OR QUANTITY AND DRIVER ALERTNESS

### Data Analysis Overview

*Alertness Measures*

The Observer Rating of Drowsiness values and the Karolinska values were used as alertness measures for this objective. The Observer Rating of Drowsiness (ORD) scale was used by trained data reduction analysts during the video reduction procedure. These analysts watched from 3 to 12 minutes of continuous videotape and rated each driver's drowsiness level for every minute of the continuous video segment. The ORD scale is a continuous scale from 0 to 100. For the following analyses, the scale was separated into 5 categories for which the maximum and median values were analyzed for each day of the data collection run:

1. Not Drowsy (rating of 0-12.49),
2. Slightly Drowsy (rating of 12.5 – 37.49),
3. Moderately Drowsy (rating of 37.5 – 62.49),
4. Very Drowsy (rating of 62.5 – 87.49), and
5. Extremely Drowsy (rating of 87.5- 100).

Drivers used the Karolinska scale to rate their own drowsiness levels. The Karolinska scale is a scale with discrete rankings from 1 to 9. Drivers were asked to rate their drowsiness levels at pseudo-random intervals varying between 45 and 75 minutes while they were driving. For several analyses, the nine categories were collapsed into three categories to analyze the data. This was necessary to provide an adequate number of data points as the data were parsed to address the issues in question. A Karolinska rating from 1 to 3 was categorized as "not drowsy," 4 to 6 was categorized as "somewhat drowsy," and 7 to 9 was categorized as "very drowsy." As with the ORD scale, the maximum and median Karolinska values reported in each of the three categories were analyzed for each day of the data collection run.

There were three sleep measures used as dependent variables for this objective, as listed in Table 26. As an objective measure of sleep quality, REM Percent, or the percentage of the sleep bout that the driver had REM sleep, was calculated from the drivers' Nightcap data. As a subjective measure of sleep quantity, driver response to Wake-up Survey Question 8 was used. Drivers answered the question, "How well did you sleep?" based on a 6-point scale from "very badly" to "very well." As a measure of sleep quantity, falling asleep and waking up times reported from the Wake-up Survey were used to calculate Subjective Sleep Time.

**Table 26. Objective and subjective measures of sleep quality and quantity used in the data analyses.**

| Measure | Sleep Quantity | Sleep Quality |
|---|---|---|
| **Objective** | ---- | REM Percent<br>The percent of the sleep bout spent in REM sleep |
| **Subjective** | **Wake-up Survey**<br>Reported falling asleep and wake-up times | **Survey Question 8**<br>"How well did you sleep?"<br>1. Very badly<br>2. Badly<br>3. Fairly badly<br>4. Fairly well<br>5. Well<br>6. Very well |

*Driver Data Included in the Analyses*
Three sets of analyses were planned for this objective to determine sleep quality and quantity levels in relation to ORD and Karolinska values. These were:

1. Examine survey-reported sleep quantity in relation to ORD and Karolinska values. Questions 2 and 3 on the Wake-up Survey asked drivers when they fell asleep and when they woke up. These times were subtracted to obtain a value for Subjective Sleep Time for each day of the trip. This analysis contained the data set of 15 single and 11 team drivers. The data set represented the most complete surveys and for which there was sufficient ORD and Karolinska data. For some analyses, data from one or two drivers dropped from the analysis due to insufficient or missing data. Therefore, the total number of drivers per analysis was between 24 and 26 drivers.
2. Examine survey-reported sleep quality in relation to ORD and Karolinska values. Question 8 on the Wake-up Survey asked drivers how well they slept from six options of "very badly" to "very well." This analysis contained data from the same 15 single and 11 team drivers used in analysis 1.
3. Examine sleep quality from Nightcap sleep bout data. The dependent variable used from the Nightcap was REM Percent, or the amount of time that the driver was in REM sleep during the previous sleep bout. This analysis contained data from 12 single and 6 team drivers for the ORD and Karolinska data.

## Results

*Analysis of Subjective Sleep Time*
Subjective Sleep Time from the driver survey data was compared to the maximum and median ORD values and the maximum and median Karolinska values per each day. Maximum and median ratings were used since there were a number of ORD and Karolinska ratings in a day, but

only one (or very few) sleep measures per day. This allowed the sleep measures and alertness measures to be analyzed on a common time scale of one value per day of driving. Data for 26 drivers were used for these analyses (15 single and 11 team). For the ORD data, the analyses were conducted as 5 (ORD category) X 2 (Single, Team) ANOVAs. The Karolinska ANOVAs were conducted as 3 (Karolinska category) X 2 (single, team) ANOVAs.

The analysis of ORD Maximum and Driver Type data revealed a main effect of Driver Type, $F_{1,22} = 6.90$; $p = .015$ (Appendix D, Table D-1). As shown in Figure 67, team drivers reported more sleep for every ORD Maximum rating category. There were no data in the "extremely drowsy" category for team drivers. Note that both types of drivers were rated as "very drowsy" when they reported the least amount of sleep on average, although this finding was not significant. It is possible that there were not enough data points for this trend to show significance (106 data points were available for this analysis).

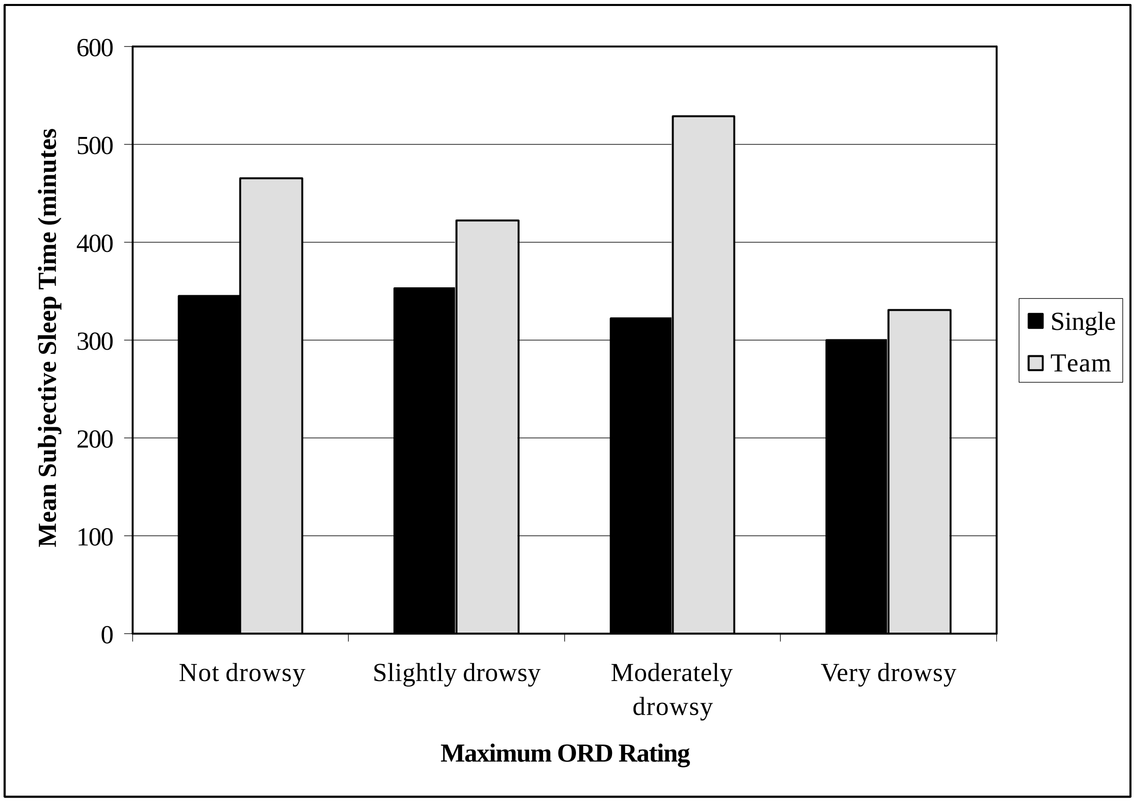

**Figure 67. Mean Subjective Sleep Time for the averaged maximum value at each category of ORD.**

The ANOVA for ORD Median showed very similar results, with the only significant main effect or interaction being Driver Type, $F_{1,22} = 4.41$; $p = .048$ (Appendix D, Table D-2). As shown in Figure 68, there were only data available for three of the five ORD categories; that is, drivers were not rated in the "very" or "extremely" drowsy category. Teams reported more sleep in all categories of median ORD rating relative to single drivers.

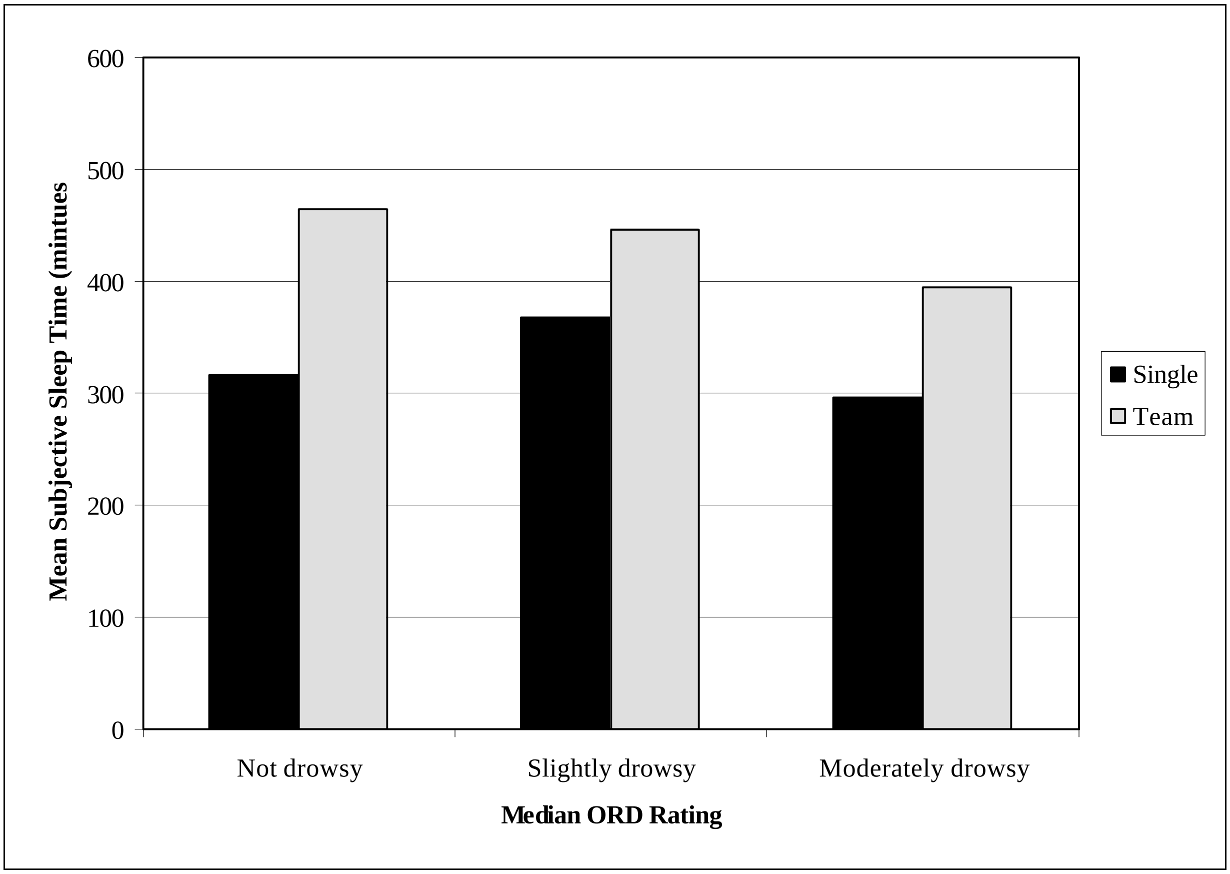

**Figure 68. Mean Subjective Sleep Time for the averaged median value at each category of ORD.**

The Karolinska Maximum data analysis showed a significant main effect of Driver Type, $F_{1,24} = 11.93$; $p = .002$ (Appendix D, Table D-3), with no other significant main effects or interactions. As seen in Figure 69, all three Karolinska categories were represented in the data (144 observations). Note that, although there appears to be a trend for both single and team drivers to rate themselves as more drowsy on the Karolinska scale when they had less sleep in their previous sleep bout, this interaction failed to approach significance, $F_{2,21} = 0.52$; $p = .603$ (Appendix D, Table D-3).

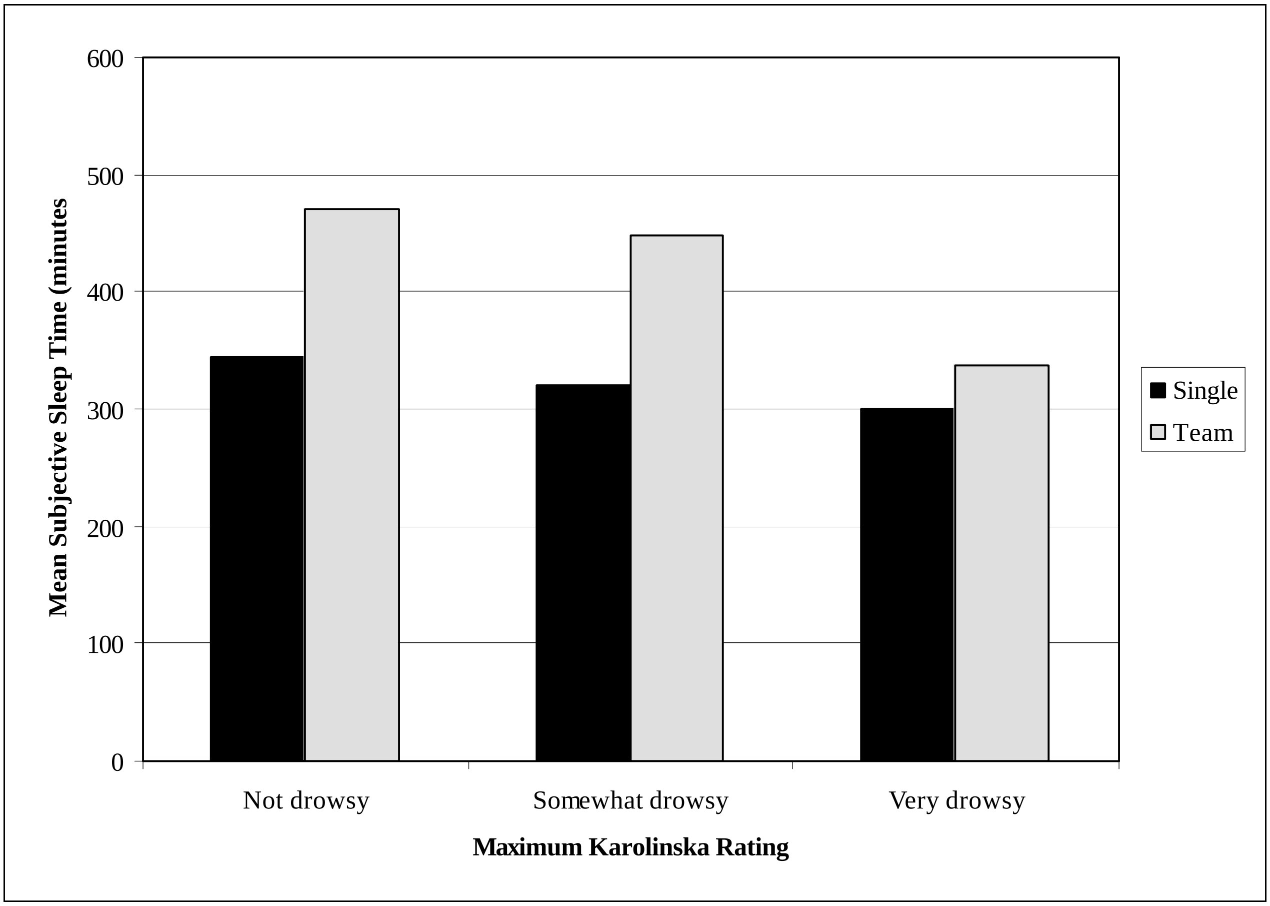

**Figure 69. Mean Subjective Sleep Time for the averaged maximum value at each category of Karolinska rating.**

The Median Karolinska data analysis had no significant main effects or interactions (Appendix D, Table D-4).

*Analysis of Sleep Quality from Driver Survey Data*
These analyses used the same data set as the first analyses reported in this objective, except that they were analyzed using Subjective Sleep Quality (Question 8 from the driver survey data) as the dependent variable. Question 8 asked, “How well did you sleep?” Drivers responded by using a 6-point scale:

1. Very badly
2. Badly
3. Fairly badly
4. Fairly well
5. Well
6. Very well

Four analyses were performed: Maximum ORD, Median ORD, Maximum Karolinska, and Median Karolinska. Driver type was also analyzed for each of the four analyses.

Driver Type was the only significant main effect or interaction found in the analysis of Maximum ORD by Driver Type, $F_{1,22}$ =10.99; $p$ = .003 (Appendix D, Table D-5), with single drivers reporting higher sleep quality than team drivers. None of the drivers in this sample were rated as "extremely drowsy." As can be seen in Figure 70, singles rated their sleep quality as higher than team drivers in all but the "very drowsy" category, although the Driver Type by Maximum ORD interaction was not significant. In general, the drivers in each of the maximum ORD categories rated their sleep quality as quite good on average.

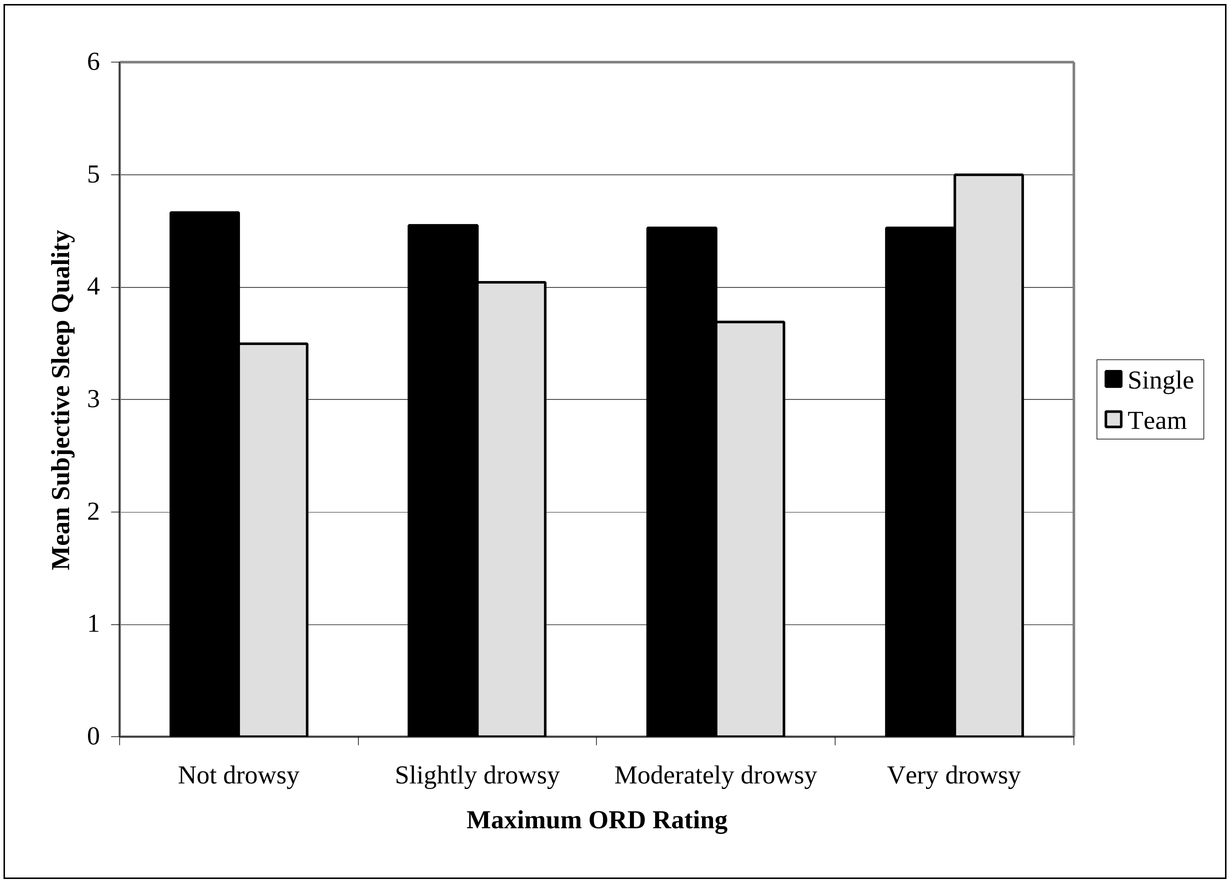

**Figure 70. Mean subjective sleep quality for the averaged maximum value at each category of ORD rating.**

For the Median ORD analysis, the Driver Type main effect approached the traditional level of statistical significance, $F_{1,22}$ = 4.10; $p$ = .055 (Appendix D, Table D-6). As was true with the maximum ORD rating, single drivers rated their sleep quality as higher than team drivers overall.

Neither of the Sleep Quality analyses for the Karolinska ratings showed significance for any of the main effects or interactions analyzed (Appendix D, Tables D-7 and D-8). The graphical presentation of these data also did not reveal any obvious trends in the data.

*Analysis of Sleep Quality from the Nightcap Sleep Bout Data*

For the analyses examining the ORD values, 55 nights of Nightcap data were available for the subject pool. A 5 (ORD Category) X 2 (Single, Team) ANOVA was conducted for Nightcap REM Percent (the percent of Total Sleep Time that the driver was in REM sleep). Separate analyses were conducted to examine both ORD maximum and median values.

The analysis of Nightcap REM Percent for maximum level of ORD Category did not show any significant results (Appendix D, Table D-9). The analysis of Nightcap REM Percent for median level of ORD Category resulted in a significant main effect for Driver Type, $F_{1,16} = 7.64$; $p = .0138$ (Appendix D, Table D-10). Figure 71 shows that single drivers had more REM sleep than did team drivers for each of the three ORD categories for which there were data points.

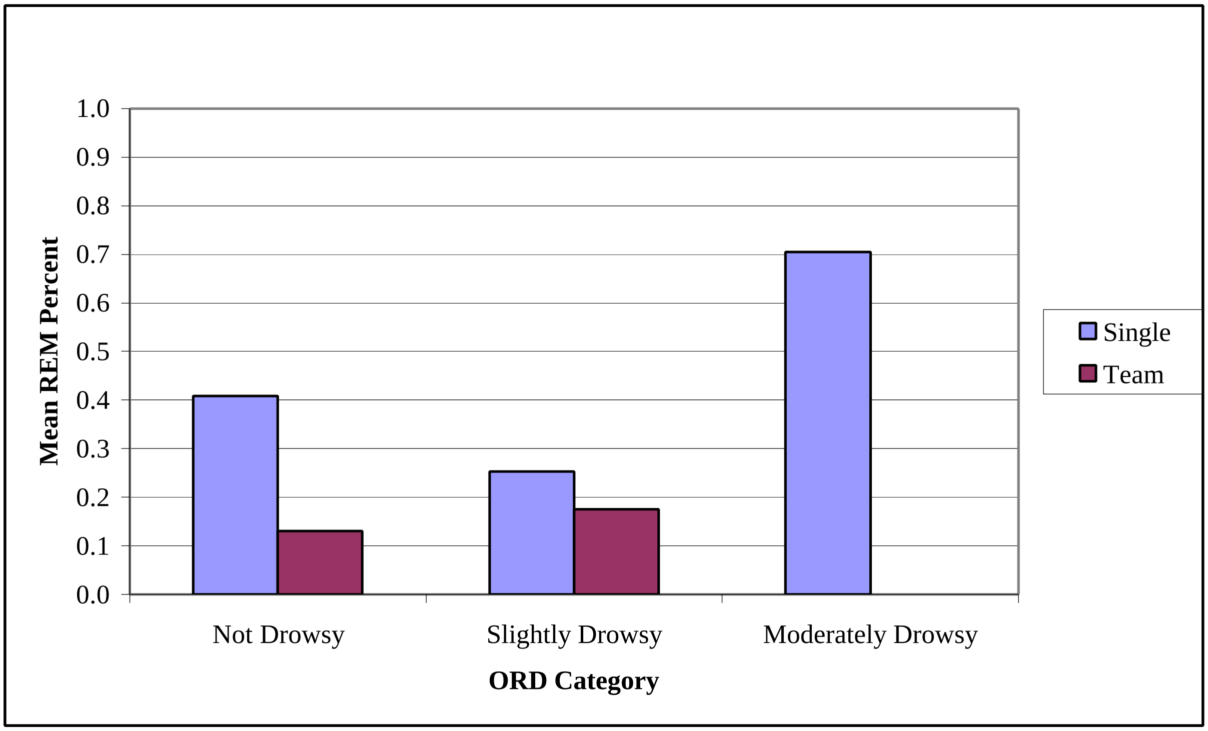

**Figure 71. Mean REM Percent for ORD Category.**

For the analyses examining the Karolinska values, 66 nights of Nightcap data were available for the subject pool. A 3 (Karolinska Category) X 2 (Single, Team) ANOVA was conducted for Nightcap REM Percent. Separate analyses were conducted to examine both Karolinska maximum and median values.

The analysis of Nightcap REM Percent for maximum and median levels of Karolinska Category did not yield any significant results (Appendix D, Tables D-11 and D-12). A review of the data revealed that the lack of any significant findings may have been due to a lack of Karolinska ratings above the “not drowsy” category; that is, the maximum and median Karolinska values fell almost completely into one category for single and team drivers for this subset of data.

### *Analysis of the Sleep Quantity and Quality for the Most Severe Cases of Drowsiness*

A separate descriptive analysis was conducted to determine whether or not any trends in sleep quality or quantity were present for the most severe cases of drowsiness recorded while driving. The results of the analysis are summarized in Table 27. There were 23 cases where drivers were rated as “moderately drowsy,” “very drowsy,” or “extremely drowsy” as part of this data set.

As has been shown in other sections of this report, the single drivers apparently had more difficulty with extreme fatigue relative to the team drivers, with over six times as many occurrences present. Other interesting items of note:

- Twenty of the occurrences were recorded from single drivers; three were from team drivers.
- Six of the 23 occurrences took place when the drivers had less than 5 hours of sleep in the previous 24 hours. Only 9 drivers had greater than 7 hours of sleep in the previous 24 hours.
- Only 3 of the drivers had subjective sleep quality ratings (“How well did you sleep?”) of less than 4 (4 = “fairly well,” 5 = “well,” 6 = “very well”).
- Fifteen of the 23 cases were from 4 of the single drivers, who had at least three separate incidents on the road each.

In general, there are a number of cases of very high Sleep Latencies, a large Number of Awakenings, and several cases of very high REM Percent (indicating possible cumulative fatigue). However, these measures vary greatly across the various subjects and cases.

These findings are similar to those in several other sections of this report. The vast majority of cases of greater difficulty with apparent fatigue while driving were from the single drivers, and many (15 out of 23) were from a few specific single drivers. It is interesting to note, however, that the driver’s self-rating of sleep quality during the sleep episode prior to these bouts of drowsiness were very high.

**Table 27. Subjective Sleep Time, Subjective Sleep Quality, REM Percent, Sleep Latency, and Number of Awakenings for instances when the Maximum ORD level was “moderately” (3), “very” (4), and “extremely drowsy” (5).**

| Driver Number | Driver Type | ORD Rating | Subjective Sleep Time (minutes) | Subjective Sleep Quality Rating (Scale 1-6) | REM Percent Time | Sleep Latency (minutes) | Number of Awakenings |
|---|---|---|---|---|---|---|---|
| 6 | Single | 3 | 510 | 5- Well | 0.33 | 11 | 2 |
| 6 | Single | 3 | 480 | 6- Very Well | 0.43 | 21 | 1 |
| 9 | Single | 3 | 375 | -- | 0.00 | 153 | -- |
| 9 | Single | 3 | 495 | 6- Very Well | 0.00 | -- | -- |
| 13 | Single | 3 | 390 | -- | 0.65 | 77 | 2 |
| 26 | Single | 3 | 300 | 4- Fairly Well | 0.44 | 12 | 1 |
| 20 | Single | 3 | 420 | 5- Well | 0.26 | 17 | -- |
| 9 | Single | 4 | 275 | 4- Fairly Well | 0.00 | 10 | 3 |
| 9 | Single | 4 | 495 | 5- Well | 0.00 | -- | 2 |
| 9 | Single | 4 | 505 | 3- Fairly Badly | 0.33 | 69 | 5 |
| 19 | Single | 4 | 315 | -- | 0.00 | 167 | 4 |
| 19 | Single | 4 | 245 | 5- Well | 0.52 | 85 | 1 |
| 20 | Single | 4 | 45 | 4- Fairly Well | 0.00 | 7 | 0 |
| 22 | Single | 4 | 510 | 4- Fairly Well | 0.70 | 13 | 1 |
| 26 | Single | 4 | 210 | 5- Well | 0.07 | 39 | 1 |
| 26 | Single | 4 | 315 | -- | 0.31 | 47 | 4 |
| 6 | Single | 4 | 510 | 4- Fairly Well | 0.44 | 13 | 1 |
| 22 | Single | 5 | 240 | 4- Fairly Well | 0.38 | 56 | 4 |
| 22 | Single | 5 | 120 | 3- Fairly Badly | 0.29 | 38 | 1 |
| 22 | Single | 5 | -- | * | 0.28 | 20 | 3 |
| 116 | Team | 4 | 255 | 5- Well | 0.47 | 106 | 4 |
| 209 | Team | 4 | 425 | 4- Fairly Well | 0.00 | -- | 5 |
| 209 | Team | 4 | 330 | 4- Fairly Well | 0.00 | -- | 3 |
| **MEDIAN for entire data set** | | **4** | **353** | **4** | **0.0227** | **19** | **2** |

## Discussion

The purpose of this analysis was to explore the relationships between sleep quality, sleep quantity, and driver drowsiness. This was approached from two different directions: objective measures of sleep quality as assessed by the Nightcap monitoring system, and subjective measures of sleep quality and quantity as assessed by the Wake-up Survey. In all cases, driver drowsiness was measured either subjectively by the driver (Karolinska rating) and/or by a video analyst (observer rating of drowsiness, or ORD).

In general, the main effect for Driver Type for both sleep quantity and quality mirrored the results for Objective 1. That is, team drivers got more sleep relative to single drivers, but it was of lower quality. However, single drivers had much greater problems with alertness while driving than did team drivers. Objective 3 of the report deals with the over-representation of a few drivers with a large amount of critical-incident data.

In terms of sleep quality, there was general agreement between the Nightcap and survey data: single drivers received higher quality of sleep than did the team drivers. In general, the sleep quality data did not show any other obvious trends.

Overall, the ORD and Karolinska drowsiness measures did not show any significant or meaningful relationship to Subjective Sleep Time or Sleep Quality, whether these were measured objectively or subjectively. Limited data could be used for this analysis because when the two data sets were merged (i.e., sleep data and alertness data), there were a number of missing data points due to driver failure to fill out the surveys, or truck or data collection hardware failure. It is possible that the relatively small data set limited the statistical power and thus created a situation of Type 2 error in the analyses.

However, as is indicated in Table 27 for the moderate to extreme drowsiness cases, the more likely explanation is related to the nature of the data themselves. In the case of the subjective sleep quality data, the self-reports were very uniform (and positive) among the drivers regardless of the REM Percent or Length of Sleep. It is unknown whether this apparent uniformity was due to insensitivity in the scale, or possibly driver unwillingness to give an accurate rating. In the case of the REM Percent and Total Sleep Time data shown in Table 27, even though the numbers were low in many instances, the variability was quite high. This variance was even greater for the data set as a whole, and it appears to be the nature of trucking. That is, sleep quality and quantity vary throughout a trip, as do cumulative sleep loss, individual differences, schedule requirements, driving environment, time of day, and time-on-task, just to name some of the effects at work. The combinations of these effects may be masking any alertness effects attributable to the quality and quantity of sleep during the previous 24 hours. Note, however, that the effect size of sleep quantity and quality is fairly small, at least relative to Driver Type in this particular analysis.

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## OBJECTIVE 5: DETERMINE THE LEVEL OF DRIVING PERFORMANCE, AS MEASURED BY THE FREQUENCY AND TYPE OF TRIGGERED CRITICAL INCIDENTS/DRIVER ERRORS, FOR SINGLE VERSUS TEAM TRIPS, LENGTH OF TRIP, TIME OF DAY, AND LENGTH OF SHIFT

### Data Analysis Overview

These analyses evaluated measures of driving performance such as the number of critical incidents and driver errors detected during the data collection runs. A critical incident is operationally defined as a valid triggered event that a data analyst has deemed either "critical" or "critical: secondary." A triggered incident was classified as "valid" if the data analyst was able to ascertain the cause of the trigger and determine that it was not a sensor false alarm (e.g., due to a radar return from a bridge abutment or some other non- situation consequential object). A triggered incident was defined as critical if the trigger was valid and was either the first in a sequence of triggers, the only trigger present, or was the direct cause of one or more other triggers. A triggered incident was deemed critical: secondary if the trigger was valid, followed another trigger in a sequence of triggers, and was directly caused by the presence of one or more of the preceding triggers. The types of triggered incidents are listed in Table 28.

**Table 28. Driving behaviors that result in triggered incidents.**

| | **Driving Behavior** | **Triggered Incident** | **Sensor Technology Used** |
|---|---|---|---|
| 1. | Abrupt Steering Maneuver | 1. Steering Trigger<br>2. Lateral Acceleration Trigger | 1. Steering wheel encoder.<br>2. Y-axis accelerometer |
| 2. | Hard braking | 1. Longitudinal Acceleration | 1. X-axis accelerometer |
| 3. | Following too Closely | 1. Time-to-Collision | 1. Eaton-Vorad |
| 4. | Lane Deviation | 1. Lane Deviation | 1. SafeTRAC™ |
| 5. | Drowsiness | 1. Perclos Trigger<br>2. Karolinska Rating of 7,8 or 9 | 1.PerClos Drowsiness Detection System<br>2. Karolinska query box |
| 6. | Change lanes with a vehicle in adjacent lane | 1. Lane Deviation/Steering Trigger | 1. Combination of sensor detecting turn signal and Eaton-Vorad on side of truck |
| 7. | Baseline data | 1. Timed trigger where the driver rates his drowsiness level using the Karolinska rating scale. This trigger was activated every 60 minutes (+/- 15 minutes) of continuous driving. | 1. No input in query box within 2 minutes. |

Driver errors are operationally defined as a subset of critical incidents. Specifically, a valid critical incident that a data analyst deemed to be the fault of the subject was also classified as a driver error.

For this objective, the number and type of critical incidents and driver errors were analyzed across the major independent variables associated with this study. Specifically, addressed were

Driver Type (single versus team), Time of Day, Length of Shift and number of shifts/breaks per day, and Length of Trip.

For selected analyses, given that each driver or team of drivers operated the instrumented vehicle for varying lengths of time each day and numbers of days, rate values were calculated to account for exposure. Calculating the frequency of incidents that occurred for each hour of driving allowed the data to be compared while controlling for differences in exposure. For example, many more drivers drove at 3 pm than at 3 am. Thus, any comparison in the raw frequencies of incidents would be somewhat misleading. The number of critical incidents per Hour of Shift and the number of critical incidents per Hour of Day were also calculated for each driver to determine whether drivers were involved in greater or fewer critical incidents over the course of a day as fatigue potentially became more of an issue.

Similar rate values were also calculated for the number of driver errors. The total number of driver errors that occurred in one day, shift, and hour were divided by the number of hours the driver drove to obtain the number of errors/hour. Note that, as described above, the number of error/hours value is a subset of the number of critical incidents and is therefore somewhat redundant since driver errors are those critical incidents that have been deemed to be the driver's fault.

For several of the analyses, missing data required that analyses be conducted in several parts. For example, when analyzing length of shift data, many drivers did not drive over six or seven hours. Thus, hours eight and higher had numerous "missing" data points. This means that Analyses of Variance could not be conducted on more than two factors at a time.

### *Driver Data Included in the Analyses*

Thirteen single subjects and seven teams (14 subjects) were chosen from the entire data set of 30 single subjects and 13 teams. These subjects were chosen based upon the number of days that data were available. When there was less than three days of data collected (due to truck failure, hardware system failure, or other extenuating circumstances), the driver was not included in the subject pool.

Since the goal of this objective was to determine the level of driver alertness for the variables of interest (i.e., Driver Type, Time of Day, Length of Shift, and Length of Trip for each analysis), the "timed event" or baseline triggers were excluded from many of the analyses. Thus, only the critical incident triggers from the data were used.

Data were used for the first eight days of the trip. Few of the drivers had data for days 9 and 10. There were only six subjects' data for day 9, resulting in 49 data points, and only one subject's data for day 10, resulting in eight data points. Therefore, data for days 9 and 10 were not used for analyses in Objective 5.

## Results

*Number of Critical Incidents/Driver Errors for Single and Team Drivers*

The first analysis conducted under this objective was a chi-square test to determine if there was a difference in the frequency of critical incident triggers and timed triggered events for single and team drivers. The result from this chi-square test was significant, $X^2$ (1, $N$ = 4841) = 167.34; $p < .01$. The frequencies for the triggered events (i.e., critical incidents) and time triggered (i.e., baseline) events for single and team drivers are shown in Figure 72. As can be seen, single drivers had substantially more critical incidents than did team drivers. The total number of critical incidents for single and team drivers was 1,898 and 564, respectively. The mean number of critical incidents for the two groups of drivers was 146.0 for the single drivers and 40.3 for the team drivers. A t-test of these means indicated that the difference in the number of critical incidents was significantly different between the two groups, $t_{24} = 13.16$; $p < .01$. It could be argued that this large and significant discrepancy could have been due to a difference in the amount of data that was collected for each group of drivers. That is, perhaps a substantially greater amount of data was collected for single drivers than for team drivers.

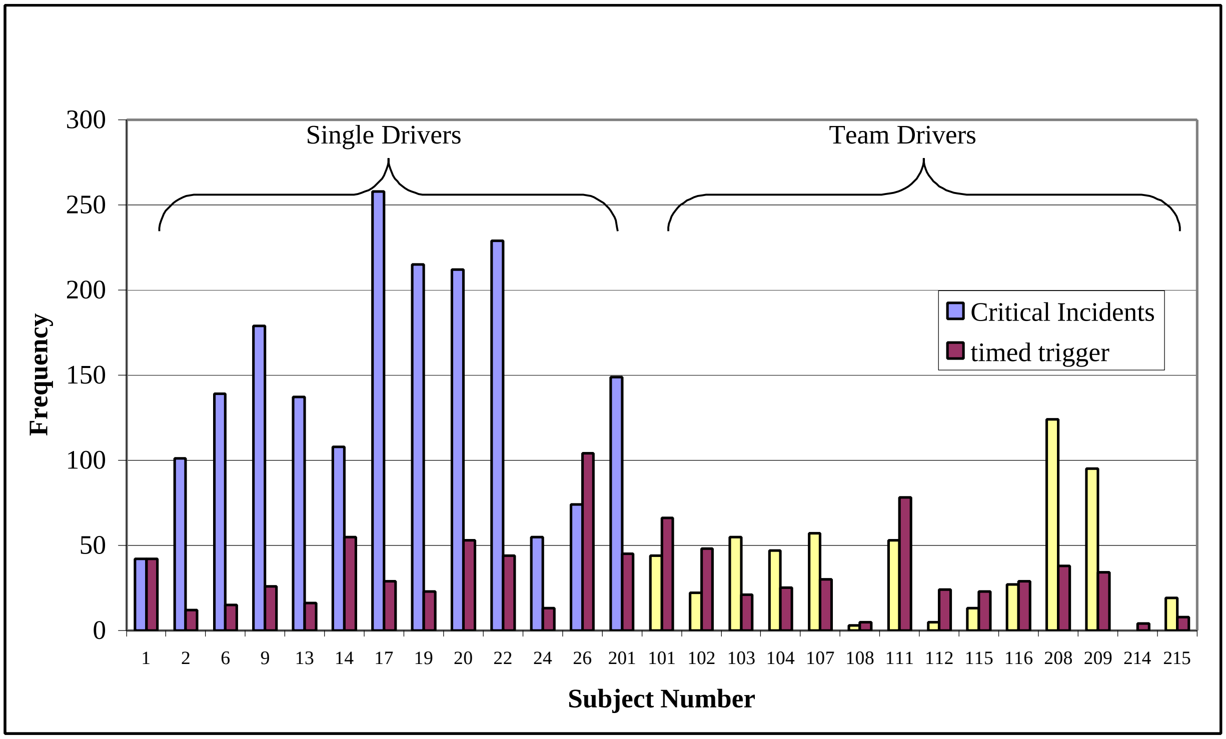

**Figure 72. Frequency of critical incidents and timed triggers for single and team drivers.**

As a surrogate measure of the amount of data collected per driver, Figure 72 shows the number of timed triggered events for each driver. Recall, time triggered events were baseline events that were recorded every 45 to 75 minutes for each driver. The total number of time-trigged events was 1,024 for single drivers ($M$=78.77) and 849 for team drivers ($M$=60.64). Although there is some apparent difference between these sample sizes, this difference in no way mirrors the differences in the number of critical incidents. A t-test of these means indicated that these values were not significantly different, $t_{25} = 1.61$; $p > .05$. The point of this discussion is to highlight the somewhat surprisingly large discrepancy between the number of critical incidents involving each group of drivers; that is, single drivers were involved in over three-times as many critical incidents than were team drivers. It is also important to note that eight of the 13 single drivers used in this analysis had a higher number of critical incidents than *any* of the team drivers.

Note that several of the subjects had relatively few timed triggers. Some of these were due to either driver non-compliance or a failure in the Karolinska query box. However, in the case of the teams, several of the cases reflect the fact that those drivers did not drive very often or for very long. Specifically, there were three teams consisting of married couples where the wife seldom drove. As an aside, this finding has implications for the hours-of-service regulations, since in all of these cases the husbands often drove well over the ten-consecutive-hours-per-day driving limit to keep the truck moving. While the ‘adverse driving conditions’ clause allows drivers to legally drive over 10 consecutive hours, weather was not an issue in any of these cases.

An important result highlighted in Figure 72 is that the frequency of critical incidents occurring with single drivers is considerably higher than that for team drivers. There are two hypotheses for this that are based on results obtained during the focus group interviews (Neale *et al.*, 1998a). One hypothesis suggested that team drivers must have driven more smoothly in order for the partner in the sleeper berth to get rest. The drivers who participated in the focus groups commented that it was very important to team with a driver who was conscientious about the fact that someone was sleeping behind them. A team driver must take certain precautions that will promote a smoother ride out of consideration for their partner, such as allowing a greater following distance to minimize the need for quick braking maneuvers and, in general, driving less aggressively. Another hypothesis was that team drivers learned to be more cautious drivers, thus allowing for a successful teaming operation. The focus group participants explained that it was necessary to have a driving partner that one could “trust with your life.” In order to investigate this second hypothesis, the data were examined to look at whether many of the teams in this study were regular teams or teams who drove together just for the purpose of participating in this study (Figure 73). Only one team had never driven together, and two other teams had driven together for only a few months. Aside from one team that had never driven together, it could be assumed that the team drivers were relatively comfortable with their partner’s driving ability.

Another possibility for the discrepancy in the number of incidents between single and team drivers would be if team drivers were older and/or had more driving experience than did the single drivers who participated in this study. Figure 74 shows the age breakdown of single versus team drivers. The mean ages for single drivers and team drivers were 44.9 years and 41.1 years, respectively. A t-test indicated that the ages for the two groups of drivers was not statistically different, $t_{39} = 0.04$; $p > .05$.

Figures 73 and 75 show the breakdown of driving experience for single and team drivers. The mean number of years experience for single drivers was 15.2 years, while the mean number of years experience for team drivers was 10.1 years. Though the experience difference between the two groups was 5.1 years, there was a large standard deviation for both groups ($SD = 9.26$ for single drivers, and *SD* = 9.88 for team drivers). Due to these large standard deviations, the result of a t-test on the mean years experience was not significant, $t_{36} = 2.75$; $p > .05$. An interesting note with regard to driving experience is that three of the teams that participated were married couples, and three of these team members had less than two years of driving experience.

The findings regarding age and experience suggest that these factors did not play a role in the increased number of critical incidents for single drivers. This non-result may suggest that the reason for the fewer critical incidents for team drivers is that they drove more conservatively and cautiously than single drivers, perhaps to allow their partner a smooth ride and quality rest.

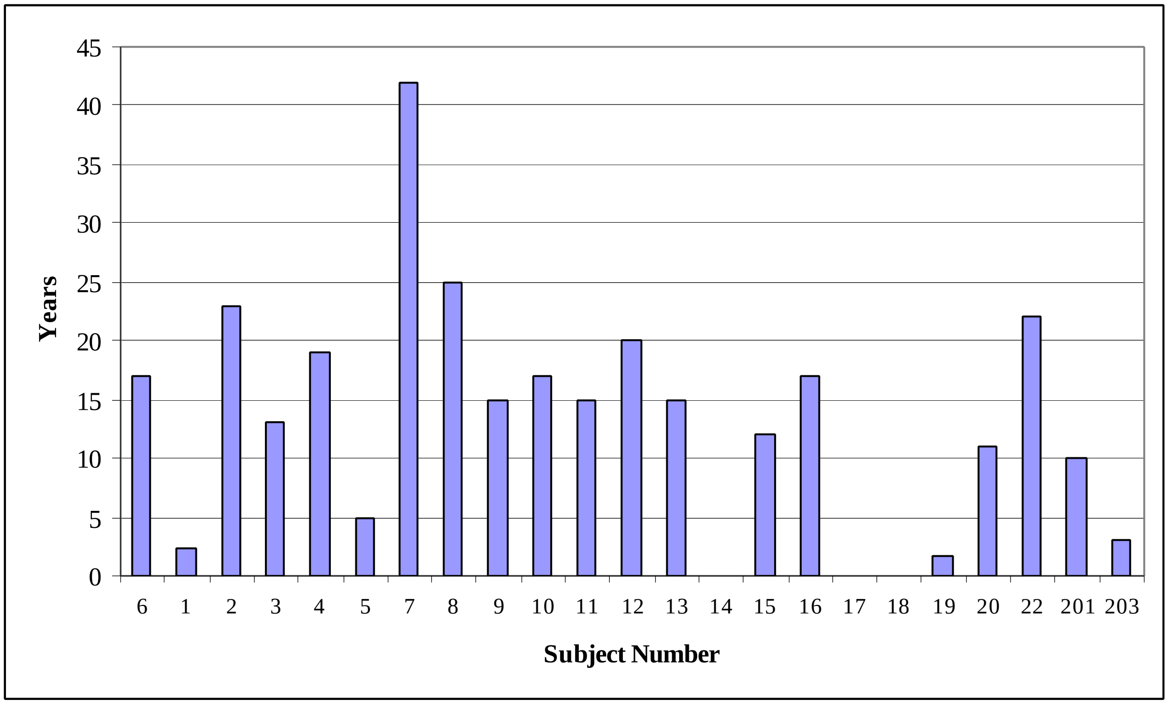

**Figure 73. Total driving experience of single drivers who participated in this study. (The mean number of years driving was 15.2 years (*SD* = 9.26) and the median was 15 years.)**

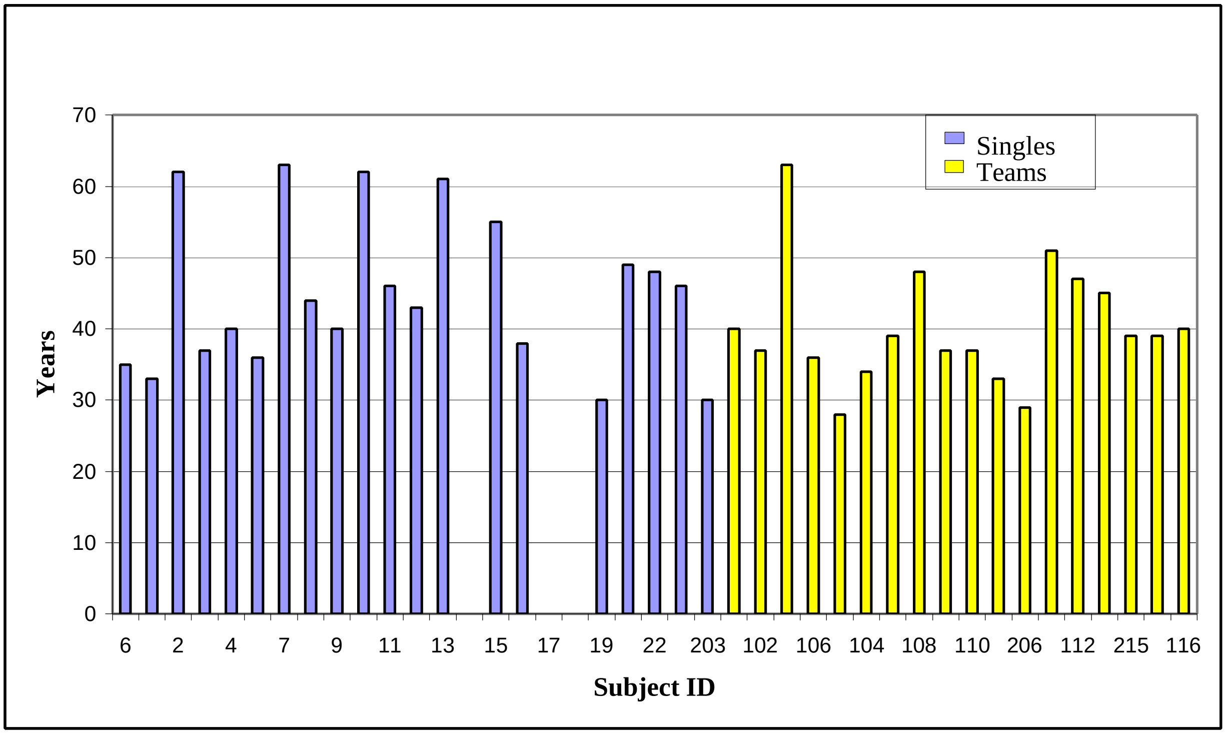

**Figure 74. Driver age for single and team drivers used in this analysis.**

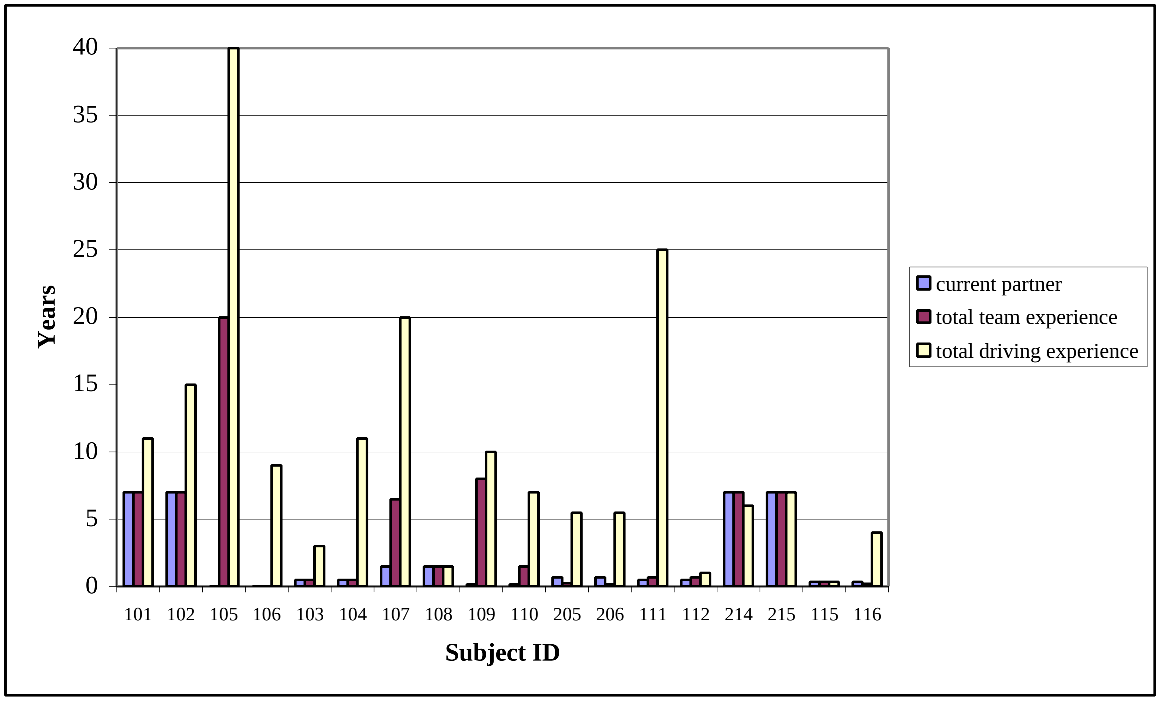

**Figure 75. Number of years that each team member: (1) drove with the teammate for this study, (2) has driven in a teaming operation, (3) total driving experience, single or team. (The mean total driving experience for teams was 10.1 years (*SD* = 9.88) and the median was 7 years.)**

*Number of Critical Incidents by Hour of Day*

The number of critical incidents that occurred at each hour of the day was calculated for singles and teams (Figure 76). As shown, the largest number of critical incidents occurred during the afternoon hours. Single drivers were apparently involved in a greater number of critical incidents in the morning and afternoon hours than were the team drivers, whereas team drivers were involved in a greater number of critical incidents in the early morning hours than were single drivers. As shown in other analyses, single drivers generally drove more aggressively than team drivers, which could explain why they were involved in more critical incidents during the daylight hours.

It is important to note that the results shown in Figure 76 are raw frequencies and do not account for exposure. For example, team drivers tended to drive more in the early morning hours than did single drivers. To account for these effects, an Analysis of Variance (ANOVA) was conducted on the *rate of critical incidents.* Rate was calculated by taking the number of critical incidents that occurred for a subject for a given hour of the day and dividing that number by the number of times that the same subject was driving during that hour of the day for a given trip.

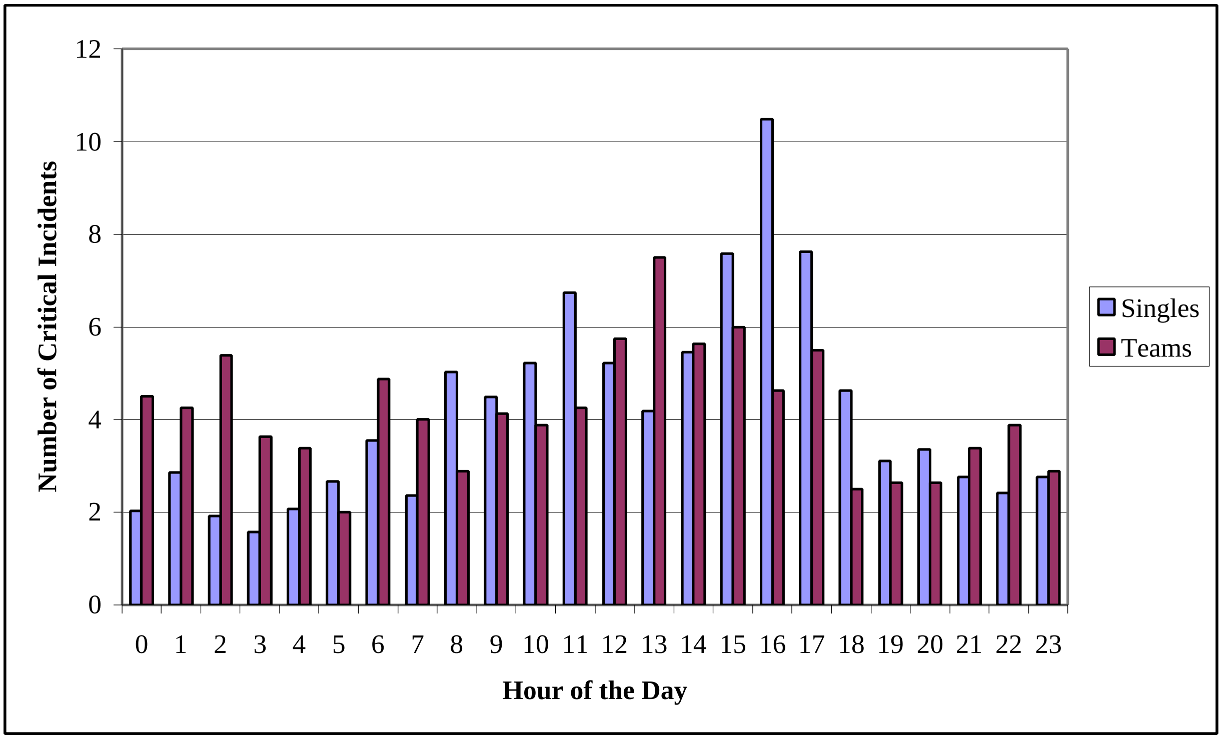

**Figure 76. Number of critical incidents occurring for singles and teams at each Hour of Day.**

The ANOVA for Critical Incident Rate (dependent variable) for this analysis was a two-way, mixed-factor design with Driver Type (single, team) and Hour of Day as independent variables. The complete ANOVA table for this analysis is shown in Appendix E. The results showed that the Driver Type, $F_{1,25}$ = 8.49; $p$= .007, and Hour of Day, $F_{23,480}$ = 1.93; $p$= .006, were significant (Appendix E, Table E-1). Since Driver Type is addressed in detail in the previous section, it will not be repeated here. A graph showing the Critical Incident Rate by Hour of Day is presented in Figure 77. The highest critical incident rates occurred during daylight hours between 11:00 am and noon, and 3:00 pm and 6:00 pm. In contrast, the lowest rates occurred in the hours starting at 8:00 pm, 9:00 pm, and 11:00 pm. The rates at night, even very late at night, were low. This finding may indicate that the presence of heavier traffic may have provided a greater influence on the presence of critical incidents than did driver fatigue.

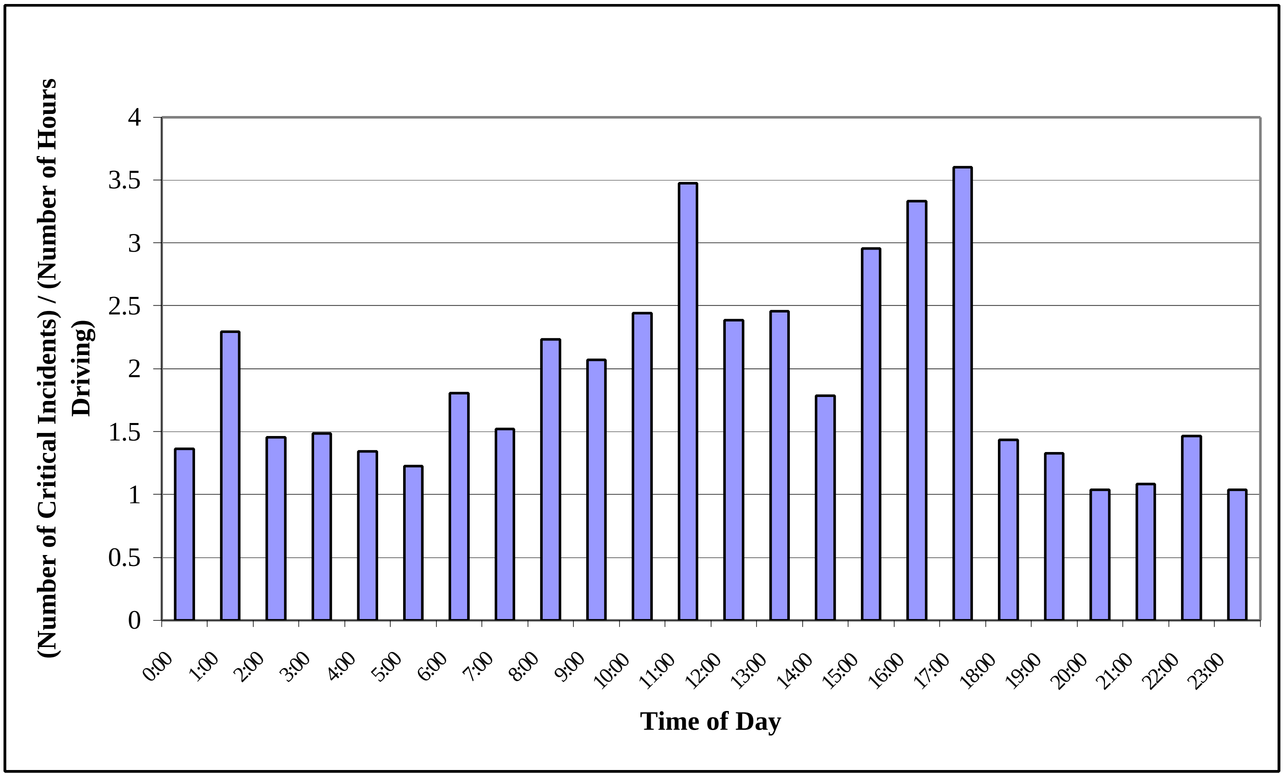

**Figure 77. Number of critical incidents occurring at each Hour of Day corrected for exposure.**

The number of driver errors per Hour of Day, not corrected for exposure, is shown in Figure 78. Note that driver errors are those critical incidents that were judged to be the fault of the participant. The results (as expected) are similar: single drivers committed more driver errors during the daylight hours and the team drivers committed more driver errors during the nighttime periods.

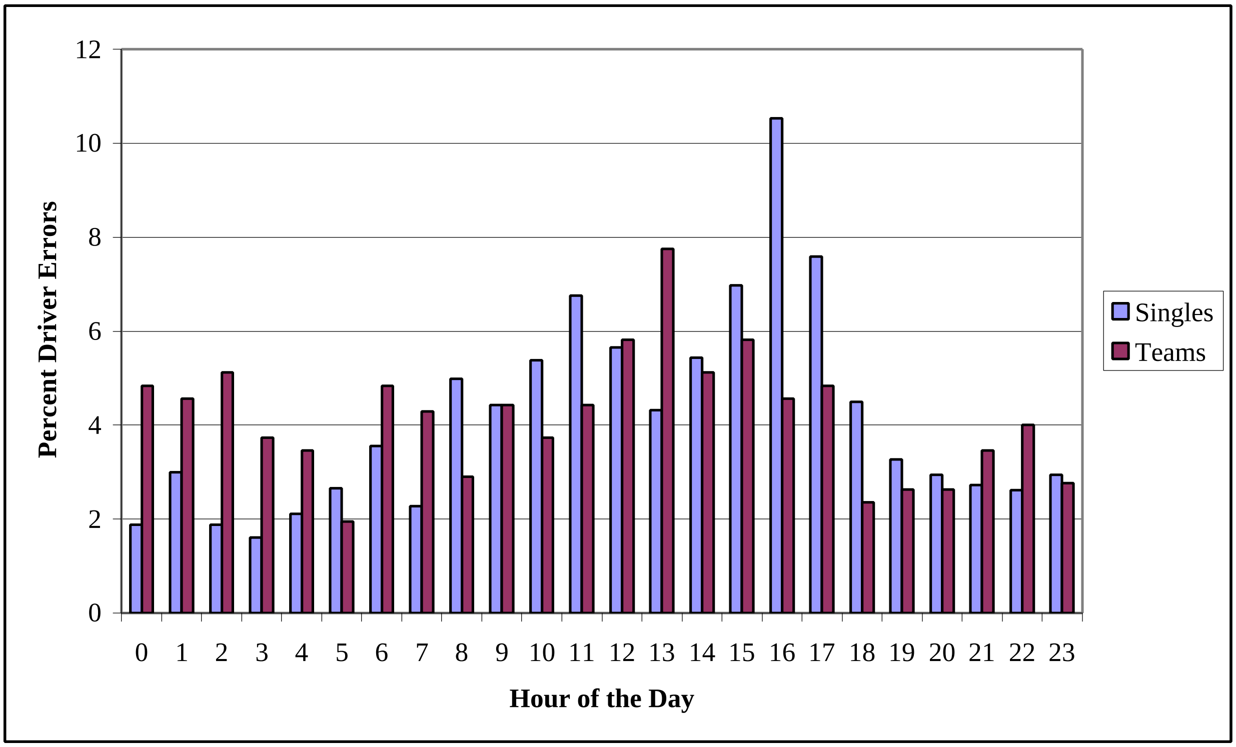

**Figure 78. Number of driver errors occurring at each Hour of the Day.**

The ANOVA results for driver errors corrected for exposure per Hour of Day for singles and teams are provided in Appendix E. Like the critical incident data, the number of driver errors that occurred during a given hour of the day for a given subject was divided by the associated number of instances where the same driver drove during that hour of the day to create an “error rate/hour of driving.” The ANOVA results were significant for both main effects: Driver Type, $F_{1,25} = 8.27$; $p < .01$, and Hour of Drive, $F_{23,480} = 1.59$; $p < .05$ (Appendix E, Table E-2). The interaction of Driver Type by Hour of Day was not significant, $p<.05$.

Figure 79 shows the frequency of driver errors, corrected for exposure, by hour of the day. The results are very similar to those seen in Figure 77 for critical incidents. Namely, the highest rate of driver errors occurred during the afternoon hours and the lowest rates generally occurred at night. This finding is contrary to the hypothesis that drivers exhibit poor driving performance late at night due to circadian rhythm-induced fatigue. However, it appears likely that the possible influence of higher traffic volumes might have had a much greater impact on the number of driver errors.

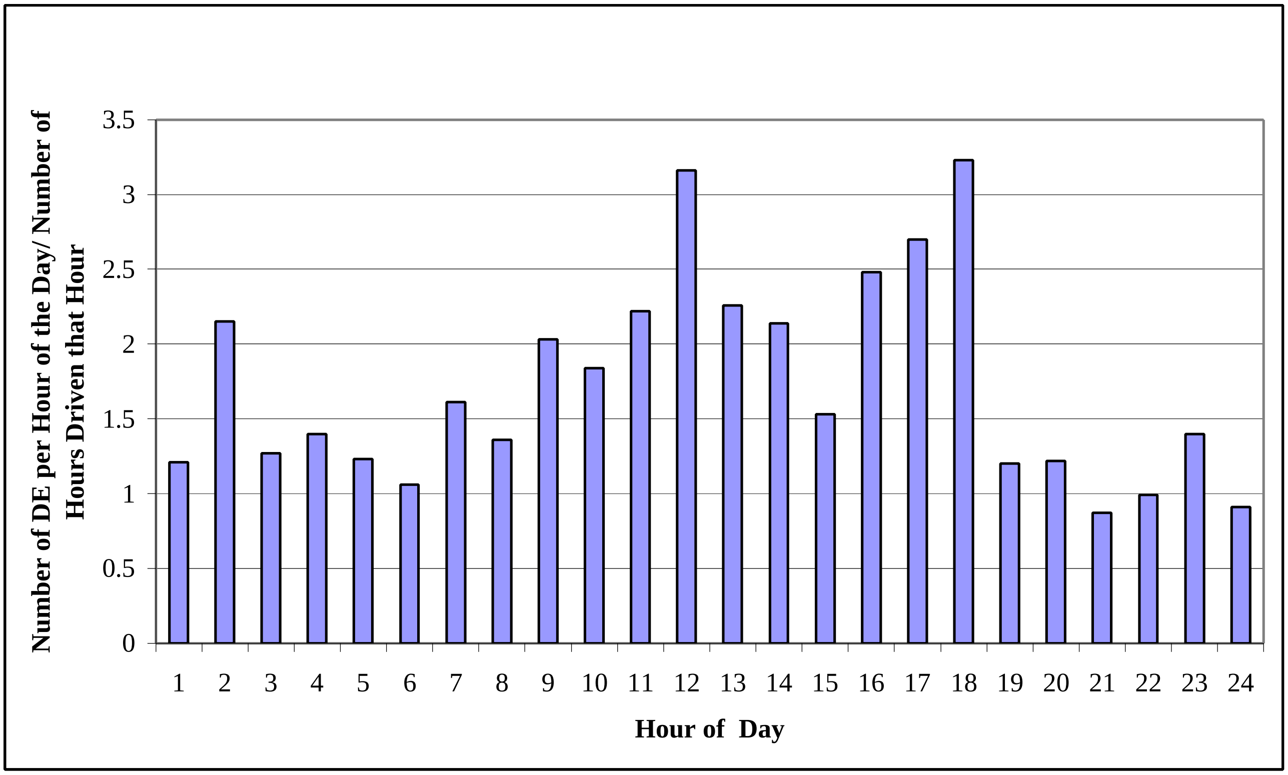

**Figure 79. Number of driver errors occurring per Hour of the Day corrected for exposure.**

To further assess the effects of Time of Day, a second analysis was conducted by grouping Hour of Day into four day segments: Morning (4:00 to 11:59), Afternoon (12:00 to 17:59), Evening (18:00 to 21:59), and Night (22:00 to 3:59) (Pinel, 1997). This was done in order to get a clearer picture of the general effects of factors such as meals, circadian rhythms, and traffic. "Rates" of the occurrence of critical incidents were calculated by dividing the number of critical incidents per time category by the number of hours driven in that same time category. This procedure was conducted for each subject. The resulting mean rates for each day segment for team and single drivers are shown in Figures 80 and 81, respectively. An ANOVA conducted on the rates proved to be significant, where there was a difference across time segments, $F_{3,71} = 4.23$; $p = .008$ (Appendix E, Table E-3). A post-hoc comparison, using a Fisher's Least Significant Difference procedure, found that the significant ANOVA result was due to differences between the Evening segment and the Morning and Night Segments, $p < .05$. That is, there was a significantly higher incident rate in the Evening segment than in the Morning and Night segments.

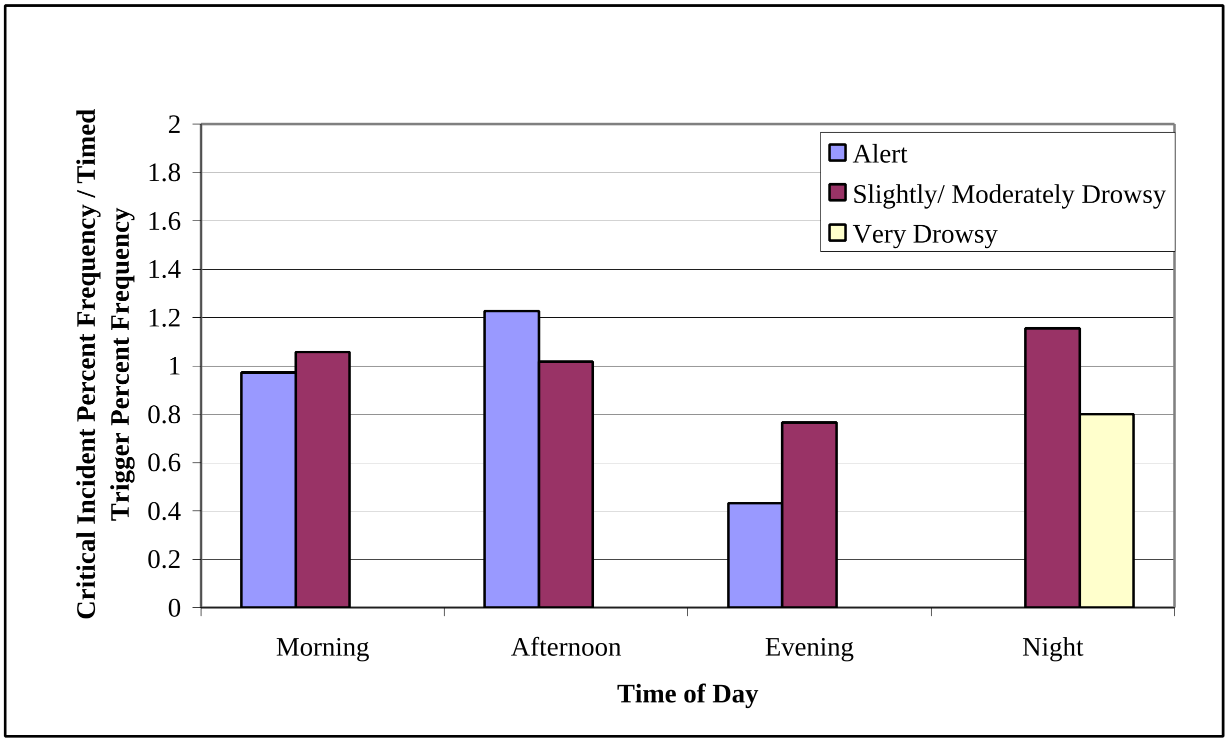

**Figure 80. Ratio of critical incident percent frequency to timed trigger percent frequency for team drivers.**

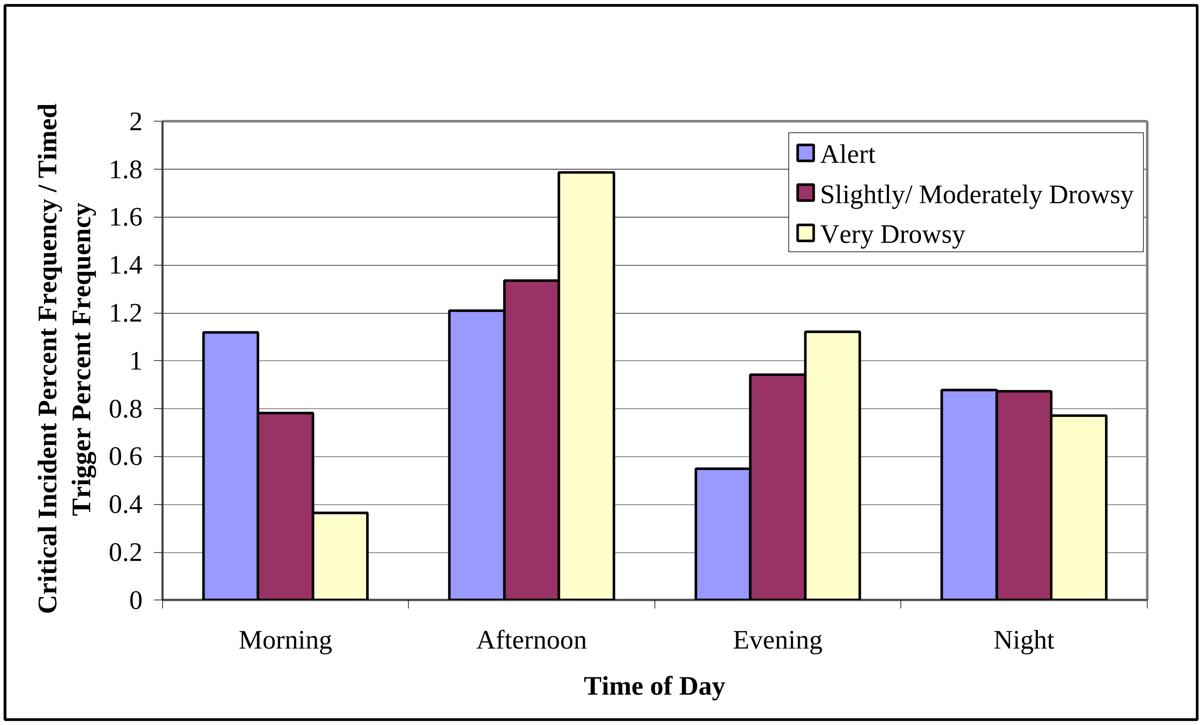

**Figure 81. Ratio of critical incident percent frequency to timed trigger percent frequency for single drivers.**

*Number of Critical Incidents/Driver Errors per Hour of a Single Shift*
An ANOVA was conducted to determine whether there were differences in the number of critical incidents per hour for each Driver Type for each hour of a shift. A shift is defined as the amount of time each driver drove without taking more than a 20-minute break. If a driver stopped driving for less than 20 minutes, it was not considered a break and the shift continued uninterrupted. If the driver took a break for 20 minutes or longer, then the shift ended at the beginning of the break and a new shift started when that driver or another driver began driving. In the case of team drivers, a shift would change automatically if another driver began driving.

A two-way, mixed factor ANOVA that included Driver Type (single vs. team) and Hour of Shift was conducted using the number of critical incidents/hour and the number of driver errors/hour as dependent variables. Like the results in the previous section, the team main effect was significant. (Since the team main effect was discussed above, it will not be repeated here.) Neither the Shift Hour nor the Shift Hour by Team effects was significant (Appendix E, Table E-4). The same result was found for driver errors in that single drivers (*MN* =2.04) committed significantly more errors than did team drivers (*MN* = 0.93), $F_{1,25} = 4.10$; $p = .05$ (Appendix E, Table E-5), but no other effects were significant.

To look descriptively at the behavior associated with shift length, the number of incidents and driver errors per hour of shift are shown in Figure 82. Please note that the sample size dropped quickly after about 6 hours in a shift. Only about 15 percent of the shifts were over 7 hours. Five percent of the shifts (*N*=17) exceeded the hours-of-service regulations of 10 consecutive hours per day. It is interesting to note that very few critical incidents and driver errors occurred while drivers were driving outside of the hours-of-service regulations. In fact, even though there were 22 cases where a driver drove over 14 hours in a single shift, there were *no occurrences* of a critical incident or driver error in any of these cases. This is in contrast to an average of 2.16 critical incidents/per hour and 1.90 driver errors per hour during the first hour of the shift. In these cases, it appears that drivers were driving more conservatively and cautiously, perhaps because they were compensating for increased fatigue, or because they knew that they were operating outside of the regulations and did not want to risk being stopped by law enforcement officials.

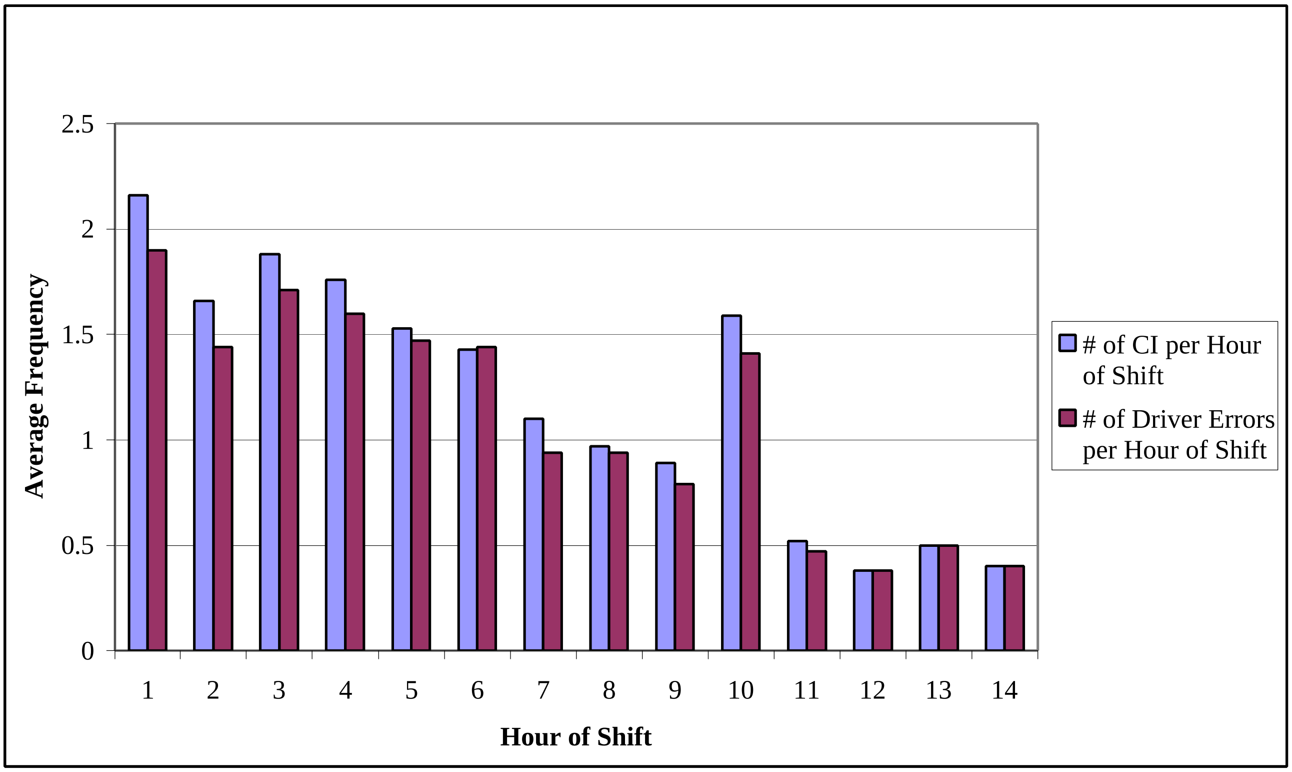

**Figure 82. Number of critical incidents and driver errors per Hour of Shift.**

*Number of Critical Incidents/Driver Errors per Total Hours of Driving/Day*

To further investigate the effects of the amount of driving time on critical incidents/driver errors, an analysis was conducted on the Hour of Drive independent of shift. That is, for a 24-hour period starting at midnight, the total number of hours that the driver drove, summed across shifts, was analyzed. For this analysis, a two-way, mixed factor ANOVA was conducted for Team and Hour of Drive as independent variables and Critical Incidents and Driver Errors as dependent variables. The complete ANOVA tables are shown in Appendix E, Tables E-6 and E-7. Like the single shift analysis above, only the Team main effect was significant. Based on the findings in the previous sections, single drivers had over twice the rate of critical incidents and driver errors than did team drivers.

Neither the Hour of Drive main effect nor the Hour of Drive by Team interaction showed significance for this analysis.

The descriptive look at the number of cases present per Hour of Drive and the associated number of critical incidents and driver errors revealed a very similar trend to the one shown in Figure 82. For this data set, there were 61 total cases where drivers drove a total of more than 10 hours in a single day. This number, indicating an hours-of-service violation, represents 4.7 percent of the total cases.

*Number of Driving Shifts per Day*

In order to determine if taking more breaks and/or driving more shifts in a day had an effect on the number of critical incidents/driver errors, a two-way ANOVA was conducted with Driver Type and Shift as independent variables and Critical Incidents and Driver Errors (corrected for exposure) as dependent variables. The complete ANOVA tables appear in Appendix E, Tables E-8 and E-9. Neither the Shift main effect nor Shift by Driver type interaction was significant for either Critical Incidents or Driver Errors.

The number of critical incidents for the number of shifts is shown in Figure 83. There appears to be a slight decrease in the rate of driver errors committed when more shifts were driven and/or when more breaks were taken. However, this insignificant trend is small and, even if it were significant it would probably not be a meaningful result in practical terms.

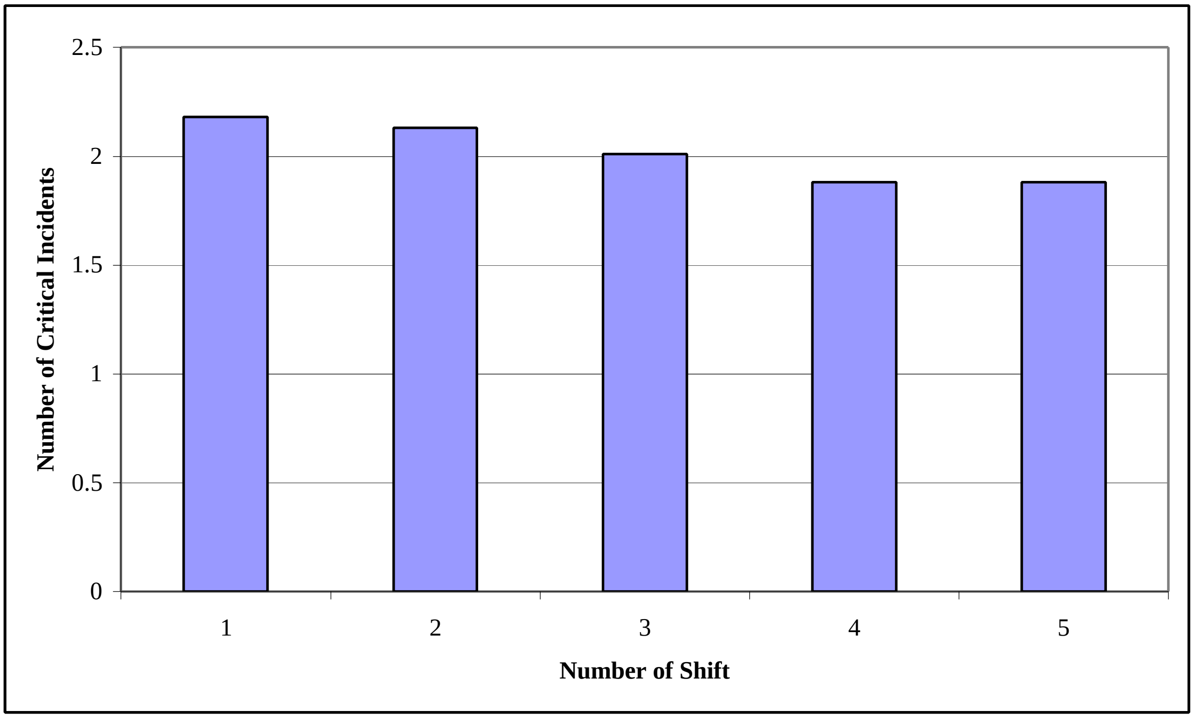

**Figure 83. Number of critical incidents per Hour of Shift.**

*Day of Trip Analysis*

An ANOVA was conducted to determine if any differences existed between single and team drivers for the number of critical incidents or driver errors that were committed across Days of Trip. As with the analyses described previously, a two-way, mixed factor ANOVA was conducted with Driver Type and Day of Drive as independent variables and Critical Incidents/Hour of Driving and Driver Errors/Hour of Driving for each day as dependent variables. The complete ANOVA tables are shown in Appendix E, Tables E-10 and E-11. Neither the Day of Drive main effect nor the Day of Drive by Team approached significance for either of the dependent variables.

To determine if any trends existed in the Day of Drive variable, the total number of critical incidents, corrected for exposure, was graphed for each day of the drive (Figure 84). Contrary to one of the major hypotheses associated with this study, there does not seem to be any overall degradation in driving performance, as measured by critical incidents/driver errors, across the day of the drive.

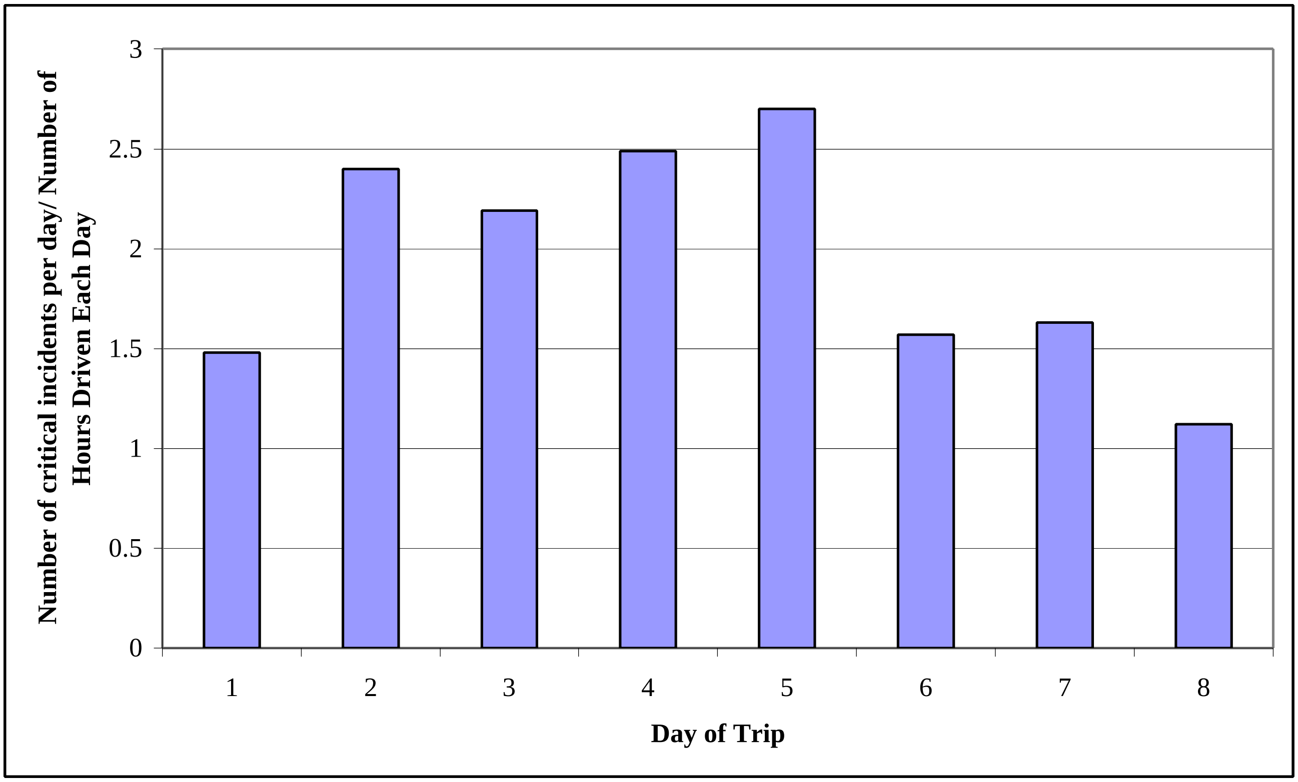

**Figure 84. Number of critical incidents per Day of Trip corrected for exposure.**

*Critical Incident Severity Analysis*
As part of the data reduction/classification process for this project, the "severity" of each critical incident was determined. Severity was operationally defined to include the following categories:

- Collision: Any contact between the truck and any other fixed or moving object, animal or pedestrian. Since no injury crashes occurred during this study, this category was not broken down any further.

- Near Collision: Any conflict between moving vehicles or situation of very close speed/distance proximity between the truck and any other fixed or moving object, animal, or pedestrian that required a rapid, evasive maneuver to avoid a crash.

- Driver Error/Hazard Present: The commitment of a driving error such as an unplanned lane deviation, improper lane change with a vehicle present, judgment error related to "tailgating," etc. in close proximity to another vehicle or fixed or moving object, animal, or pedestrian that *did not* require a rapid evasive maneuver to avoid a crash.

- Driver Error/No Hazard Present: The commitment of a driver error, as described above, where there was not close proximity to another vehicle or fixed or moving object, animal, or pedestrian.

- Other Driver: On occasion, critical incidents were caused by another driver, and the truck driver had no contribution to the incident. None of these instances were Collisions. Thus, since the truck driver was not at fault, it was decided that this would be kept as a separate category, even though it was not mutually exclusive of the above categories per se.

Trained data reduction analysts classified each valid critical incident into one of the above categories.

For these types of data, often the most informative data are contained in the cases of the most severe classifications. Specifically, the Collisions and Near Collisions are the cases where the driver was at the greatest risk, and was often out of control of the vehicle for at least a moment.

The Collisions and Near Collisions analyzed as part of this data set are shown in Table 29. The table provides information on whether the driver was a single or team driver, a classification of the incident as a Collision/Near Collision and type of Collision/Near Collision, and the reviewer's notes regarding the incident. As shown, there were two collisions captured as part of this study. Both were non-injury, non-police-reported crashes. One was a lane deviation collision with a road sign where the driver was extremely fatigued. The second was a collision with an animal where fatigue was not an apparent factor.

### Table 29. Collision and Near Collision data.

| Sub # | Type | Classification | Severity | Description |
|---|---|---|---|---|
| 9 | Single | Lane Deviation:<br>Collision with fixed object off-road under extreme fatigue. | Collision | Trigger was activated when driver was traveling in the left lane and started to drift left towards the median. The driver hit a sign and had to jerk the wheel to the right to get back into his lane. It was too dark to see the driver's face clearly but his body movements (head nods) indicate he is very drowsy. |
| 13 | Single | Forward Collision:<br>With Animal | Collision | The driver hit a dog-did not directly cause a trigger. Longitudinal acceleration trigger was activated when the driver pulled over to investigate. |
| 2 | Single | Lane Change:<br>With Vehicle in Adjacent Lane | Near Collision | Trigger was activated when the driver was traveling in the middle lane and was about to move into the right lane. The driver did not see a vehicle in the right lane until he had already begun the lane change (vehicle was in his blind spot). The driver had to quickly jerk the wheel back to the left to avoid hitting the other car. |
| 4 | Single | Close headway with sudden deceleration by Forward vehicle | Near Collision | Vehicle ahead of vehicle directly in front of the subject truck turned right and the vehicle ahead of truck slowed and stopped. The truck was following too closely and had to brake hard when the car slowed. The brakes squealed as truck stopped and truck momentarily crossed the centerline. |
| 6 | Single | Other Vehicle Cut off:<br>Sudden Lane Change required<br>Hard Braking | Near Collision | A car was in front of the subject driver in the left lane of an interstate and another tractor-trailer was ahead in the right lane. The other tractor-trailer suddenly signaled and moved into the left lane ahead of the car in order to exit to the left. The car and the subject driver both braked for the tractor-trailer. |
| 7 | Single | Judgment Error/Dangerous Maneuver: Driver cut across traffic | Near Collision | Subject was driving through a construction zone in the right lane. He realized he wanted to make a left exit. Unknown whether there were signs warning of this exit. Subject drove across other lanes to try to get onto exit ramp. Other exiting traffic forced him to stop the truck and block one lane while he waited for an opening. A truck passed by closely and honked horn at subject. Subject tried to advance down exit ramp but ran over small concrete divider. |

| Sub # | Type | Classification | Severity | Description |
|---|---|---|---|---|
| 9 | Single | Other Vehicle Cut off:<br>Sudden Lane Change required<br>Hard Braking | Near Collision | Trigger was activated when the driver was in the left lane proceeding through an intersection and another vehicle was beside the driver in the right lane. Both vehicles passed through the intersection and the other vehicle moved into the left lane directly in front of him, causing the trigger. |
| 9 | Single | Other Vehicle:<br>Near Head-On collision with other vehicle traveling in wrong lane | Near Collision | Trigger was activated when driver was traveling on a two-lane road and another vehicle was approaching from the opposite direction. The other vehicle was traveling very fast and came very close to the truck. The driver had to move further to the right in his lane to avoid the other vehicle. |
| 9 | Single | Close headway with sudden deceleration by Forward vehicle | Near Collision | Trigger was activated when driver was traveling behind another vehicle in the left lane. The right lane was closed due to construction so there was only one lane open. The vehicle in front of the driver braked, causing the driver to brake hard. |
| 9 | Single | Lane deviation under extreme fatigue | Near Collision | Trigger was activated when driver was traveling in the right lane and started to drift to the right (driver was almost falling asleep). Upon awakening, driver pulled the truck back into his lane. |
| 9 | Single | Other vehicle: Intersection incursion | Near Collision | Trigger was activated when the driver was traveling on a two-lane road and another vehicle almost pulled out in front of him coming from the right side of the road, driver braked hard. |
| 9 | Single | Near Forward Collision with Stopped Vehicle (waiting LTAP) | Near Collision | Trigger was activated when driver was traveling on a two-lane road and there was a car stopped on the road waiting to turn left. The driver braked and quickly swerved into a right turning lane. When he past the stopped vehicle he hurried to get back into correct lane. |
| 14 | Single | Braked/ Swerved to avoid Pedestrian Close to Roadside | Near Collision | Man was walking on right side of road to close to the lane, driver braked hard and went into left lane halfway to avoid the person. Conditions clear and dry. |
| 16 | Single | Close headway with sudden deceleration by Forward vehicle | Near Collision | Driver triggered 'critical incident' button and provided verbal description; said that the van in front of him slowed and signal suddenly. He also commented that car drivers often signal at the last minute and this was difficult for truck drivers. |
| 16 | Single | Close headway with sudden deceleration by Forward vehicle | Near Collision | The driver reported that the car in front of him slowed abruptly as the speed limit decreased to 45mph, causing him to brake hard. |
| 19 | Single | Lane Change with Vehicle in Adjacent Lane | Near Collision | The trigger was activated when the driver was trying to change lanes and the other vehicles would not let him. It was a construction zone. |

| Sub # | Type | Classification | Severity | Description |
|---|---|---|---|---|
| 19 | Single | Other Vehicle: Lane Change Cut-off | Near Collision | The trigger was activated when the driver decreased speed because a dump truck directly ahead of him suddenly decreased and merged to the left. It was a construction zone. |
| 22 | Single | Lane deviation under extreme fatigue. Near head on. | Near Collision | The driver was on a two-lane road that was curving sharply to the right. The driver crossed the centerline into the oncoming lane as he went around the curve. Another tractor-trailer approached in the oncoming lane and the subject driver quickly moved back into his own lane. It was nighttime and the driver was very tired (Karolinska sleepiness rating greater than 6 reported 2 minutes prior). |
| 22 | Single | Close headway with sudden deceleration by Forward vehicle | Near Collision | The driver was on a heavily congested two-lane exit ramp. The lead vehicle slowed to a stop, causing the SB driver to brake abruptly. The driver's body was thrown forward slightly. |
| 101 | Team | Other Vehicle: Lane Change Cut-off | Near Collision | All other lanes were in gridlock, while subject's lane (the far right one) was partially clear. Another vehicle decided to move into the subject's lane. Subject was moving slowly but much faster than the other traffic. From a standstill, the other car moved into the subject's lane, cutting him off. Subject had to brake hard. |
| 102 | Team | Other Vehicle(s):<br>Driver had to Brake and Swerve to avoid | Near Collision | Subject was in the right lane. Traffic had slowed up ahead. In the left lane, two cars either had an accident or came very close to one. Subject had to slow down very quickly and swerve to the right over the right line to avoid the incident. |
| 206 | Team | Judgment Error: Extreme Fatigue Detected | Near Collision | Trigger was activated because the driver seemed to be very sleepy, her eyes were slowly closing and then opening back up while in traffic. |
| 208 | Team | Close headway with sudden deceleration by Forward vehicle | Near Collision | The trigger was activated when the driver had to reduce speed and change lanes very fast when the truck directly ahead of him had to reduce speed suddenly because of a car ahead. |
| 215 | Team | Close headway with sudden deceleration by Forward vehicle | Near Collision | The trigger was activated when the driver had to reduce speed due to a car directly ahead of her. The car suddenly stopped at a yellow flashing light causing the driver to almost hit the car. |

In addition to the Collisions, there were 22 Near Collisions recorded for a total of 24 “severe” incidents. As shown in Table 29, there were a variety of causes and circumstances associated with these incidents. Specifically, of the 24 incidents:

- Seven were clearly caused by the other driver.
- Nineteen involved single drivers and 5 involved team drivers; 15 drivers total were involved.

- Seven were caused by one single driver; 13 (over half) were caused by four single drivers.
- In contrast, no team driver was involved in greater than one incident.
- Four involved cases of extreme fatigue.
- Four occurred in work zones.

Even though there were relatively few cases, the most severe incidents could almost all be classified in several categories. Specifically:

- Seven were caused by close headway with a rapid deceleration of the forward vehicle.
- Two were near forward collisions with a stationary obstacle or vehicle in the roadway.
- Three were caused by an unplanned lane deviation.
- Two were caused by an attempted lane change with a vehicle present in the adjacent lane.
- Of the 7 "other" vehicle cases, 4 were lane change "cut-offs."

Several of the findings summarized above are of particular interest to this study. As was described in a previous section that analyzed all critical incidents, single drivers had a much higher rate of involvement in these "most severe" incidents than did team drivers. This difference was statistically significant, $X^2$ (1, N = 22) = 8.16; $p < .01$. This finding may indicate that the single drivers were not just driving more aggressively because they did not have to be concerned about waking or disturbing a partner, but were driving less safely in general. A related important finding is that only four of the single drivers (about 15 percent of the drivers present in this analysis) accounted for over one-half of the most severe incidents. This finding is similar to one found by Hanowski *et al.*, 2000, where a small number of local short haul operators accounted for the majority of the unsafe acts that occurred during a naturalistic observation study.

Furthermore, four of the 17 cases that were not Other Driver related involved "extreme" fatigue, three by single drivers and one by a team driver. Although these are low numbers in general, they serve to confirm that there is a presence of extreme fatigue in long haul trucking and it does impact driving safety.

At the lower levels of severity, namely Driver Error with a Hazard Present and Driver Error with No Hazard Present, the results mirrored many of the above findings, with much greater frequencies. Single drivers committed 1,803 total errors in the course of this study while team drivers committed 725. This, of course, is significantly well below the measurable level of $p<.0001$. It is interesting to note that there were relatively few cases of a Driver Error with No Hazard Present (95 total). This is probably a function of the data triggering system. That is, in all but two of the measures (lane deviation and Perclos activation), the data were triggered partially as a result of an object in close proximity to the vehicle.

*Investigation of Critical Incident Cause for each Type of Incident and Driver (Single vs. Team)*
Each type of triggered driving behavior was evaluated by the type of incident to determine if there were systematic differences among types of drivers for each category of incident. The "hard braking" triggers activated by a rapid deceleration of the truck had some interesting differences as shown in Figure 85. The findings discussed in this section are all statistically

different at a very high level of confidence. Note that team drivers had half as many incidents caused by Other Driver than did single drivers. This finding could be related to the apparent finding that single drivers are more aggressive, drive faster, and therefore have more situations at higher closure rates that create the opportunity for an error/trigger to occur if the lead vehicle does something unexpected. The highest frequency of team and single drivers' hard braking incidents were caused by judgment error. Judgment errors included braking too hard for a traffic control device and other instances in which the drivers had to compensate for driving too fast.

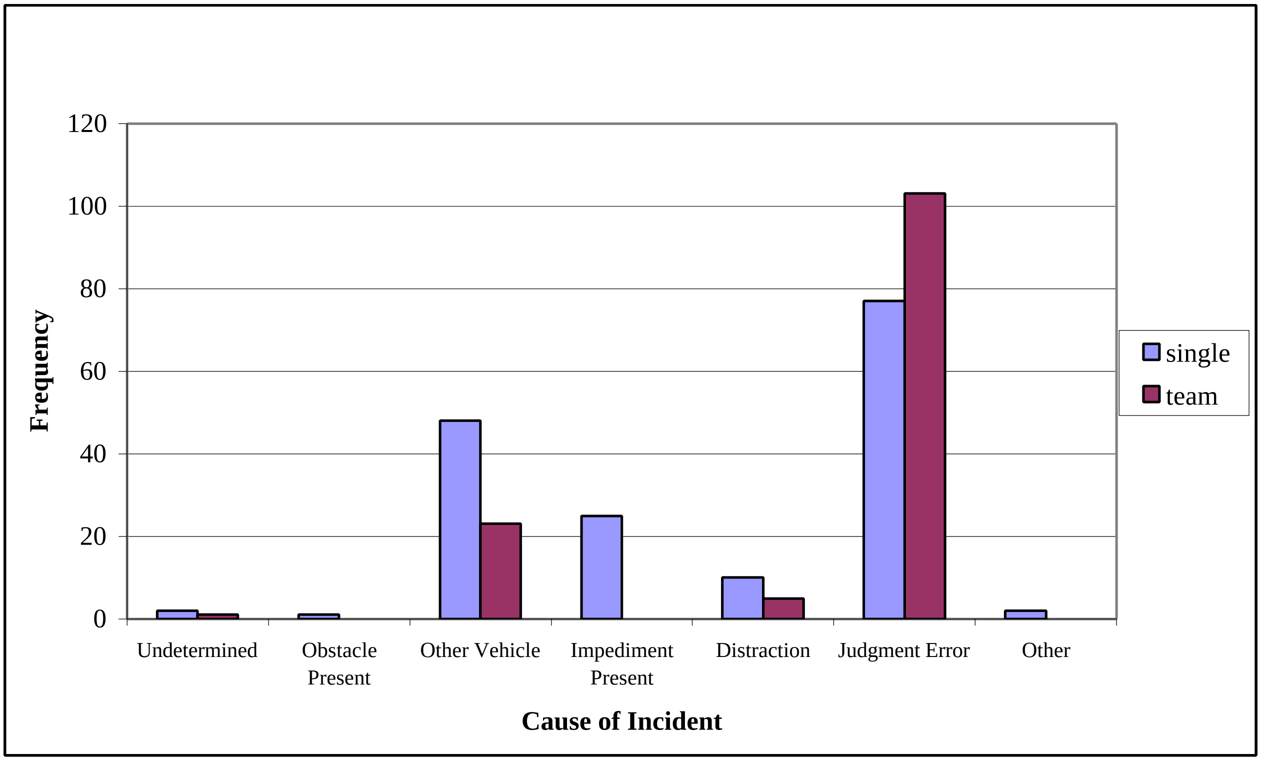

**Figure 85. Number of hard braking incidents occurring for these causes.**

The data for the number of lane departures showed some interesting differences between singles and teams. These results indicated that more of the single drivers' lane departures were caused by distraction, whereas more of the teams' lane departures were caused by judgment error (Figure 86). Judgment errors included such behaviors as going too fast in a curve, or allowing the truck to drift out of lane.

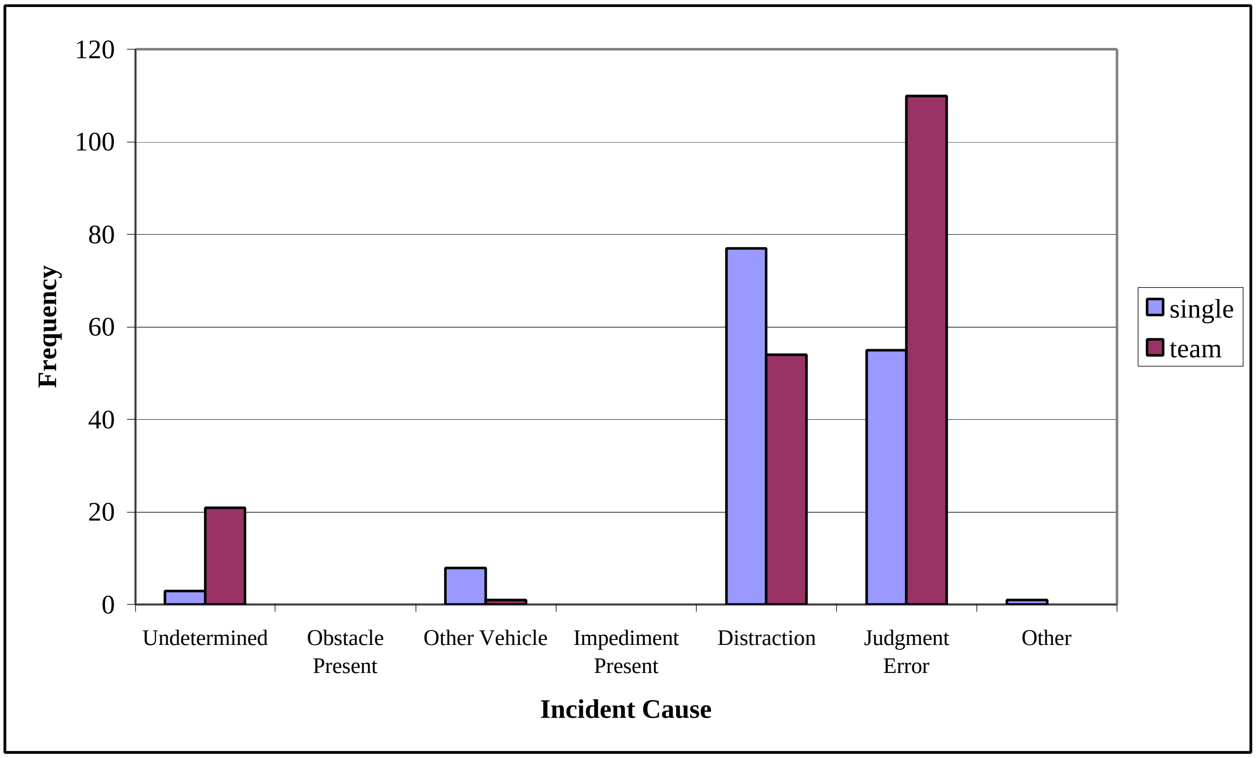

**Figure 86. Number of lane departures associated with these causes.**

The analysis for the following too closely behavior was also significant for the driver behavior. As shown in Figure 87, there is a significant difference between the number of single drivers' following too closely behaviors being judgment errors or due to other vehicles as opposed to the team drivers' behavior. This finding is probably related to the aggressive driving tendency of the single drivers demonstrated in several other analyses in this section. Following too closely behavior was the most common triggered event, and the single drivers violated this far more frequently than did the team drivers.

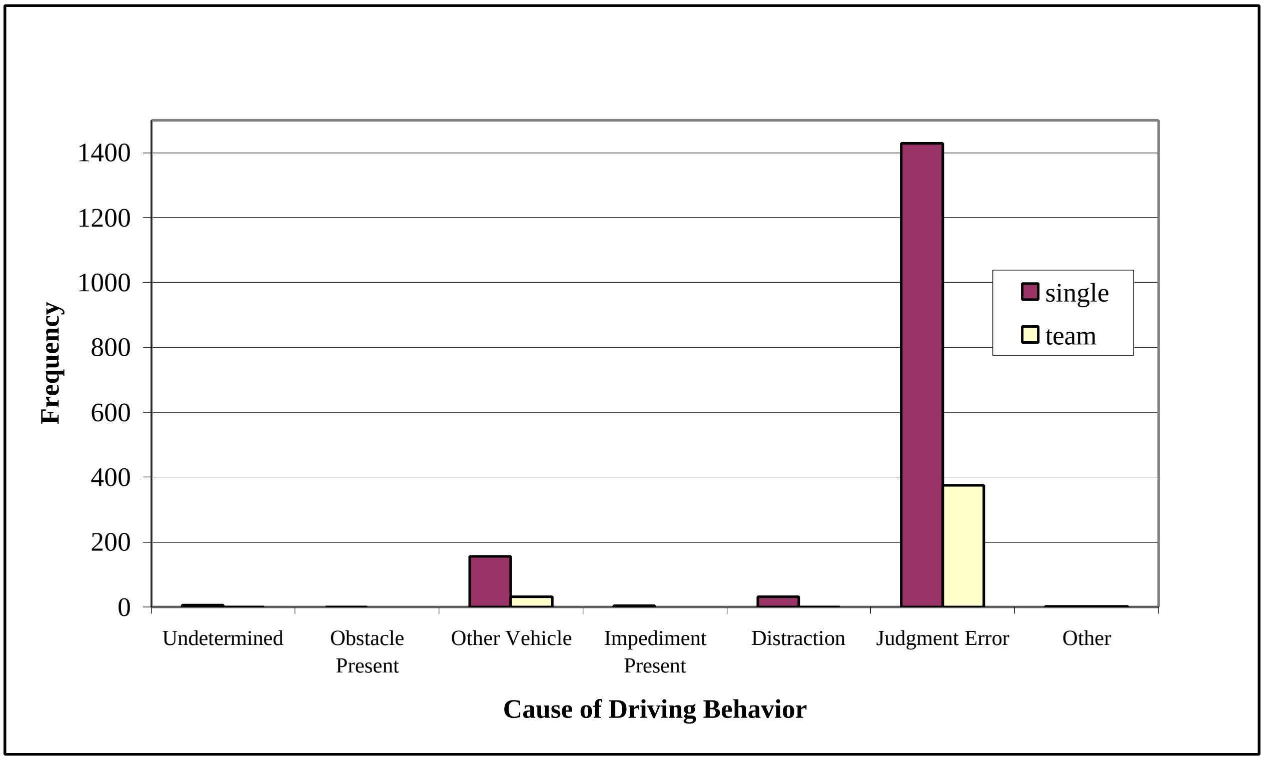

**Figure 87. Number of following too closely triggers occurring for each cause.**

**Discussion**

The purpose of this objective was to assess differences in driving performance as measured by the type and severity of triggered critical incidents such as Collisions, Near Collisions, and driver errors. This driving performance assessment was analyzed to assess whether systematic differences were present for Type of Driver (single vs. team), Length of Trip, Length of Shift, and Time of Day.

A primary finding of this section was that single drivers had many more critical incidents, at all levels of severity, as compared to team drivers. The difference was very large with ratios of between 4:1 and 2.5:1 depending on the trigger severity level. The difference was not limited to a few drivers, as has been the case with other similar studies (e.g., Hanowski *et al.*, 2000), as eight of the single drivers had more incidents than *any* of the team drivers. Analyses of possible alternative explanations for these differences (including age, experience, and company) showed that no systematic differences were present. Therefore, the conclusions drawn regarding this finding are that single drivers drive significantly more aggressively than do team drivers. Based on the focus group results for this project (Neale *et al.,* 1998a), a plausible explanation is that team drivers drive more carefully so that their partners get a higher quality of sleep and/or are not alarmed by their driving.

In looking at only the most severe of the critical incidents, including 2 Collisions and 22 Near Collisions, several additional interesting findings were discovered. Seven of these 24 incidents were caused by one single driver, and 13 of the 24 incidents were caused by four single drivers. No team driver had more than one severe critical incident. These results show that a "screening" process where drivers are required to undergo additional scrutiny prior to permanent licensing or to travel with on board monitoring systems could potentially help reduce risk in long haul trucking.

The severe critical incident analysis also found that 4 of the 24 severe incidents were caused by extreme (i.e., "head-bobbing") fatigue. This finding confirms the presence of these levels of fatigue in the long-haul trucking industry. The only interesting pattern regarding these four events was that three of them occurred with single drivers. A primary issue regarding this study was whether or not team drivers were more fatigued since they may not get a high enough quality of sleep in a moving sleeper berth truck. It is important to note there were very few occurrences of this extreme fatigue recorded. Even so, these findings suggest that team drivers may not be at the greatest risk for extreme fatigue.

Another important finding related to this objective was that the frequency incidents varied significantly by the hour of the day. However, contrary to what might be expected, the largest number of incidents (even corrected for exposure) occurred in the late afternoon/early evening hours. It was apparent from this analysis that interaction with heavier traffic had a greater impact upon the occurrence of critical incidents, and most likely the greatest impact on crash risk overall, than did fatigue due to circadian rhythm effects. Thus, there is a trade-off that must be considered when attempting to address the truck driver fatigue issue. For example, proposals have been made in the past that would limit truck drivers driving late at night to minimize fatigue. In considering such a proposal, however, these results show that one must also consider the relative risk reduction due to the presence of far less traffic during those time periods.

The results of this analysis also revealed that there were a number of hours-of -service violations during this study. One of the most interesting aspects of this analysis is that, in general, there were very few critical incidents or driver errors of any kind during these periods. In fact, in 22-hour-long periods where a total of three drivers drove over 14 hours in a single shift, there were *no instances* of a driver error or critical incident. This is in contrast to an average of over 2.0 critical incidents per driver-hour during the first hour of a shift (i.e., over 44 critical incidents would have been expected based upon this average instead of *zero*). Thus, it appears that these drivers were driving very carefully to either compensate for fatigue or because they knew they were well beyond the regulation and did not want to risk being stopped by law enforcement officials.

## OBJECTIVE 6: DETERMINE THE RELATIONSHIP BETWEEN THE LEVEL OF SLEEP QUALITY OR QUANTITY AND THE FREQUENCY OR TYPE OF CRITICAL INCIDENTS/DRIVER ERRORS

### Data Analysis Overview

The aim of this objective is to examine sleep measures as they relate to the frequency, severity, and type of critical triggered incidents. A triggered incident was classified as "valid" if the data analyst was able to ascertain the cause of the trigger and determine that it was not a sensor false alarm (e.g., due to a radar return from a bridge abutment or some other non-situation consequential object). Each valid triggered incident was deemed either critical or critical: secondary. A triggered incident was defined as critical if the trigger was valid and was either the first in a sequence of triggers, the only trigger present, or was the direct cause of one or more other triggers. A triggered incident was deemed critical: secondary if the trigger was valid, followed another trigger in a sequence of triggers, and was directly caused by the presence of one or more of the preceding triggers. The types of triggered incidents are listed in Table 30.

**Table 30. Driving behaviors that result in triggered incidents.**

| | Driving Behavior | Triggered Incident |
|---|---|---|
| 1. | Abrupt Steering Maneuver | 1. Steering Trigger<br>2. Lateral Acceleration Trigger |
| 2. | Hard braking | 1. Longitudinal Acceleration |
| 3. | Following too Closely | 1. Time-to-Collision |
| 4. | Lane Deviation | 1. Lane Deviation |
| 5. | Change lanes with a vehicle in adjacent lane | 1. Lane Deviation/Steering Trigger |
| 6. | Baseline data | 1. Timed trigger where the driver rates his drowsiness level using the Karolinska rating scale. This trigger was activated every 60 minutes (+/- 15 minutes) of continuous driving. |

Driver errors are operationally defined as a subset of critical events. Specifically, a valid critical incident that a data analyst deemed to be the fault of the subject was also classified as a driver error.

There were three sleep measures used in the analyses for this objective, listed in Table 31. As an objective measure of sleep quality, REM Percent, or the percentage of the sleep bout that the driver had REM sleep, was calculated from the drivers' Nightcap data. As a subjective measure of sleep quantity, driver response to Wake-up Survey Question 8 was used. This question asked drivers, "How well did you sleep?" on a 6-point scale from "very badly" to "very well." As a measure of sleep quantity, the falling-asleep and waking-up times reported in the Wake-up Survey were used to calculate Subjective Sleep Time. The measures of sleep quality and quantity were usually treated as dependent variables; however, regression analyses were conducted as part of this objective to examine the sleep measures as possible predictors of critical incident frequency.

**Table 31. Objective and subjective measures of sleep quality and quantity used in the data analyses.**

| Measure | Sleep Quantity | Sleep Quality |
|---|---|---|
| **Objective** | ---- | REM Percent<br>The percent of the sleep bout spent in REM sleep |
| **Subjective** | **Wake-up Survey**<br>Reported falling asleep and wake-up times | **Survey Question 8**<br>"How well did you sleep?"<br>1. Very badly<br>2. Badly<br>3. Fairly badly<br>4. Fairly well<br>5. Well<br>6. Very well |

*Driver Data Included in the Analyses*

Two sets of analyses were conducted for this objective. The first set of analyses were a series of regression analyses to examine each of the three sleep measures and Driver Type as predictors of critical incident frequency. For the examination of Subjective Sleep Time, 12 single drivers and 9 team drivers were included in the analysis. For the examination of Subjective Sleep Quality, 17 single drivers and 13 team drivers were included in the analysis. Fourteen single drivers and 7 team drivers were included in the analysis for the examination of REM Percent data. Data were included when the sleep measure data and critical incident data were available for the same time frame. For some analyses, data from one or two drivers dropped from the analysis due to insufficient or missing data.

The second set of analyses was a series of ANOVAs to examine Driver Type and Incident Severity as they related to each of the three sleep measures. Sixteen single drivers and 13 team drivers were included in the analyses. These were the drivers for which there were critical incident data. For each critical incident, analysts collected Subjective Sleep Time, Subjective Sleep Quality, and REM Percent values from the sleep bout just prior to the critical incident. It is important to note that the prior sleep bout may have been the same day or the previous day, depending on how long it had been since the driver last slept. In addition, the actual number of critical incidents included in any particular analysis varied depending on whether sleep data from the Nightcap or survey was available for the incident.

Since the goal of this objective was to determine the level of driver alertness for the variables of interest, the timed event or baseline triggers were excluded from many of the analyses. Thus, only the critical incident triggers from the data were used.

## Results

### *Sleep Quality and Quantity Related to Frequency of Critical Incidents*

A Pearson Product-Moment Correlation procedure was conducted to examine survey reported Subjective Sleep Time in relation to the frequency of critical incidents. The correlation was only slightly negatively correlated and not significant, $r(97) = -.14$; $p = .1570$. A subsequent regression analysis was conducted for the variables of Subjective Sleep Time and Driver Type to predict frequency of critical incidents. Although the model was significant, it accounted for very little of the variance, $R^2 = .13$; $p = .0042$. The data points are plotted in Figure 88. As shown, the Subjective Sleep Time varied greatly for the frequency of critical incidents.

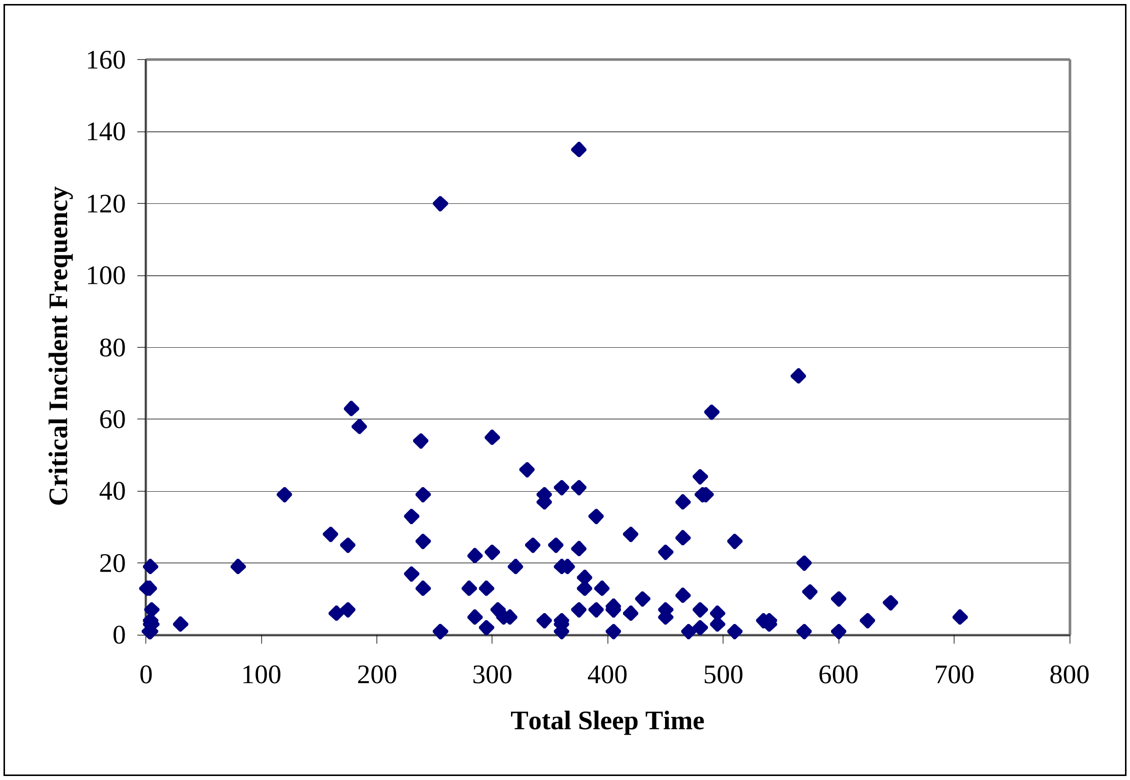

**Figure 88. Single and team drivers' Subjective Sleep Time for critical incident frequencies.**

As with Subjective Sleep Time, similar analyses were conducted using Subjective Sleep Quality as an independent variable. A Pearson Product-Moment Correlation procedure was conducted to examine Subjective Sleep Quality in relation to the frequency of critical incidents. The correlation was only slightly correlated and not significant, *r*(113) = .12; *p* = .21. A subsequent regression analysis was conducted for the variables of Subjective Sleep Quality and Driver Type to predict frequency of critical incidents. Although significant, the model accounted for very little of the variance, $R^2 = .15$; *p* = .0004. The data points are plotted in Figure 89. As shown, the Subjective Sleep Quality varied greatly for the frequency of critical incidents.

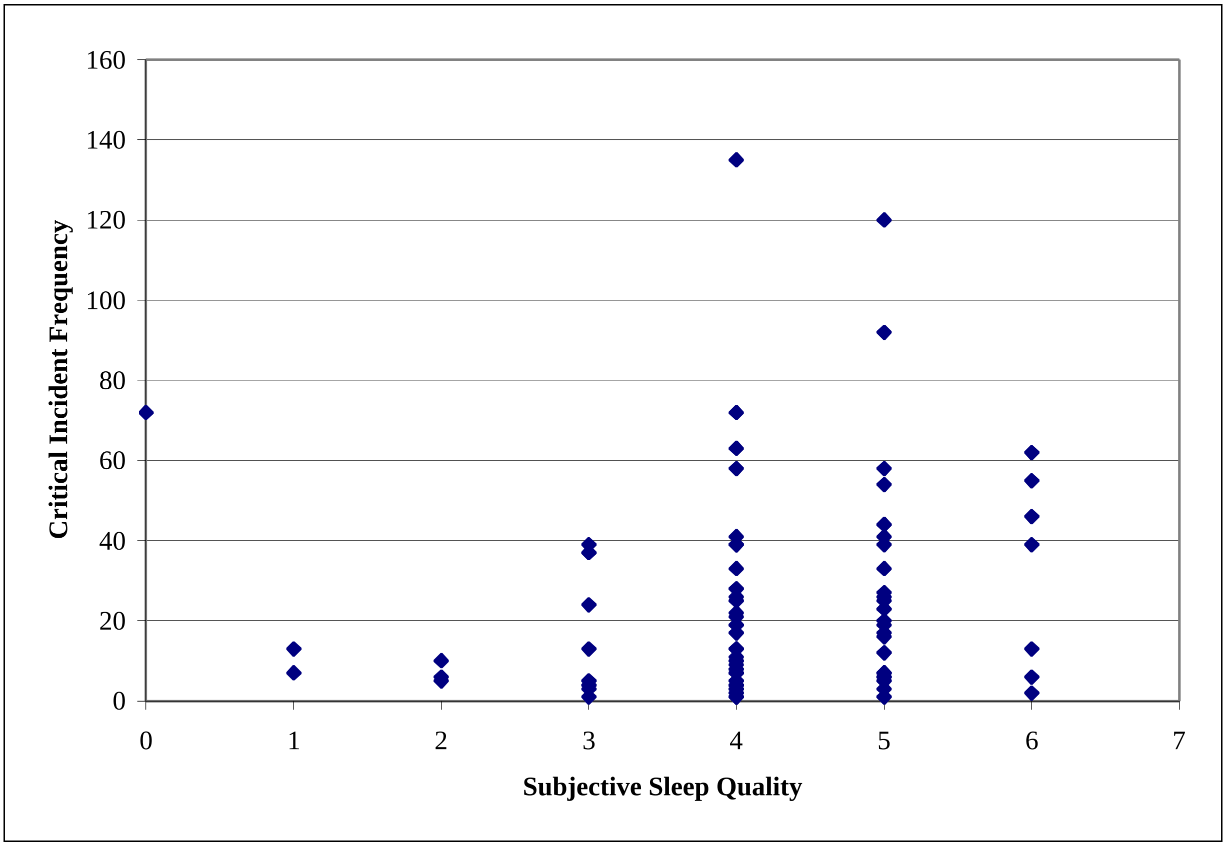

**Figure 89. Single and team drivers' Subjective Sleep Quality for critical incident frequencies.**

In addition, similar analyses were conducted using REM Percent as an independent variable. A Pearson Product-Moment Correlation procedure was conducted to examine REM Percent in relation to the frequency of critical incidents. The correlation was only slightly correlated and not significant, *r*(118) = .08; *p* = .37. A subsequent regression analysis was conducted for the variables of REM Percent and Driver Type to predict frequency of critical incidents. Although the model was significant, it accounted for very little of the variance, $R^2$ = .09; *p* = .0119. The data points are plotted in Figure 90. The Subjective Sleep Quality varied greatly for the frequency of critical incidents.

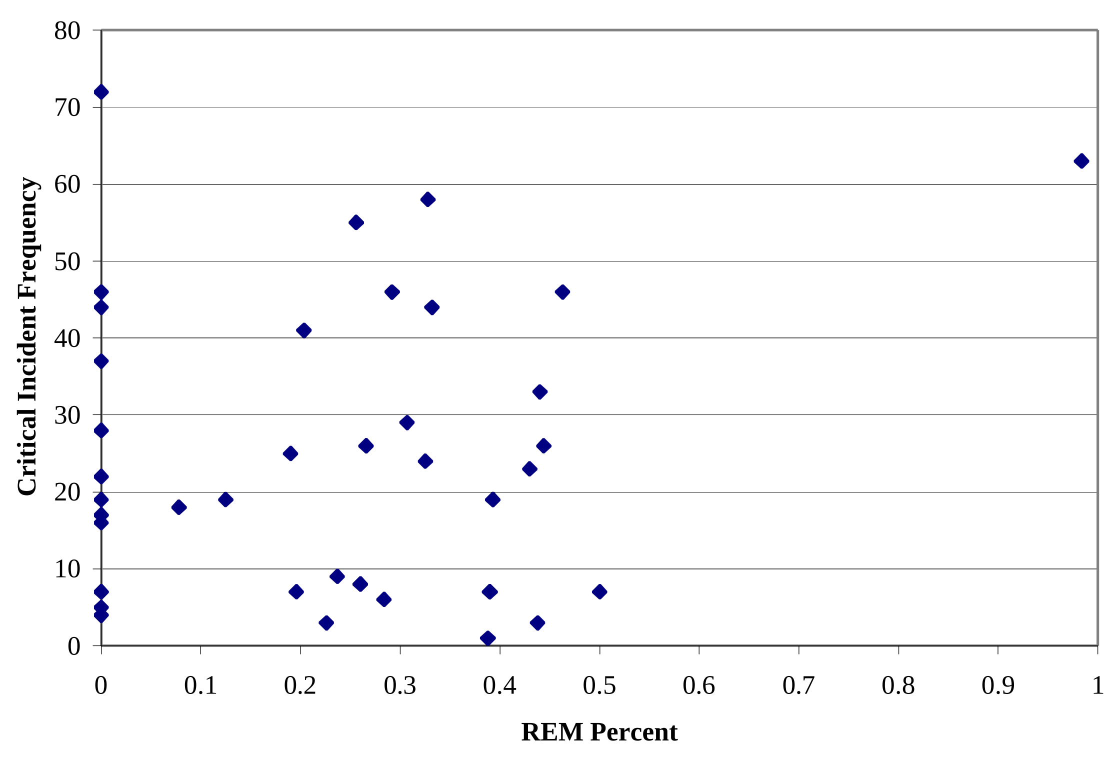

**Figure 90. Single and team drivers' REM Percent for critical incident frequencies.**

*Sleep Quality and Quantity Related to Severity of Critical Incidents*

An analysis was conducted to examine Subjective Sleep Time using a Driver Type by Severity Rating ANOVA. There were no significant results (Appendix F, Table F-1). Figure 91 depicts the Subjective Sleep Time for Severity Rating for single and team drivers. Note the values at the top of each bar, which represent the number of critical incidents in the corresponding bar. Although not significant, team drivers reported more sleep and had fewer critical incidents than did single drivers. This is in agreement with results reported in other sections of this report.

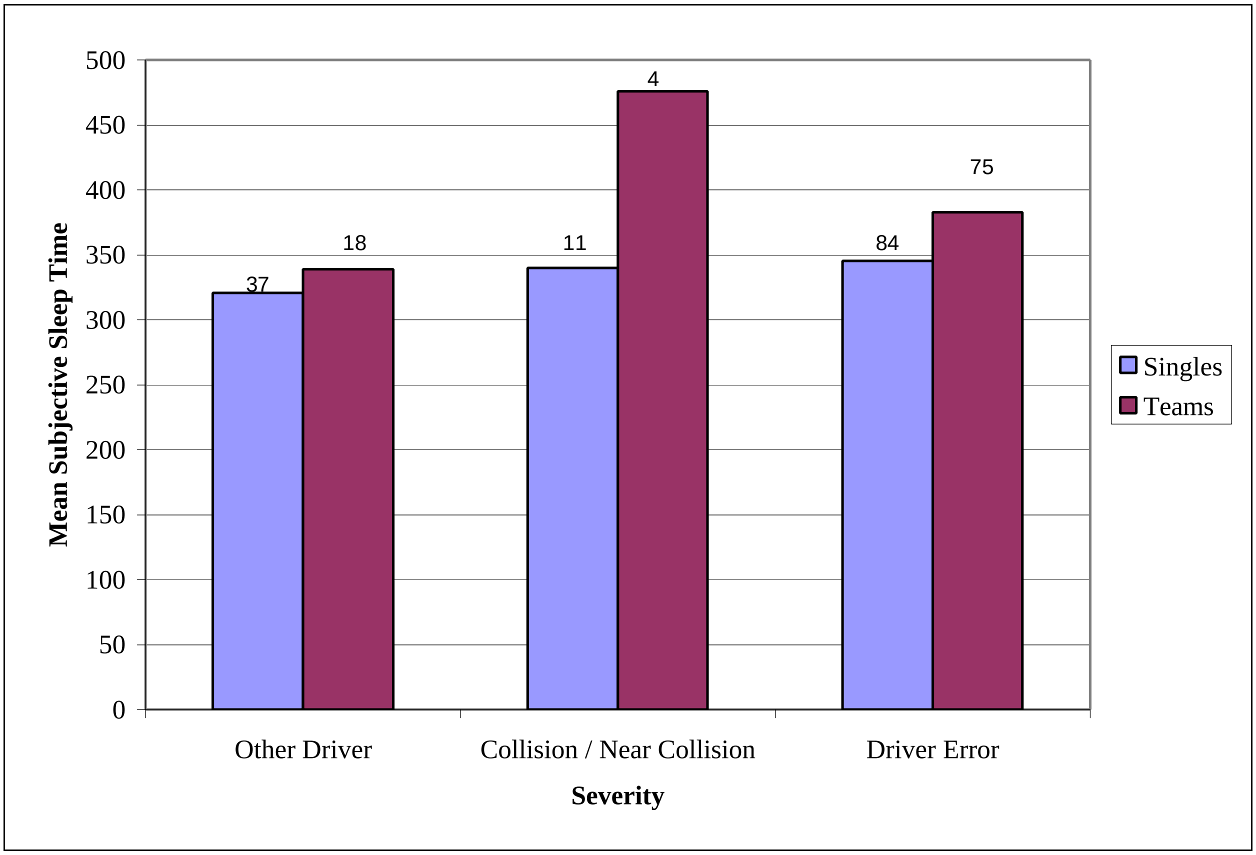

**Figure 91. Mean Subjective Sleep Time for the levels of Severity for single and team drivers.**

Using a Driver Type by Severity Rating ANOVA, an analysis was conducted to examine Subjective Sleep Quality. There were no significant results (Appendix F, Table F-2). Figure 92 depicts the Subjective Sleep Quality for Severity Rating for single and team drivers. The values at the top of each bar represent the number of critical incidents in that corresponding bar. In general, single drivers reported a higher quality of sleep, yet they had more critical incidents.

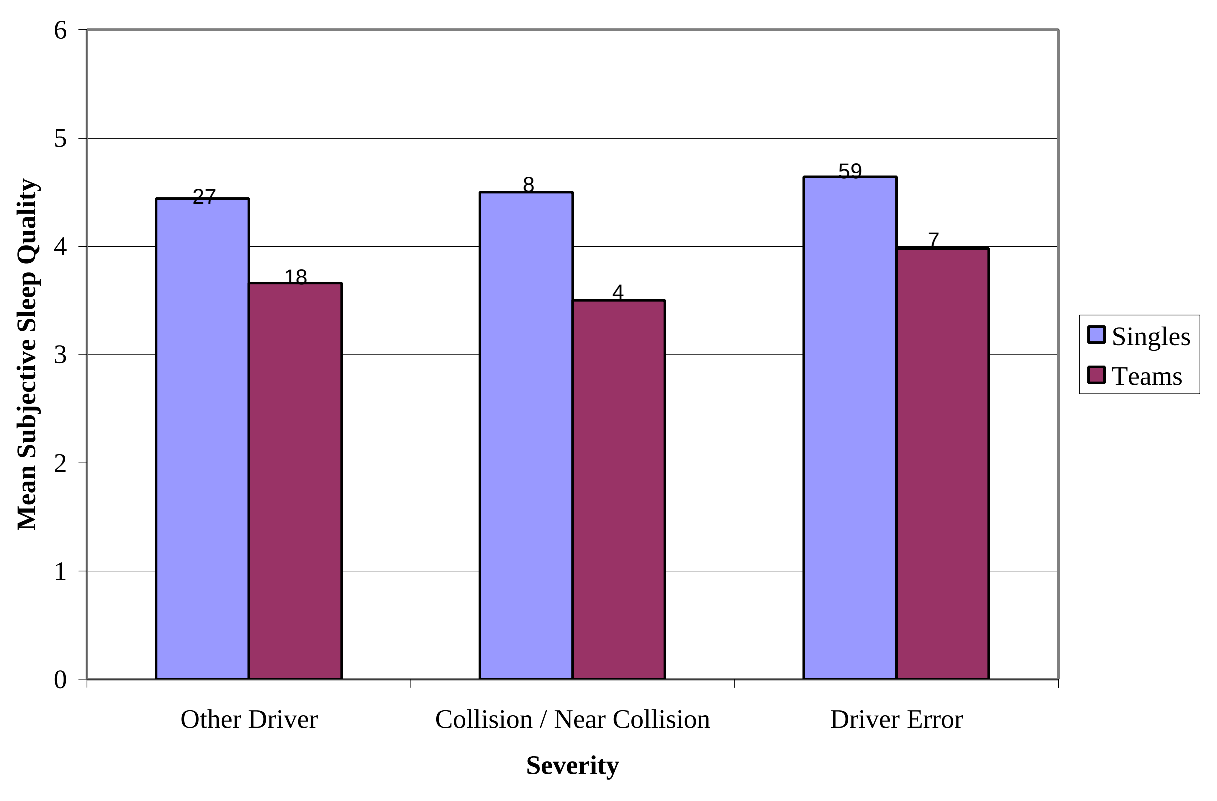

**Figure 92. Mean Subjective Sleep Quality for the levels of Severity for single and team drivers.**

An analysis was conducted to examine REM Percent with a Driver Type by Severity Rating ANOVA. There were no significant results (Appendix F, Table F-3). Figure 93 depicts the REM Percent for Severity Rating for single and team drivers. The values at the top of each bar represent the number of critical incidents in that corresponding bar. In general, REM sleep varied from approximately 17 to 28 percent; however, two team drivers who had near collisions did not have any REM sleep in the previous sleep bout.

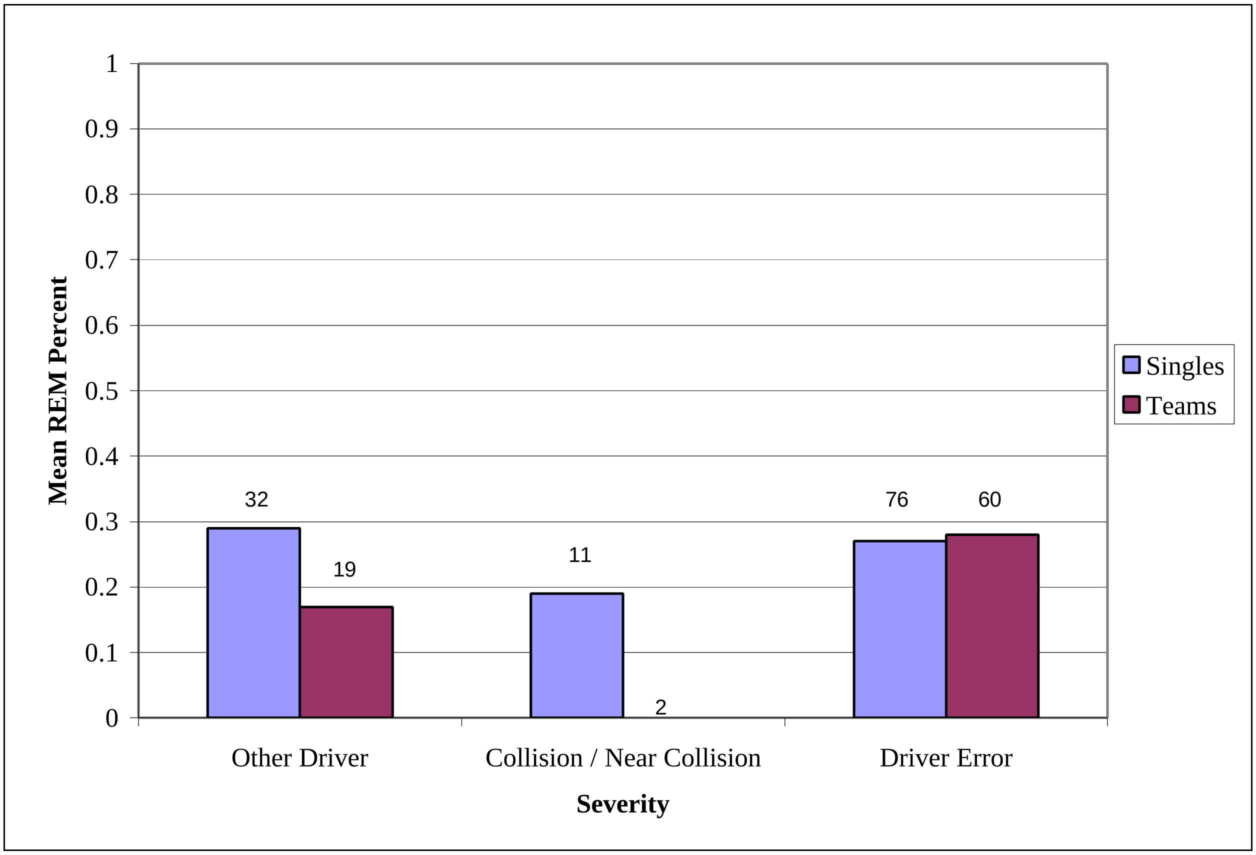

**Figure 93. Mean REM Percent for the levels of Severity for single and team drivers.**

Table 32 shows a summary of sleep quality and quantity measures for the most severe critical incidents: Near Collisions and Collisions. The table includes critical incidents for which there may not have been sleep data available for analyses.

**Table 32. Incident Type and Sleep Measures for the Collision and Near Collision critical incidents.**

| Severity | Driver Number | Driver Type | Incident Type | Subjective Sleep Time (minutes) | Subjective Sleep Quality Rating (Scale 1 – 6) | REM Percent Time | Number of Awakenings |
|---|---|---|---|---|---|---|---|
| Collision | 9 | Single | Abrupt Steering Man. | 375 | 3 – Fairly Badly | 0.33 | -- |
| Near Collision | 2 | Single | Abrupt Steering Man. | 405 | 5 – Well | 0.21 | -- |
| Near Collision | 4 | Single | Hard Braking | -- | -- | -- | -- |
| Near Collision | 6 | Single | Hard Braking | 480 | 5 – Well | 0.35 | 1 |
| Near Collision | 7 | Single | Hard Braking | -- | -- | 0.29 | -- |
| Near Collision | 9 | Single | Hard Braking | 330 | 5 – Well | 0.00 | 8 |
| Near Collision | 9 | Single | Abrupt Steering Man. | 345 | -- | 0.00 | -- |
| Near Collision | 9 | Single | Hard Braking | 465 | 5 – Well | 0.00 | -- |
| Near Collision | 9 | Single | Abrupt Steering Man. | 375 | 3 – Fairly Badly | 0.33 | -- |
| Near Collision | 9 | Single | Hard Braking | -- | -- | 0.00 | -- |
| Near Collision | 9 | Single | Hard Braking | -- | -- | 0.00 | -- |
| Near Collision | 14 | Single | Hard Braking | 480 | 5 – Well | 0.26 | 5 |
| Near Collision | 16 | Single | Hard Braking | 560 | 4 – Fairly Well | 0.16 | 2 |
| Near Collision | 16 | Single | Hard Braking | 560 | 4 – Fairly Well | 0.16 | 2 |
| Near Collision | 19 | Single | Abrupt Steering Man. | 230 | 4 – Fairly Well | 0.14 | 1 |
| Near Collision | 19 | Single | Hard Braking | 230 | 4 – Fairly Well | 0.14 | 1 |
| Near Collision | 22 | Single | Abrupt Steering Man. | 485 | 5 – Well | 0.70 | 1 |
| Near Collision | 22 | Single | Following too Closely | -- | -- | 0.28 | 3 |
| Near Collision | 101 | Team | Hard Braking | -- | -- | -- | -- |
| Near Collision | 102 | Team | Hard Braking | -- | -- | -- | -- |
| Near Collision | 208 | Team | Hard Braking | 510 | 4 – Fairly Well | 0.00 | -- |
| Near Collision | 215 | Team | Hard Braking | 270 | 3 – Fairly Badly | 0.00 | 2 |

In general, there is a high degree of variability in the sleep measures, including Number of Awakenings, which was not analyzed for this objective. The trigger cause is indicated for each of the Near Collisions and for the Collision. Note that most of the incidents were due to a hard braking maneuver (15 of 22 incidents), and the second most common trigger was abrupt braking maneuver (6 of 22 incidents). However, the sleep measures are highly variable, even for a particular trigger cause.

## Discussion

The purpose of this analysis was to explore the relationships between sleep quality, sleep quantity, and the frequency and severity of critical incidents. This was approached from two directions: objective measures of sleep quality as assessed by the Nightcap monitoring system, and subjective measures of sleep quality and quantity as assessed by the Wake-up Survey.

While not statistically significant, an interesting trend appeared in the data. Team drivers reported getting more sleep of less quality, yet had fewer critical incidents when compared to single drivers. Based on the focus group results for this project (Neale *et al.*, 1998), a plausible explanation is that team drivers drive more carefully so that their partners get a higher quality of sleep and/or are not alarmed by their driving. It may be that successful team driving depends upon the ability to drive smoothly even when fatigued.

There are several possible reasons why the trends were not significant. As shown in Table 32, there was a high degree of variability in the sleep data, which would preclude significant results with the number of data points available. In addition, there are several other variables that affected driver alertness in addition to the sleep quality and quantity obtained. One possibility is cumulative sleep loss. The data represent sleep information obtained in the last recorded sleep bout; however, the data do not represent the sleep debt of the drivers to the point of the particular critical incident. In addition, there are the Time of Day and Length of Shift variables that were discussed in Objective 5. These factors are likely involved in the outcome of these analyses, but are not represented in the data set.

## OBJECTIVE 7: DETERMINE THE RELATIONSHIP BETWEEN THE LEVEL OF DRIVER ALERTNESS AND THE FREQUENCY OR TYPE OF CRITICAL INCIDENTS/DRIVER ERRORS

### Data Analysis Overview

Two measures of alertness (Observer Rating of Drowsiness and Karolinska ratings) were compared to frequency counts and types of critical incidents/driver errors that were committed during data collection. Critical incidents were used in analyzing these data regardless of whether the observers judged the incident to be the fault of the truck driver or another vehicle driver. All incidents were included because it is hypothesized that the presence of fatigue might result in a change of the level of severity of the incident (e.g., from driver error to Near Collision) due to a late reaction by the truck driver. Thus, even when the presence of fatigue is not judged to be a contributing factor to the cause of the incident, it might change the nature and severity of the incident and therefore is important to study in this context.

As was discussed in Objective 3, the quantitative Observer Rating of Drowsiness (ORD) was categorized into five distinct categories, using a 0 to 100 point scale:

1. Not drowsy (0-12.49)
2. Slightly drowsy (12.5 – 37.49)
3. Moderately drowsy (37.5 – 62.49)
4. Very drowsy (62.5 – 87.49)
5. Extremely drowsy (87.5- 100)

Drivers used the Karolinska scale to rate their own drowsiness levels. The Karolinska scale is a scale with discrete rankings from 1 to 9. Drivers were asked to rate their drowsiness levels at pseudo-random intervals varying between 45 and 75 minutes while they were driving. For several analyses, the nine categories were collapsed into three categories to analyze the data. This was necessary to provide an adequate number of data points as the data were parsed to address the issues in question. A Karolinska rating from 1 to 3 was categorized as “not drowsy,” 4 to 6 was categorized as “somewhat drowsy,” and 7 to 9 was categorized as “very drowsy.” As with the ORD scale, the maximum and median Karolinska values reported in each of the three categories were analyzed for each day of the data collection run.

Given that several ORDs were obtained during an epoch, the second ORD rating in each epoch was used as the alertness level assigned to each incident in that epoch. The second value was used because it was the period of time just prior to the incident in question. Thus, it was hypothesized that this would provide the best indication of whether or not alertness was a contributing factor. Karolinska ratings were obtained from the drivers pseudo-randomly every 45 to 75 minutes, but were not directly tied to an incident in time. Therefore, the Karolinska rating that most closely preceded the incident in question was used as the Karolinska rating for that incident.

For the purpose of data collection, critical incidents were operationally defined as events where the driver exceeded a threshold value for one or more criteria established as part of the data collection system protocol. The behaviors that would cause a trigger threshold to be exceeded are listed in Table 33.

**Table 33. Driving behaviors resulting in a triggered incident.**

| | Driving Behavior | Triggered Incident |
|---|---|---|
| 1. | Abrupt Steering Maneuver | 1. Steering Trigger<br>2. Lateral Acceleration Trigger |
| 2. | Hard Braking | 2. Longitudinal Acceleration |
| 3. | Following too Closely | 2. Time-to-Collision |
| 4. | Lane Deviation | 1. Lane deviation |
| 5. | Drowsiness | 3. Perclos Trigger<br>4. Karolinska Rating of 7, 8 or 9 |
| 6. | Change lanes with a vehicle in adjacent lane | 3. Lane Deviation/Steering Trigger |
| 7. | Baseline data | 1. Timed trigger where the driver rates his drowsiness level using the Karolinska rating scale. This trigger was activated every 45-75 minutes (+/- 15 minutes) of continuous driving. |

With the exception of the "drowsiness" category shown in Table 33, all of the triggered critical incidents collected were used as part of this analysis. The "drowsiness" category was not included for this particular analysis since it, in effect, constituted an independent variable of interest for this objective and did not represent the direct measurement of a critical driving incident.

The data reduction analyst determined whether the triggered event was critical (i.e., the presence of an actual incident could be detected), critical but secondary (i.e., trigger caused from the resulting action in response to a critical incident), invalid (i.e., cause of the trigger known, but unrelated to any driver or other vehicle error), or normal driving behavior (i.e., trigger was too sensitive). If the trigger was deemed invalid or normal driving behavior, the triggered event was not included in the data analyses presented in this objective. If the triggered event was deemed to be critical or critical secondary, the event was included in these analyses.

Driver errors are those critical incidents or critical secondary incidents which are deemed to be the fault of the subject (i.e., truck driver) and not the fault of another driver on the roadway. Driver errors are, therefore, a refined subset of events from the critical incident database.

Thirteen single drivers and seven teams (a total of 27 subjects) were used in these analyses. The same criteria used in Objective 3 (see page 83) were used for this research objective.

### Results

The following sections outline analyses that were conducted to investigate the relationship between critical incidents, Day of Trip, Hour of Day, incident severity, and trigger type in relation to ORD and Karolinska ratings for single and team drivers.

*Critical Incidents Related to ORD and Karolinska Ratings*

A chi-square test was used to determine if a difference existed in the critical incident frequencies for single and team drivers for each category of ORD; the results from this test proved significant, $X^2$ (4, $N$ = 2477) = 45.76; $p < .01$. Figure 94 shows that single drivers had a higher frequency of critical incidents than did team drivers at every level of ORD. Both single drivers and team drivers had the largest number of their critical incidents occur when they were "slightly drowsy." The second largest number of critical incidents occurred when the drivers were judged to be "not drowsy."

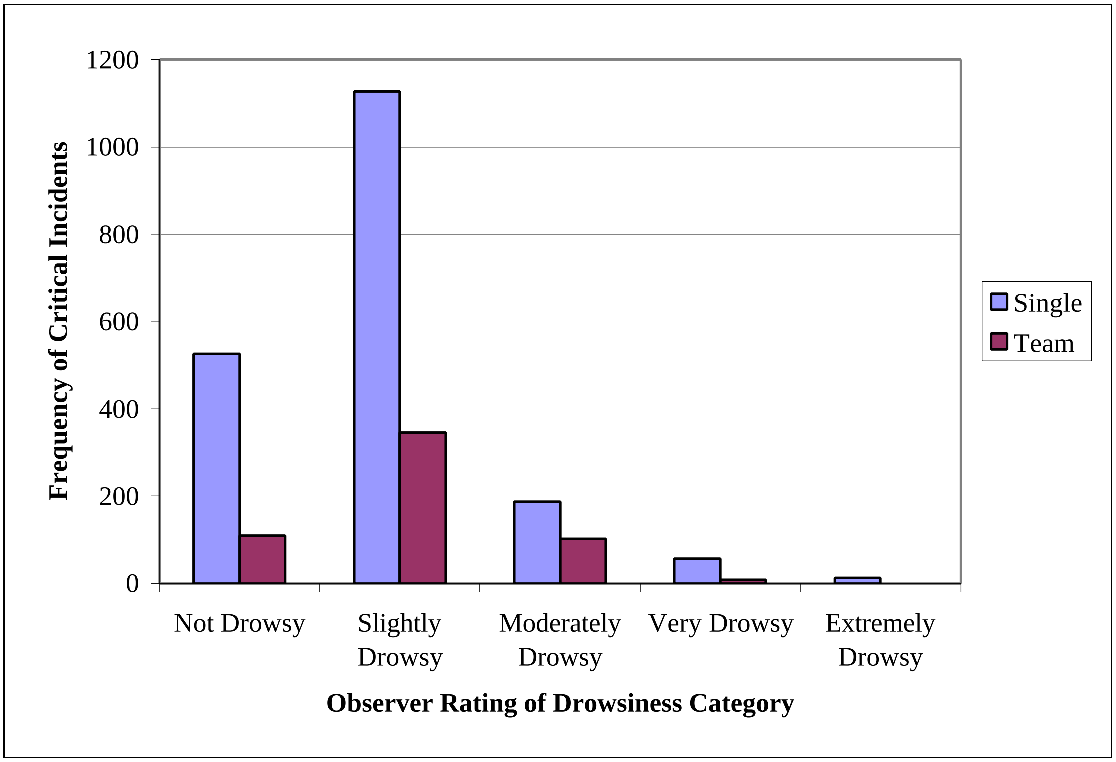

**Figure 94. Number of critical incidents occurring at each level of ORD for single and team drivers.**

Figure 95 shows the critical incident frequencies for each Karolinska rating. A chi-square test on this data found a statistically significant difference in frequencies across the rating levels, $X^2$ (2, $N$ = 1991) = 30.96; $p < .01$. As can be seen, the largest number of incidents for both single and team drivers occurred when a driver was "alert." "Somewhat drowsy" accounted for the second highest number of incidents for both driver groups. The fewest number of incidents occurred in the "extremely drowsy" category.

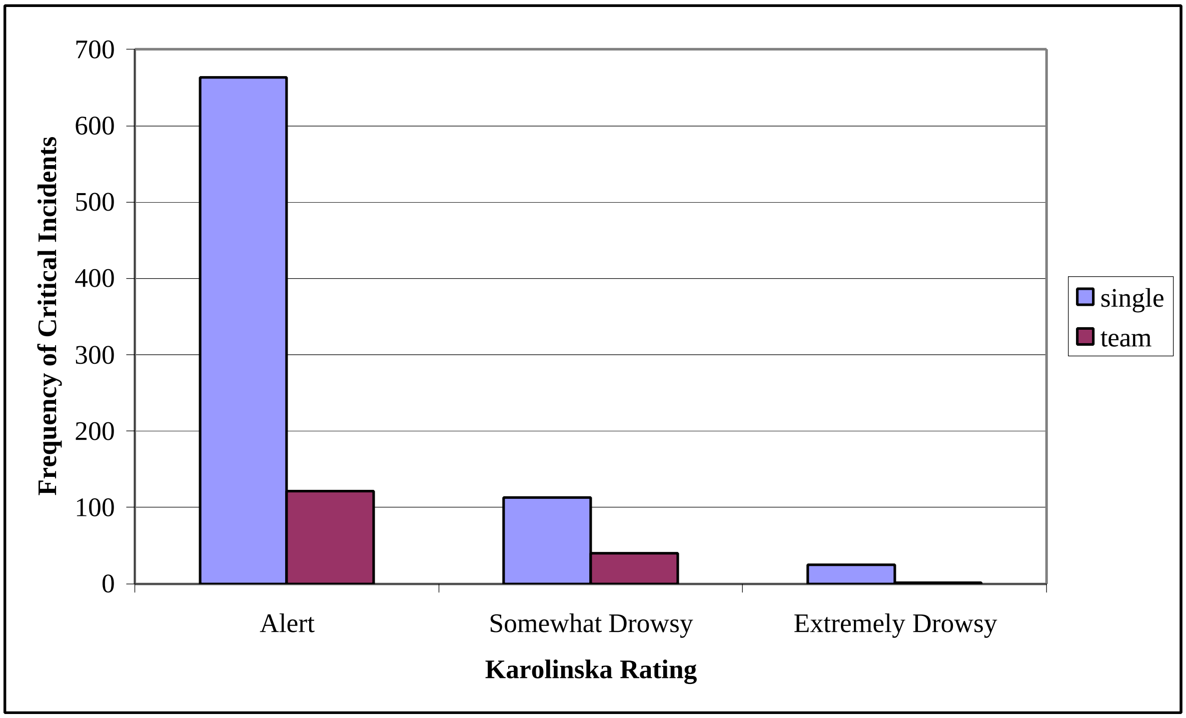

**Figure 95. Number of critical incidents occurring at each level of Karolinska rating for single and team drivers.**

A more detailed analysis of the drowsiness categories for the ORD ratings shows that the single drivers had significantly more critical incidents when they were rated "very drowsy" and "extremely drowsy" than did team drivers (Figure 96), $X^2$ (2, $N$ = 368) = 19.40; $p < .01$. This could be an indication that at least some single drivers tended to push themselves harder and drive longer when they were tired as compared to team drivers.

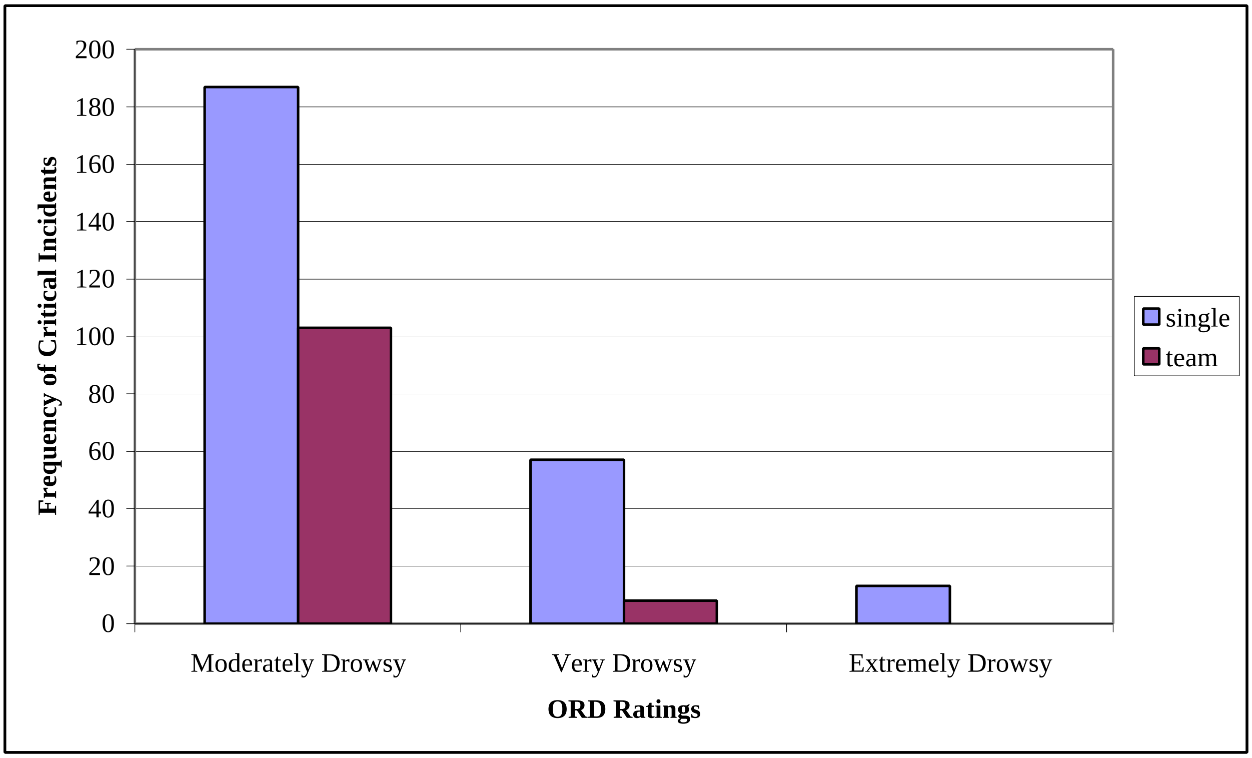

**Figure 96. Number of critical incidents occurring for the three most extreme ORD drowsiness ratings.**

The results from the analyses on the ORD and Karolinska measures shown in Figures 94, 95, and 96 indicate that most of the critical incidents occurred when the drivers were relatively alert. Although, based on the results of Objective 3, this undoubtedly is due in large part to exposure since the driver was driving in a relatively alert state in the vast majority of cases analyzed. To account for exposure (or the amount of time driving for each category), the percentage of incident occurrence for each ORD category was divided by the percentage of timed-triggered event occurrence for each category.[1] This calculation produced a ratio. The results from this calculation are presented in Figure 97. Values approximating "1" represent a similar percentage of critical incidents and timed trigger events for that category. If there was no effect of drowsiness, one might expect that all drowsy-related ORD categories would be approximately "1." Values greater than "1" indicate a greater percentage of critical incidents for that category

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[1] The primary assumption made with this analytical procedure is that it is assumed that the baseline data (i.e., time-triggered events) are representative of the data collected during a set period of time. There is no reason to believe that this is not the case; however, if there was error in this representation, it would be random error as opposed to systematic error and therefore would have little impact on the results.

than might have been expected *a priori*, while values less than "1" represent a smaller percentage of incidents.

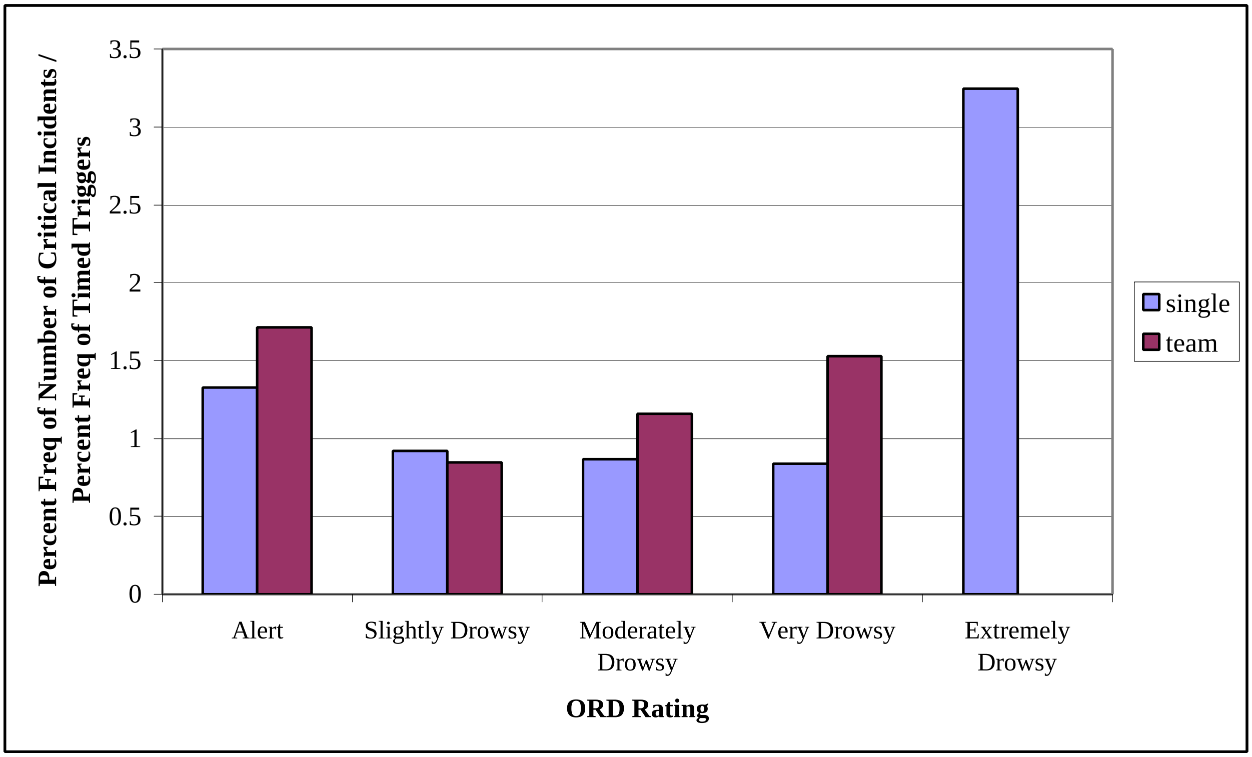

**Figure 97. Ratio of incident occurrence to timed triggers, for each ORD category, accounting for exposure.**

As can be seen, there are a number of interesting results from this analysis. As indicated previously, many of the incidents involving both groups of drivers occurred when the driver was alert. As one might expect, with regard to the single drivers, the number of incidents is approximately "1" for the "slightly drowsy," "moderately drowsy," and "very drowsy" categories. However, when the percentage of critical incidents is adjusted for exposure, the ratio of critical incidents in the "extremely drowsy" category is far greater than what would be expected. For the team drivers, there appears to be a trend upward, with increasing drowsiness, in the ratio of the percentage of critical incidents to the percentage of timed triggers. Together, these findings suggest that drowsiness is indeed a key factor in critical incidents. For single drivers, the large ratio in the "extremely drowsy" category provides further support in suggesting that single drivers push themselves and drive when they are extremely tired on occasion. Team drivers are perhaps not as likely to be pushed to driving when "extremely drowsy," as they have a partner to help out. However, even team drivers will push themselves to a point, but not to the point of being "extremely drowsy." In fact, the ratio for team drivers in the "extremely drowsy" category was "0," suggesting that they were not involved in any critical incidents where they were judged to be "extremely drowsy." Based on these data, it appears that one of the benefits of a team driving operation is that, perhaps, no one driver feels compelled to drive when their level of drowsiness is such that driving becomes unsafe.

*Analysis of Day of Trip Using ORD and Karolinska Ratings*

Critical incident frequencies, at each ORD level, were compared across Day of Trip. The result of this analysis for the team drivers is shown in Figure 98. There were generally fewer instances of “not drowsy” ratings as the trip days increased.

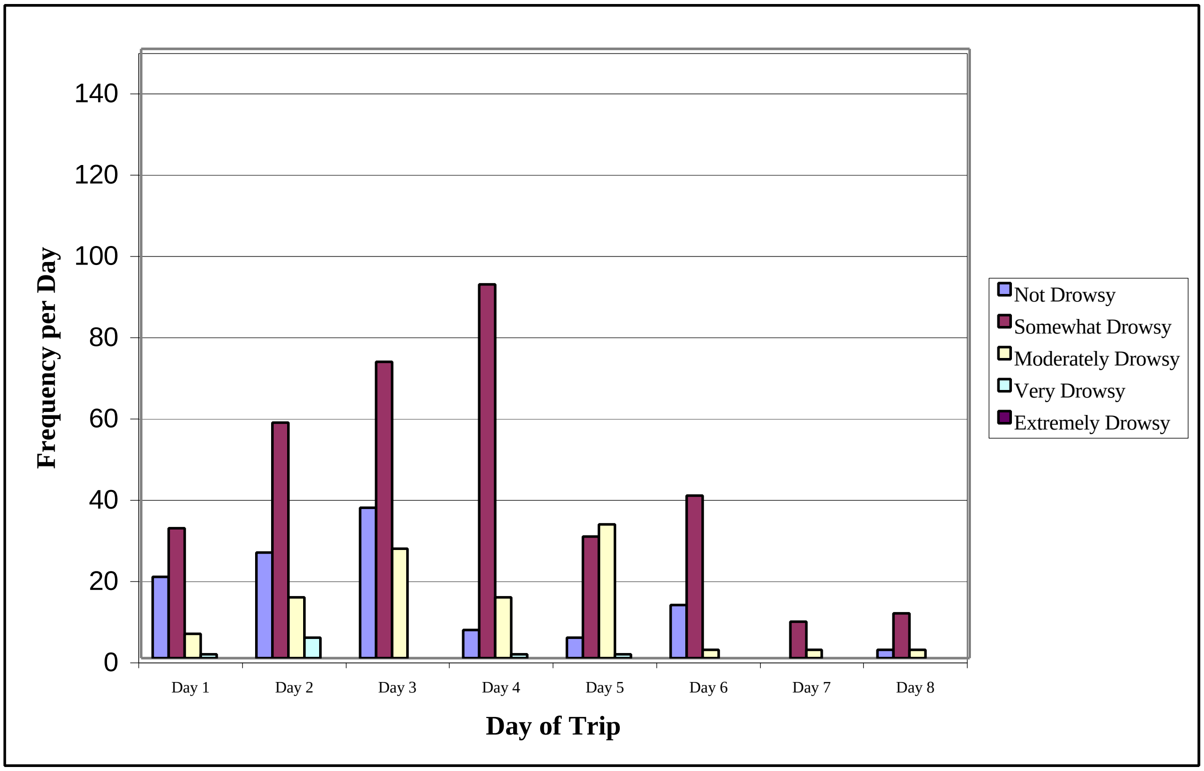

**Figure 98. Number of critical incidents occurring at each ORD level for each Day of Trip, for the team drivers.**

It is noteworthy that the incident frequency for the “somewhat drowsy” and “moderately drowsy” ratings increased during the week, and up until the middle of the week, and then precipitously dropped off. It is suspected that this finding may be an artifact of the fewer days of data for days 6 through 8 (i.e., not all drivers drove on days 6 through 8). To determine whether or not this fact affected the trend in the results, a second descriptive analysis was conducted utilizing only those drivers who drove for eight consecutive days (8 teams drove for eight consecutive days). These results are shown in Figure 99. For these drivers, the trend in number and alertness classification for critical incidents does not appear to vary systematically over the day of the drive. In general, these drivers had a greater number of incidents on days 4 and 6 and, as indicated previously, most incidents occurred when the driver was rated as “slightly drowsy.”

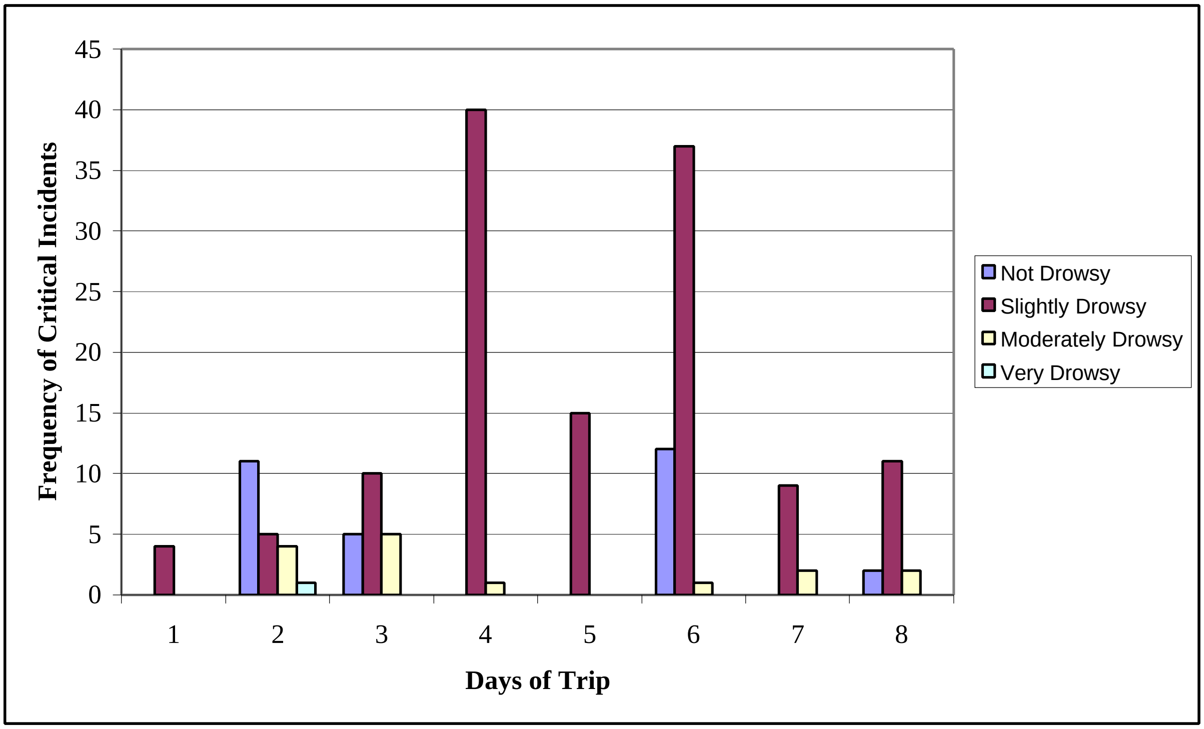

**Figure 99. Number of critical incidents occurring at each ORD level for each Day of Trip, for team drivers who drove for eight consecutive days.**

The frequencies at each alertness level across days of the trip for the single drivers are shown in Figure 100. The frequency of incidents in the "not drowsy" category apparently diminished after the fourth day of driving. This result, in combination with the relatively higher number of incidents in the "extremely drowsy" category on days 5 and 8, suggests that driver drowsiness peaked later in the trip. Put another way, the frequency data shown in Figure 100 may be indicative of cumulative fatigue. If so, this was not evident in the data from the team drivers.

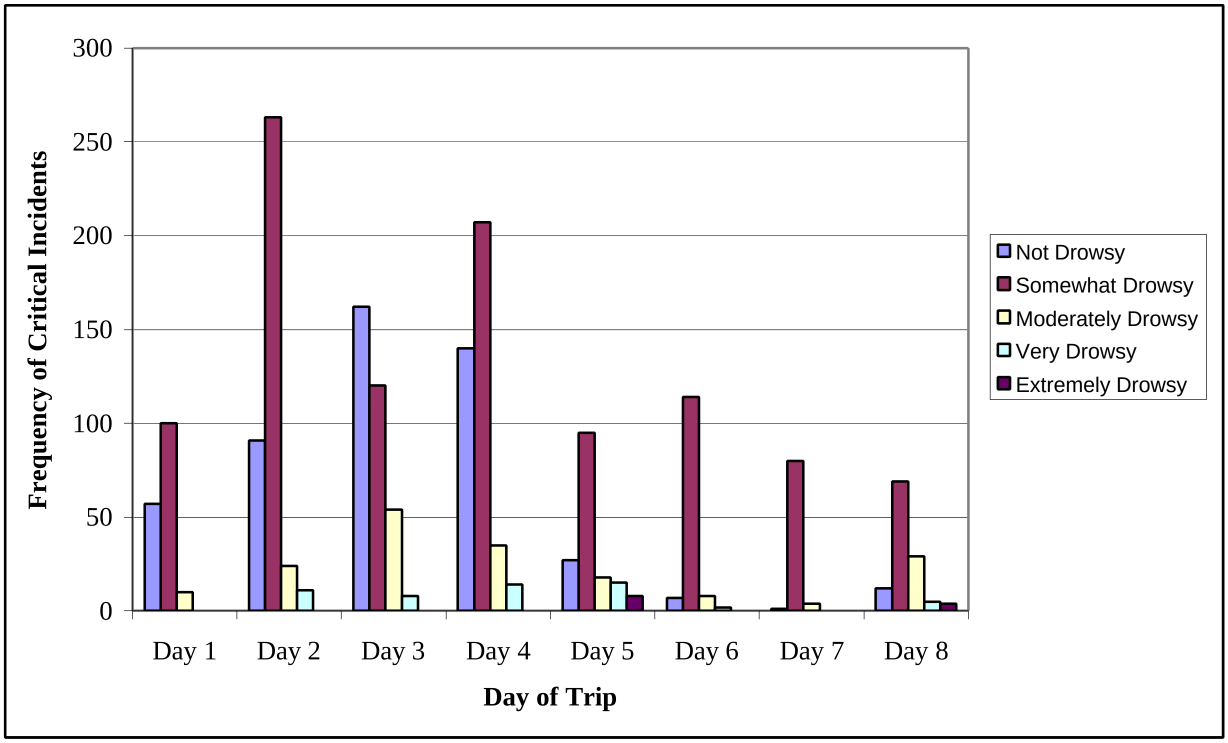

**Figure 100. Number of critical incidents occurring at each ORD level for each Day of Trip, for the single drivers.**

To determine why there was an apparent peak in the level of fatigue associated with day 5 and day 8, a second analysis was conducted for only those single drivers who completed 8 consecutive days of driving (*N* =5). The results of this analysis are shown in Figure 101 (note that this is the same analysis that was conducted for the team drivers that was shown in Figure 99). The total number of incidents for the single drivers was highest on days 3 and 4, but the incidents associated with the highest levels of drowsiness occurred on days 5 and 8. Thus, the trend shown for the total sample of drivers in Figure 100 is actually due to this sub-sample of drivers and is not a function of sample size diminishing with day of drive.

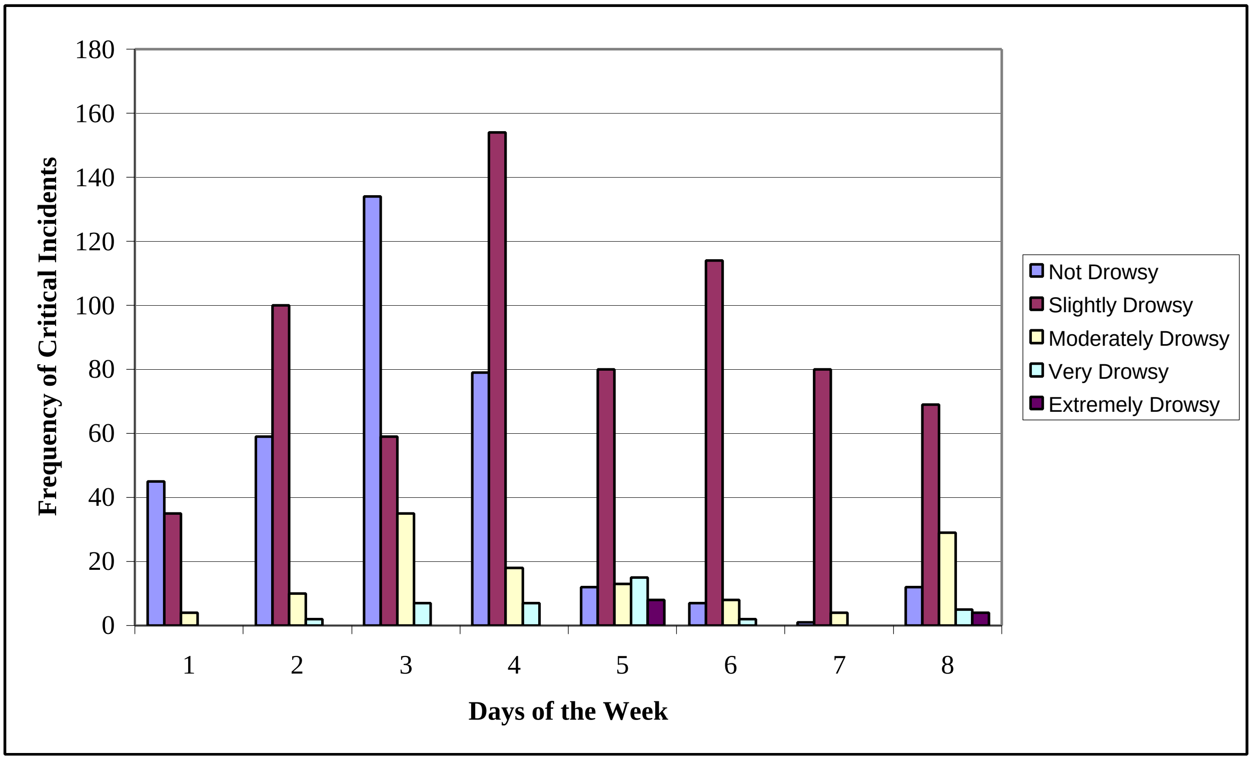

**Figure 101. Number of critical incidents occurring at each ORD level for each Day of Trip, for single drivers who drove for eight consecutive days.**

Descriptive analyses were also conducted on the frequency of incidents falling into the various Karolinska rating categories for each day of the drive. The frequencies for the team drivers are shown in Figure 102. As with the results from the analysis using the ORD measure, driver alertness appears to substantially diminish at the halfway point of the trip. A similar pattern is shown for single drivers in Figure 103, where most of the incidents that occurred when the driver was "alert" happened in the first half of the trip. In regard to incidents occurring when the driver was "extremely drowsy," the findings for both team and single drivers conflict. For team drivers, there were a greater number of "extremely drowsy" incidents early in the week; however, for single drivers, most of the "extremely drowsy" incidents occurred in days 6 and 8. Though there may not necessarily be an increase in incidents in the "extremely drowsy" category, it is evident in both the team and single data sets that alertness, as self-measured by drivers using the Karolinska scale, diminished as the trip progressed. Again, this finding is consistent with the ORD results reported previously. Because the ORD and Karolinska results are similar, and because the Karolinska measures are more prone to error due to them being self-reported values, the remainder of this objective focuses on the ORD ratings as the preferred measure of drowsiness.

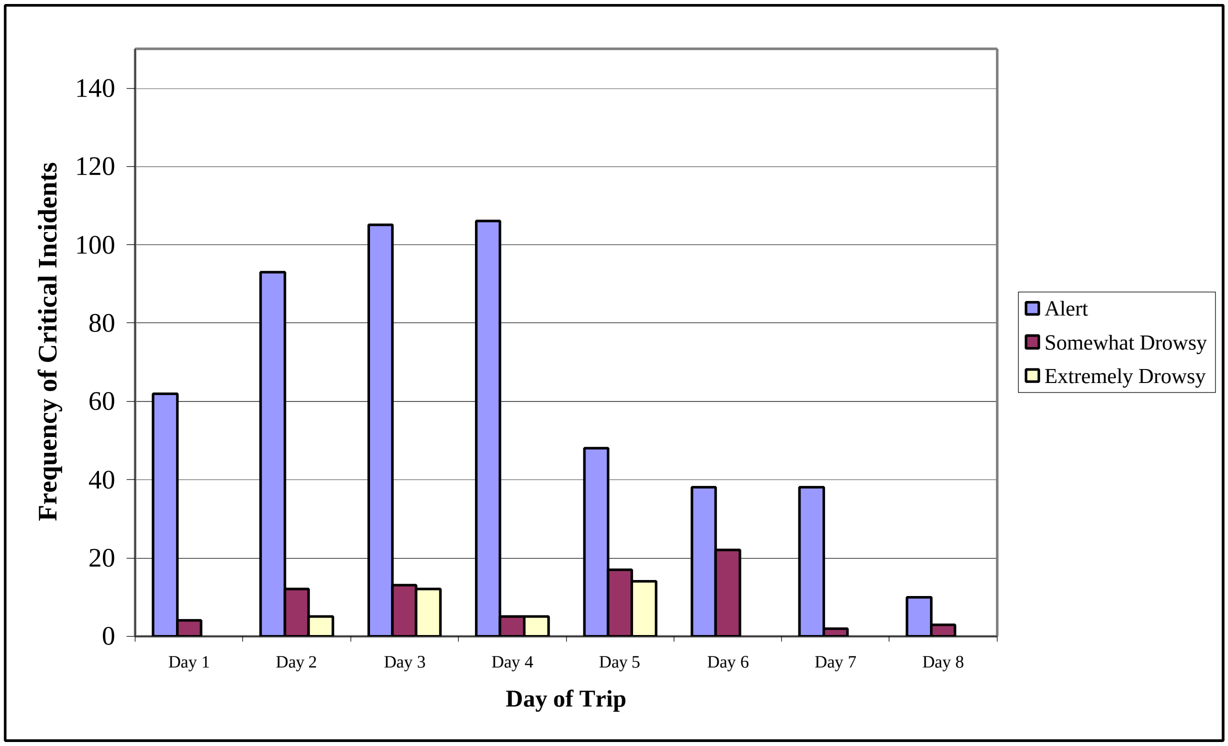

**Figure 102. Number of critical incidents occurring at each Karolinska level for each Day of Trip, for the team drivers.**

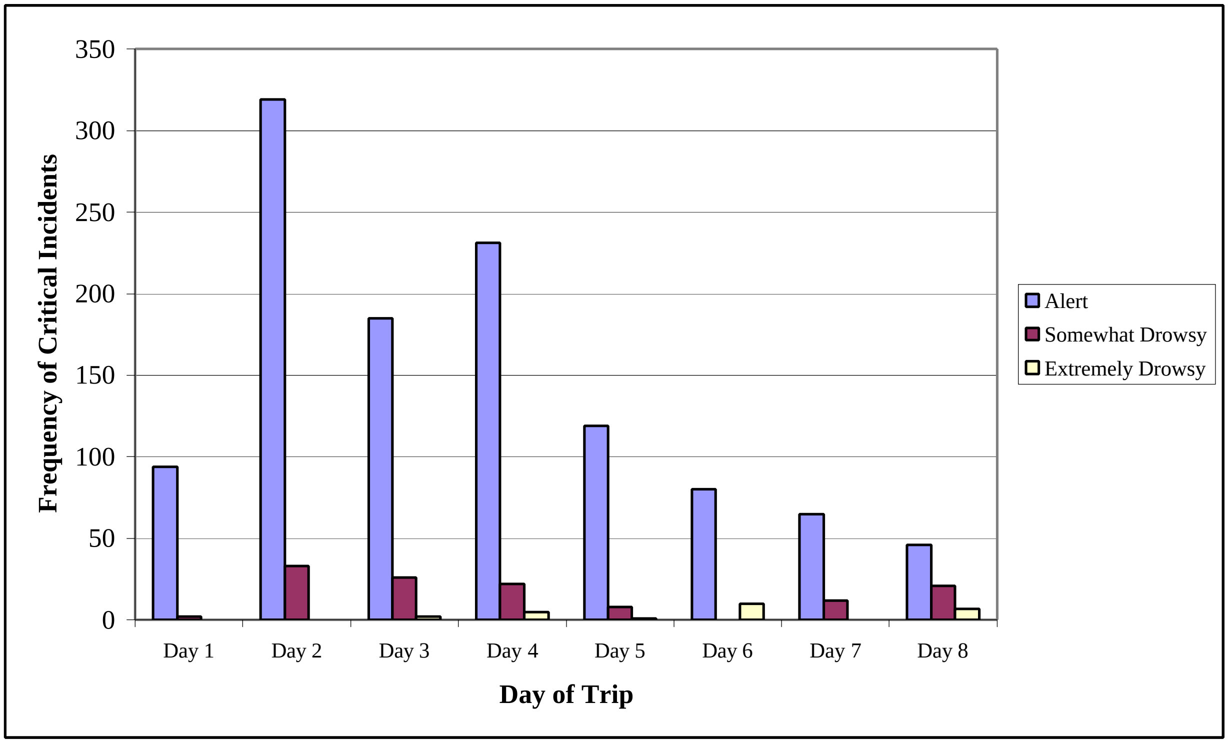

**Figure 103. Number of critical incidents occurring at each Karolinska level for each Day of Trip, for the single drivers.**

### *Analysis of Hour of Day Using ORD Ratings*

The frequency of critical incidents as a function of Time (hour) of Day and ORD rating is shown in Figure 104 for team drivers and Figure 105 for single drivers. As shown in Figure 104, teams apparently had more cases of being “moderately drowsy” and “very drowsy” in the nighttime/early morning hours. In addition, there is a general trend for single drivers to be more fatigued compared to team drivers at all hours of the day.

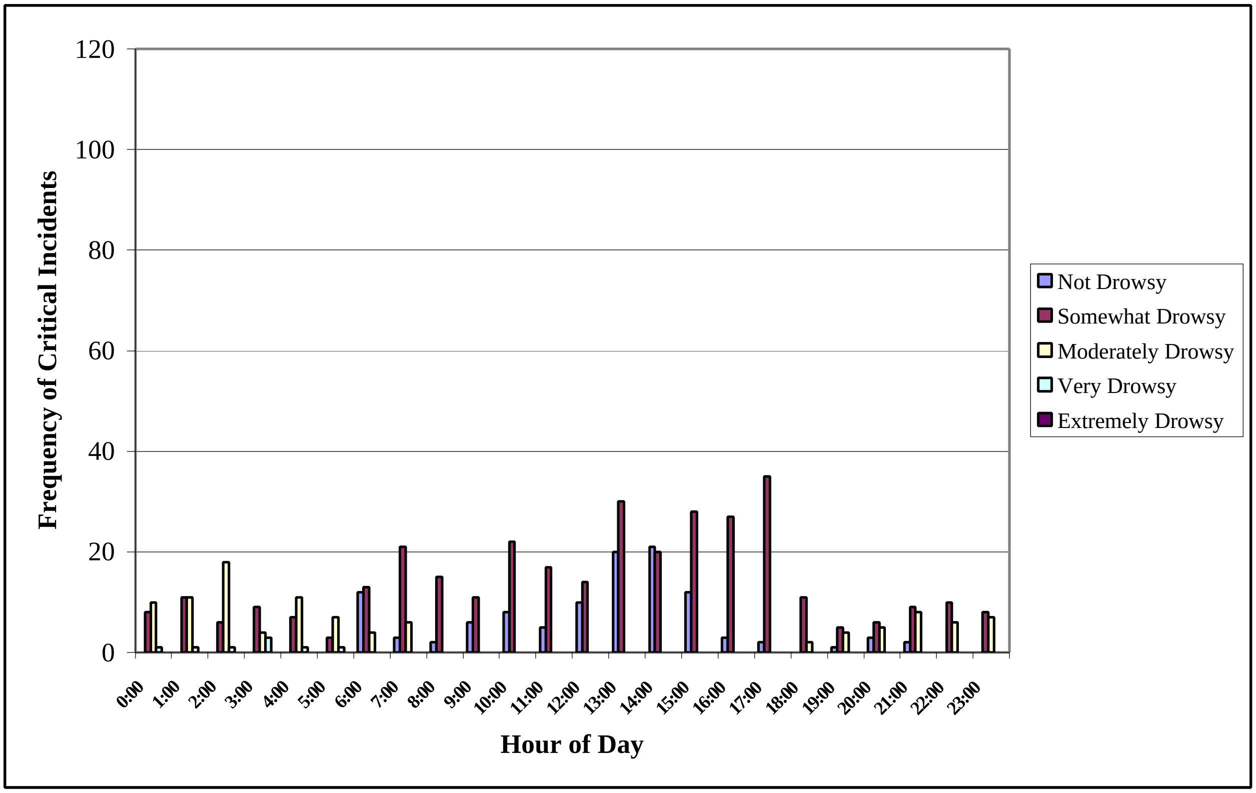

**Figure 104. Frequency of critical incidents involving team drivers that occurred each hour, as a function of ORD rating.**

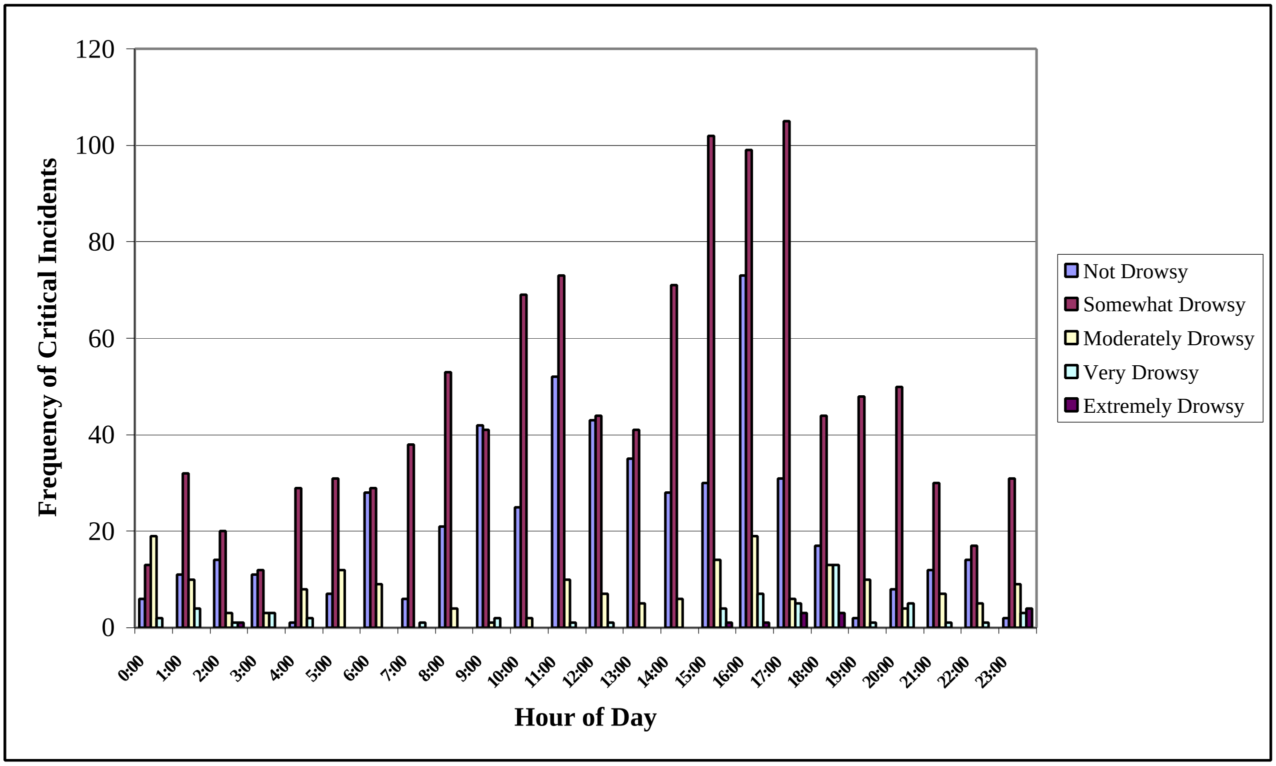

**Figure 105. Frequency of critical incidents involving single drivers that occurred each hour, as a function of ORD rating.**

After plotting the frequency data in Figures 104 and 105, it was realized that breaking up the frequencies by every hour and every ORD rating reduced the ability to identify potential trends in the data (i.e., there was too much information to consider). Another drawback of these graphs was that the data were not corrected for exposure (i.e., amount of data collected for a particular condition, such as Hour of Day). To improve on this analysis, a second analysis was conducted by first grouping Time of Day into four broad categories: morning (4:00 to 11:59), afternoon (12:00 to 17:59), evening (18:00 to 21:59), and night (22:00 to 3:59) (Pinel, 1997). Next, the number of ORD ratings was reduced to three categories: "not drowsy," "somewhat/moderately drowsy," and "very/extremely drowsy." Finally, ratios were calculated to correct for exposure by dividing the percentage of critical incidents for a given category by the percentage of timed-triggers for that same category. Recall, that this procedure produces a value where "1" represents a finding that might have been expected. Of primary interest are values much greater than "1" as they represent higher than expected incidents during that segment of time in a particular ORD category. The ratios from this calculation were used in an analysis of variance where the main effect for segment of day was significant, $F_{3,69} = 4.00$; $p < .05$ (Appendix G, Table G-1). For simplicity, the mean ratios are presented in Figure 106 for team drivers and Figure 107 for single drivers. In both figures, the ratios for most categories are near "1" (as expected). The exception to this is for single drivers in Figure 107 where the ratio of incidents in the morning category for the "not drowsy" rating was substantially higher than the others. An interpretation of this finding is that, for single drivers, there were more critical incidents where they were rated alert in the morning hours. This is particularly true when comparing the single drivers to the team drivers. Team drivers appear to maintain a steady state of alertness and critical incident occurrence throughout the day, whereas the single drivers are more alert in the morning and gradually, throughout the day, more critical incidents are attributed to the "moderately drowsy" and "very drowsy" categories.

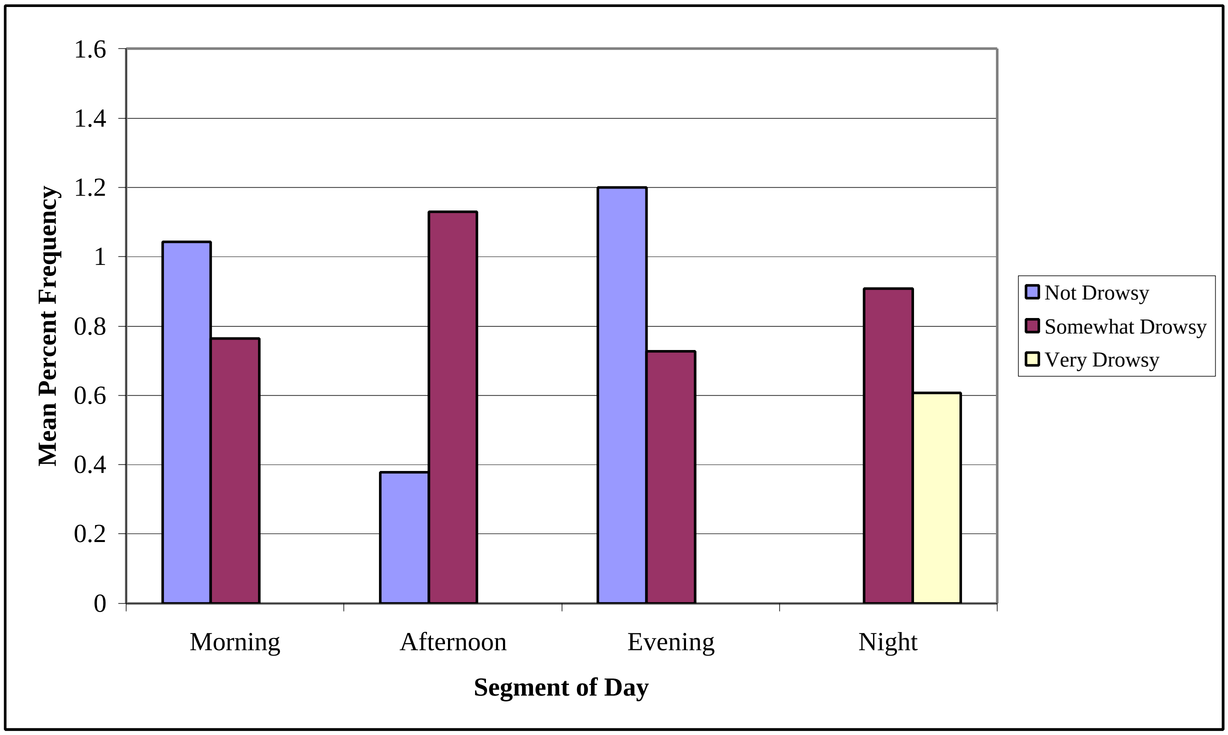

**Figure 106. Ratio of incident occurrence to timed-triggers, for a modified set of time of day and ORD categories, accounting for exposure for team drivers.**

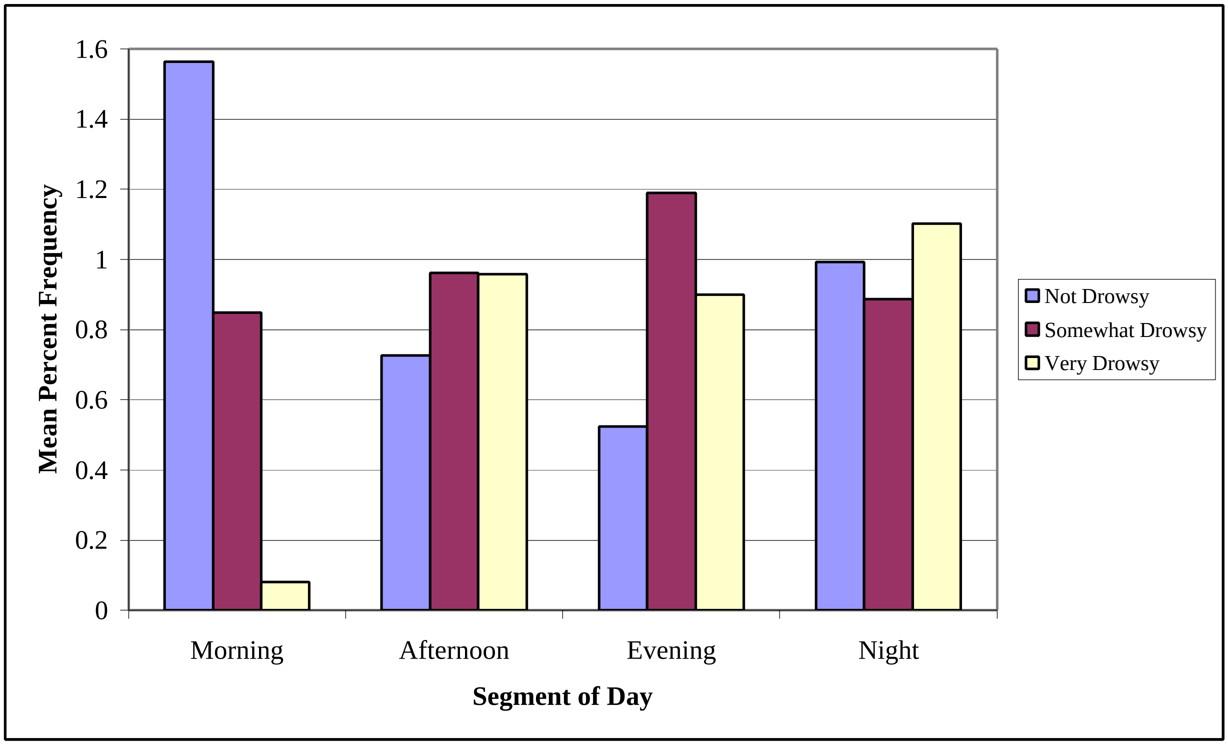

**Figure 107. Ratio of incident occurrence to timed-triggers, for a modified set of time of day and ORD categories, accounting for exposure for single drivers.**

*Relationship of the Critical Incident Severity Levels to ORD Ratings*

Figures 108 and 109 show the critical incident frequencies for team drivers and single drivers, respectively, as a function of the severity rating of the incident. As can be seen, the highest number of incidents for both groups of drivers occurred when the driver was “slightly drowsy.” “Not drowsy” and “moderately drowsy” were the categories with the next two highest frequency of incidents. Also, as seen in other analyses for both groups of drivers, the majority of incidents had a severity rating of Driver Error With Hazard Present.

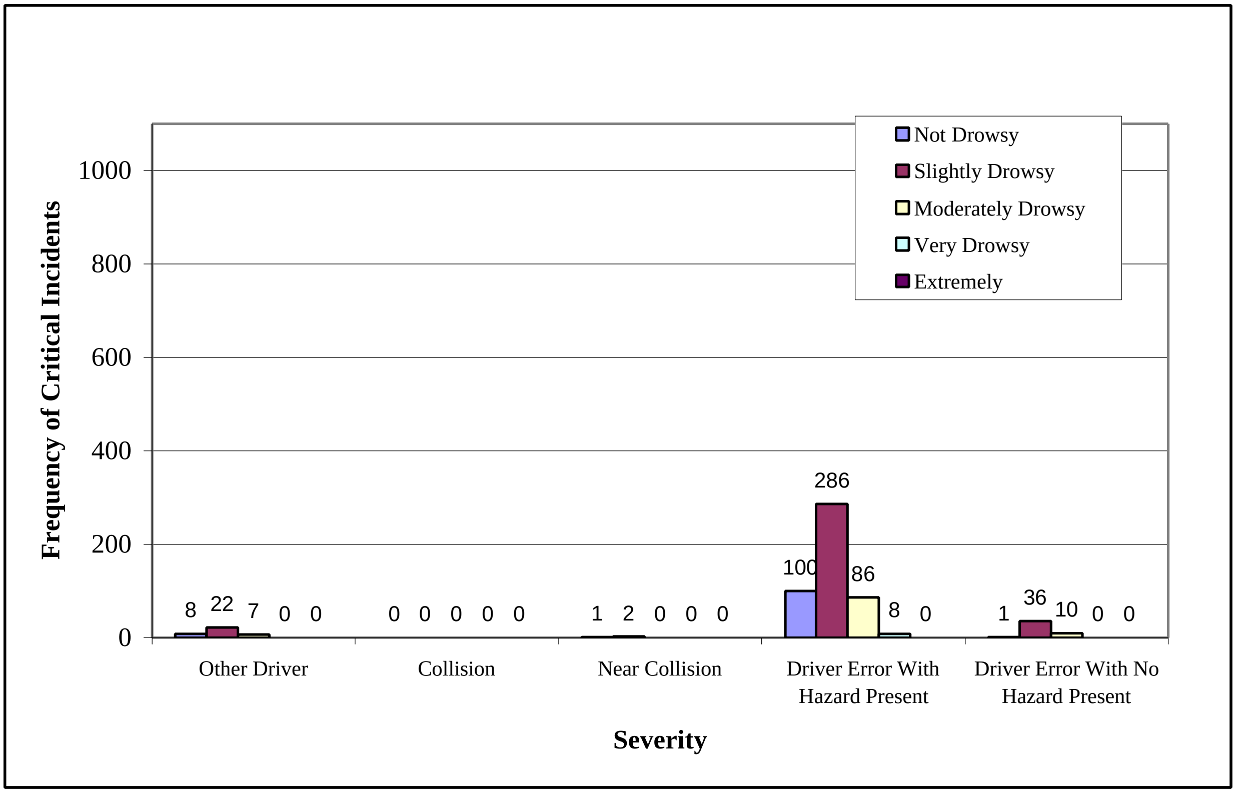

**Figure 108. Frequency of critical incidents for team drivers as a function of incident severity.**

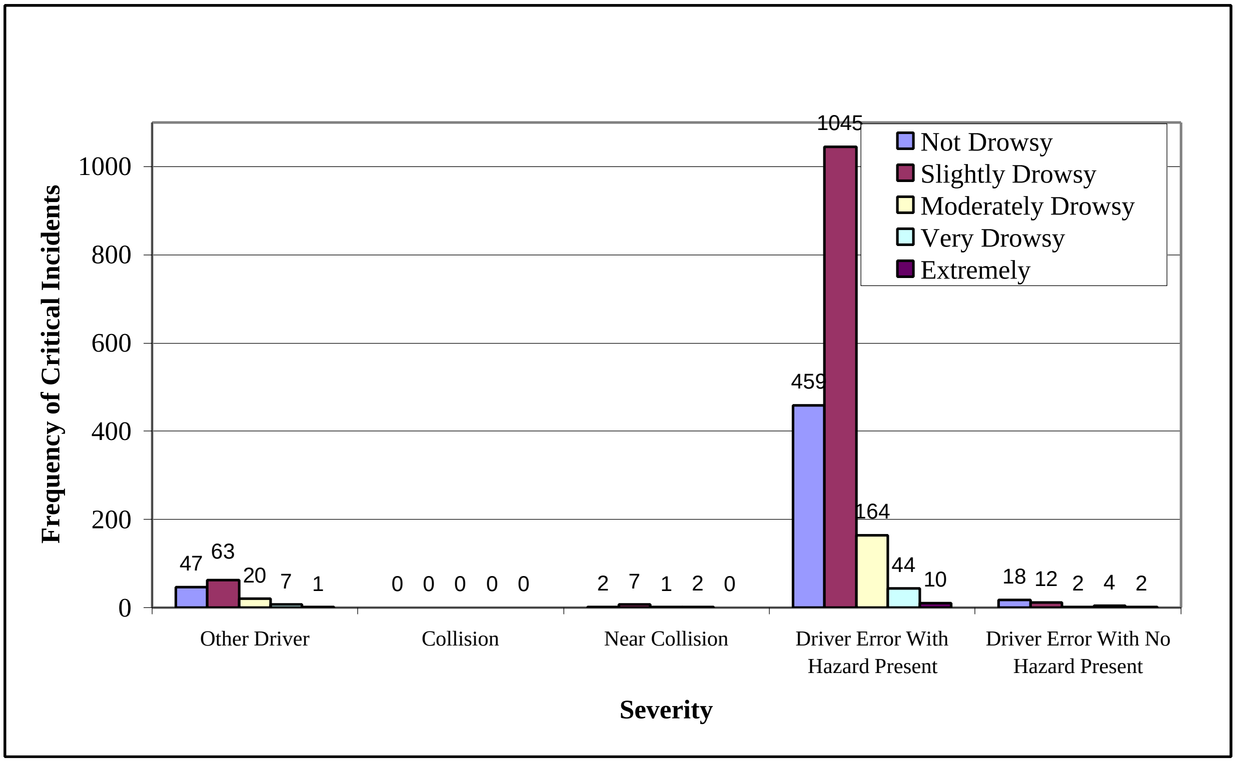

**Figure 109. Frequency of critical incidents for single drivers as a function of incident severity.**

As in previous analyses, the frequencies shown in Figures 108 and 109 do not account for exposure or the amount of data collected at each level. To account for this, the percentage of critical incidents for a given severity level was divided by the percentage of timed-triggers for that same level. Again, the result was a ratio value, where a value of "1" is what would be expected if there was no effect. Figure 110 shows these ratios for single drivers. When exposure is accounted for, the impact of drowsiness on the severity of incidents becomes very apparent. Consider the first category, Other Driver, where the incident was caused by the driver of another vehicle. In these cases, the sleeper berth drivers were "extremely drowsy" in 2.0 times as many incidents as would have been expected. For the most severe incidents that were recorded, Near Collision, the "very drowsy" category is over 2.5 times as what was expected for single drivers. The last two severity ratings involving a driver error, Driver Error/Hazard Present and Driver Error/No Hazard Present, also show a strong impact of drowsiness. Perhaps not surprisingly, these findings highlight the negative safety-related effects of being drowsy on the job. It is likely that ability to react for drivers in the "very drowsy" and "extremely drowsy" categories was compromised. Even in cases where the incident was not initiated by the heavy vehicle driver, as shown in the first severity category in Figure 110, being extremely drowsy apparently limited the driver's ability to react to other driver's mistakes.

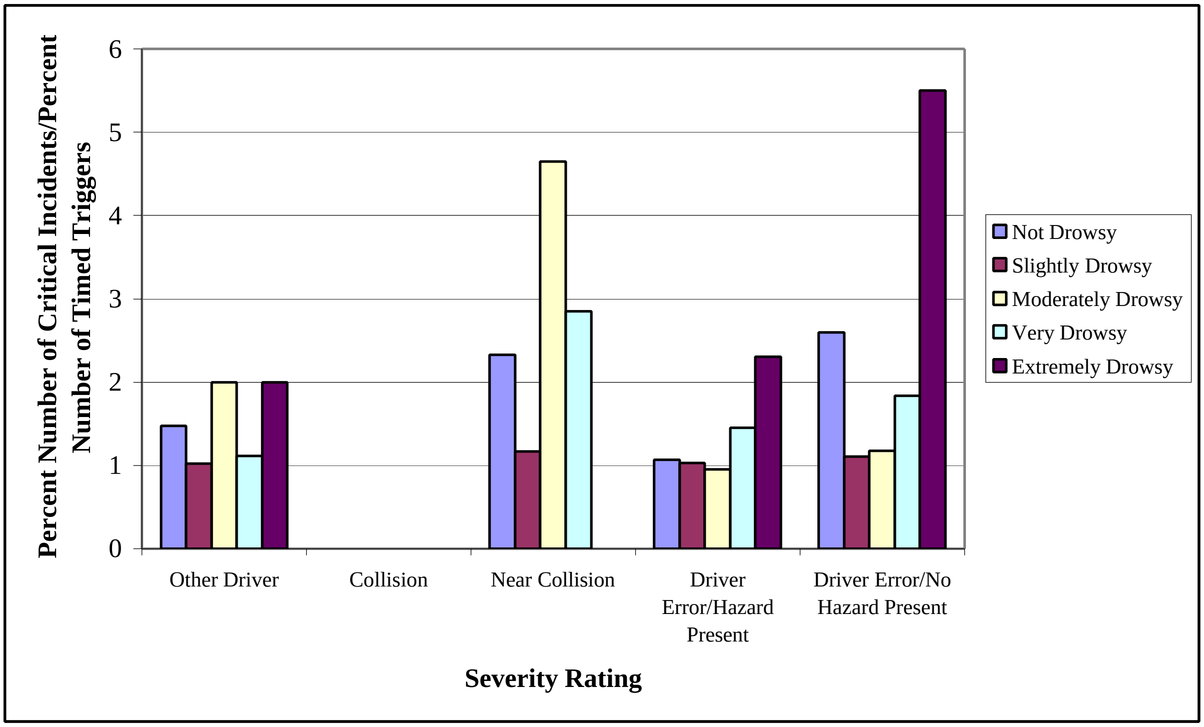

**Figure 110. Ratio of incident occurrence to timed-triggers, as a function of incident severity and ORD rating, accounting for exposure for single drivers.**

The incidents caused by the team drivers were also analyzed to account for exposure. An analysis of variance indicated that the main effect for severity and ORD rating were both significant, $F_{3,38} = 11.54$; $p < .01$ and $F_{4,41} = 2.81$; $p < .05$, respectively (Appendix G, Table G-2). The two-way interaction for severity and ORD level was also significant, $F_{10,20} = 4.30$; $p < .01$ (Appendix G, Table G-2). Again for simplicity, the ratios for the single drivers are shown in Figure 110 and the ratios for team drivers are shown in Figure 111. High levels of drowsiness appear to have been less of a problem for the team drivers. The ratio that stands out most prominently is for the "not drowsy" category of the Near Collision severity rating. Recall, the Near Collision category is the most severe critical incident type that was recorded in this study. For this combination, there were nearly 3.0 times as many incidents as expected when exposure was accounted for. For the Driver Error/Hazard Present severity rating, though there were no "extremely drowsy" incidents, the "very drowsy" category had a ratio between 0.5 and 1.0. In comparing the data from Figures 110 and 111, one striking result is the abundance of higher-level drowsiness incidents for the single drivers, and the lack of these same incidents for the team drivers. For the single drivers, there are three ratings that have an "extremely drowsy" ratio of 2.0 or higher and for team drivers, there are no "extremely drowsy" incidents for any level of severity. As with the findings presented previously, this result again demonstrates the significant impact that drowsiness had on single drivers and the limited effect it had on team drivers.

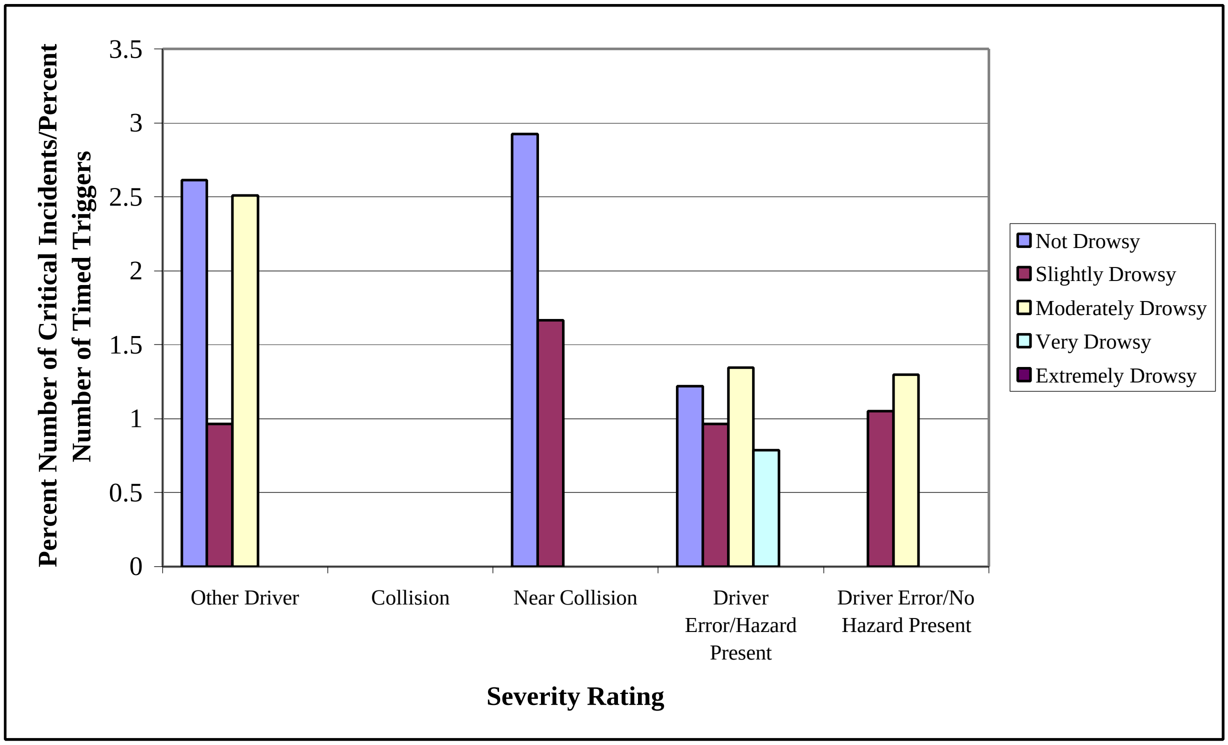

**Figure 111. Ratio of incident occurrence to timed-triggers, as a function of incident severity and ORD rating, accounting for exposure for team drivers.**

*Relationship of the Critical Incident Triggers to ORD Ratings*
Analyses were conducted to examine the relationship between the critical incident triggers and the drowsiness of the drivers. Using ORD as the measure of drowsiness, Figures 112 and 113 show this relationship for single drivers and team drivers, respectively.

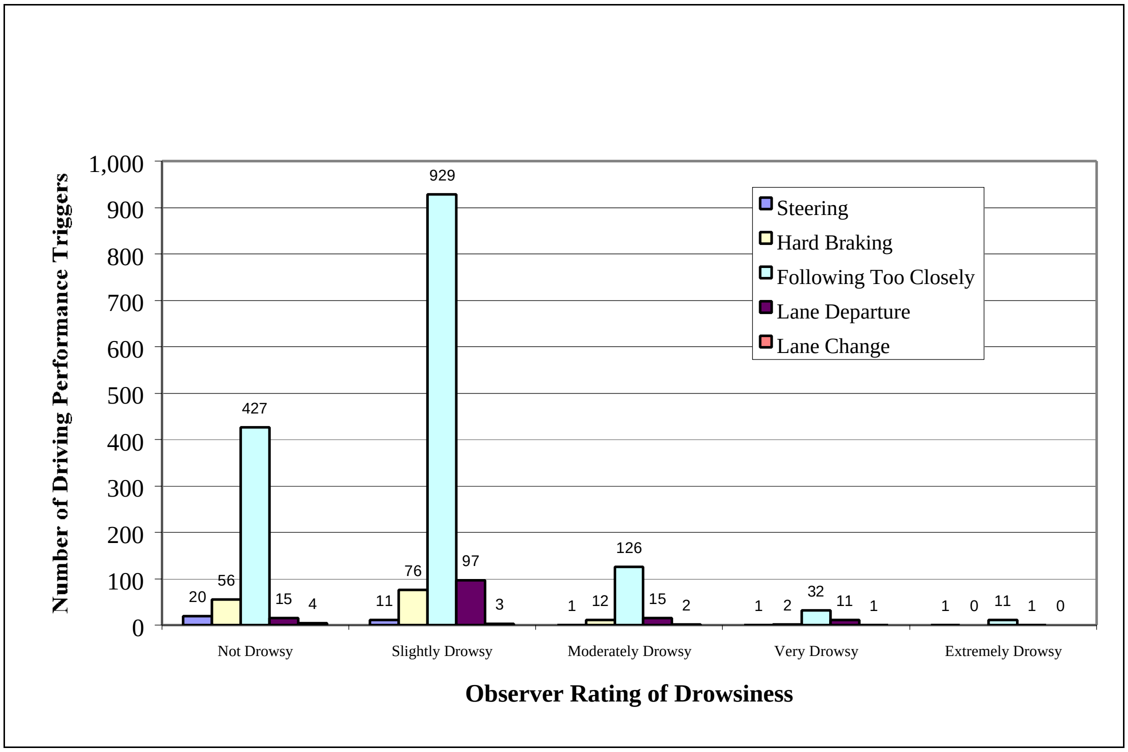

**Figure 112. Number of driving performance trigger types occurring at each level of ORD for single drivers.**

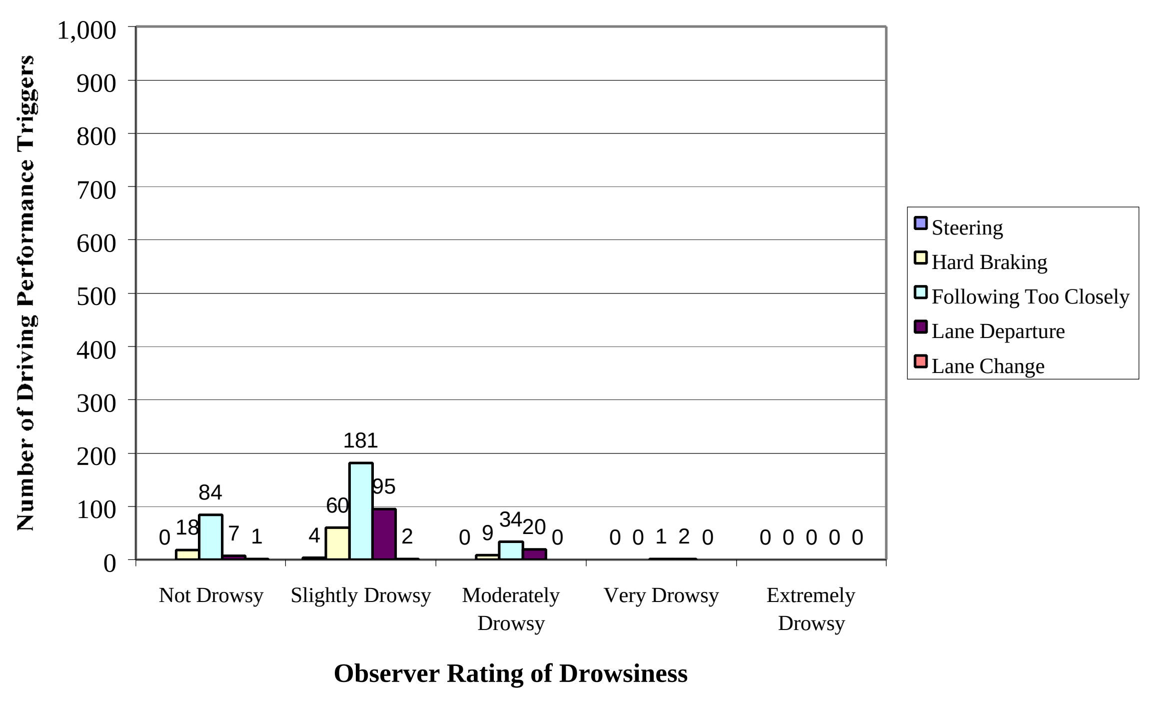

**Figure 113. Number of driving performance trigger types occurring at each level of ORD for team drivers.**

As can be seen, the most common critical incident trigger for both team and single drivers was "following too closely." Recall, that the threshold for the "following too closely" trigger was set when the time-to-collision between the vehicles was less than 4.0 seconds. For the single drivers, of the 1,898 incidents recorded, 1,502 of them (79 percent) were the result of the subject following too closely. For team drivers, 300 of the 564 incidents were of this type (53 percent). Figure 114 shows the critical incident frequencies for the "following too closely" trigger for the single and team drivers as a function of ORD rating. Figures 115 and 116 shows the incident frequencies for the remaining triggers for the team and single drivers, respectively.

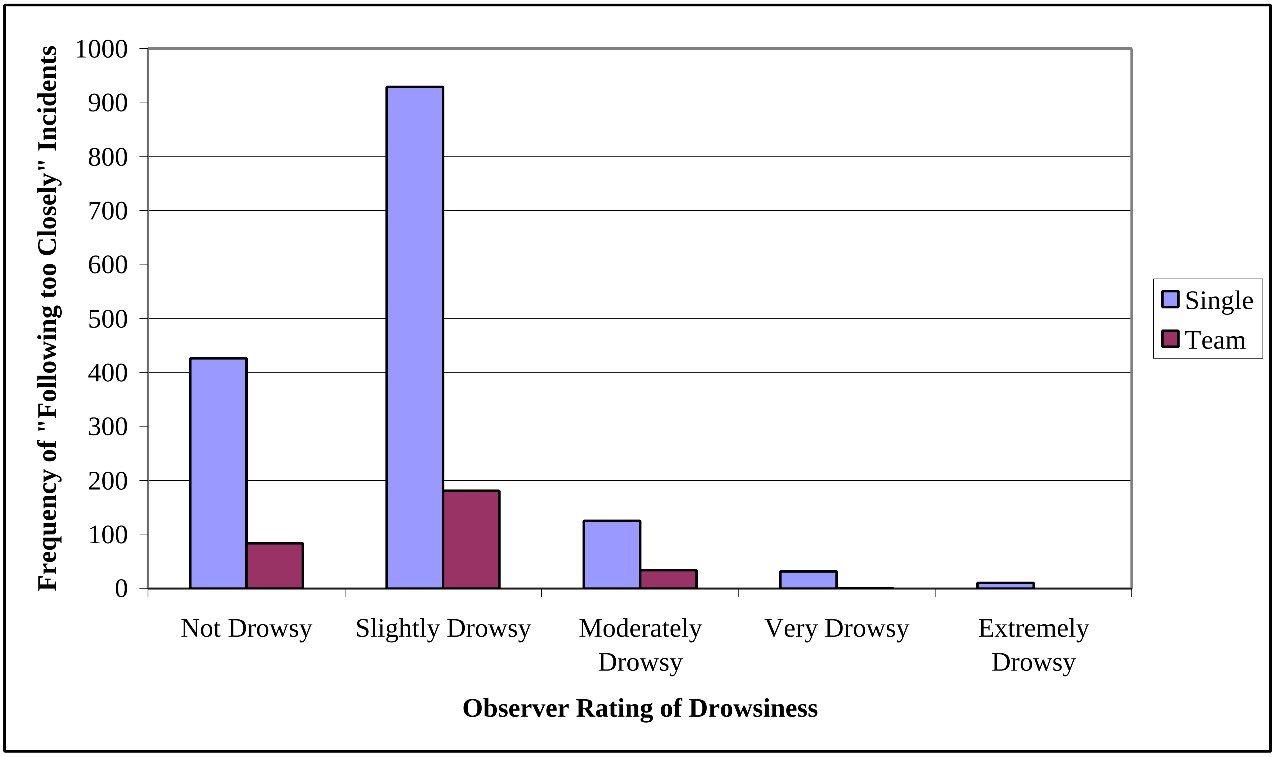

**Figure 114. Frequency of "following too closely" triggered critical incidents for single and team drivers, as a function of ORD ratings.**

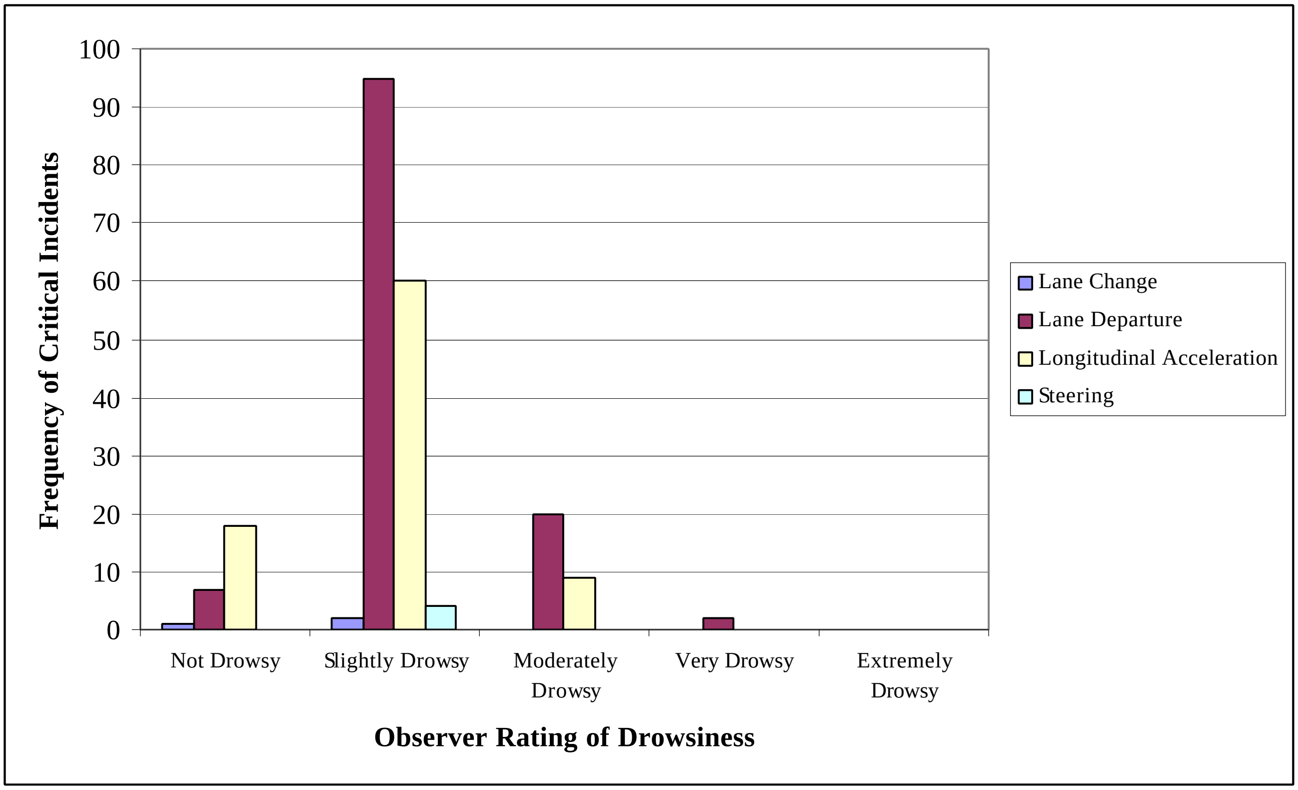

**Figure 115. Frequency of four types of triggered critical incidents for team drivers, as a function of ORD ratings.**

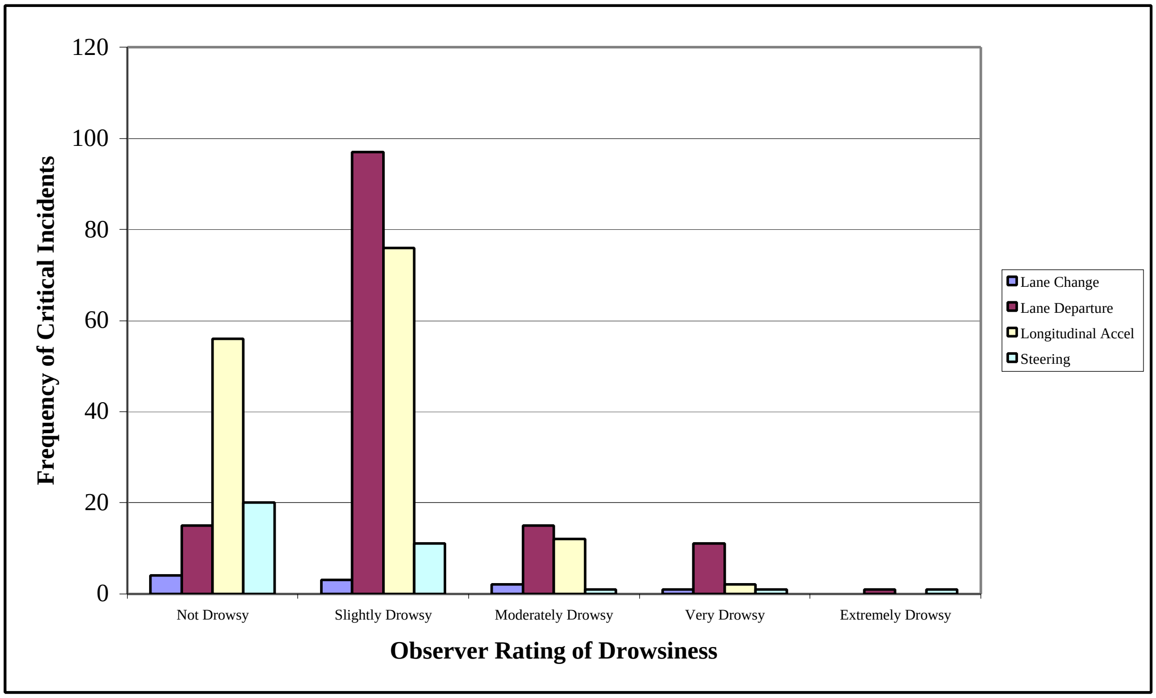

**Figure 116. Frequency of four types of triggered critical incidents for single drivers, as a function of ORD ratings.**

To correct for exposure, ratios were calculated by dividing the percentage of incidents for each ORD rating by the percentage of timed-trigger incidents. An analysis of variance revealed that the main effects for Incident Type and ORD Rating were both significant, $F_{8,68} = 74.69$; $p < .01$ and $F_{4,40} = 7.61$; $p < .01$, respectively (Appendix G, Table G-3). The interaction between Incident Type and ORD Rating was also significant, $F_{18,34} = 8.44$; $p < .01$ (Appendix G, Table G-3). Figures 117 and 118 present the ratios for team drivers and single drivers, respectively. As can be seen, when correcting for exposure, "following too closely" is not as predominant as when looking at frequencies by themselves. Rather, for team drivers, "hard braking" and "lane deviation" were the predominant triggers in the "moderately drowsy" and "very drowsy" categories, respectively. These triggers were the only triggers with a ratio greater than 2.0 in any category for team drivers.

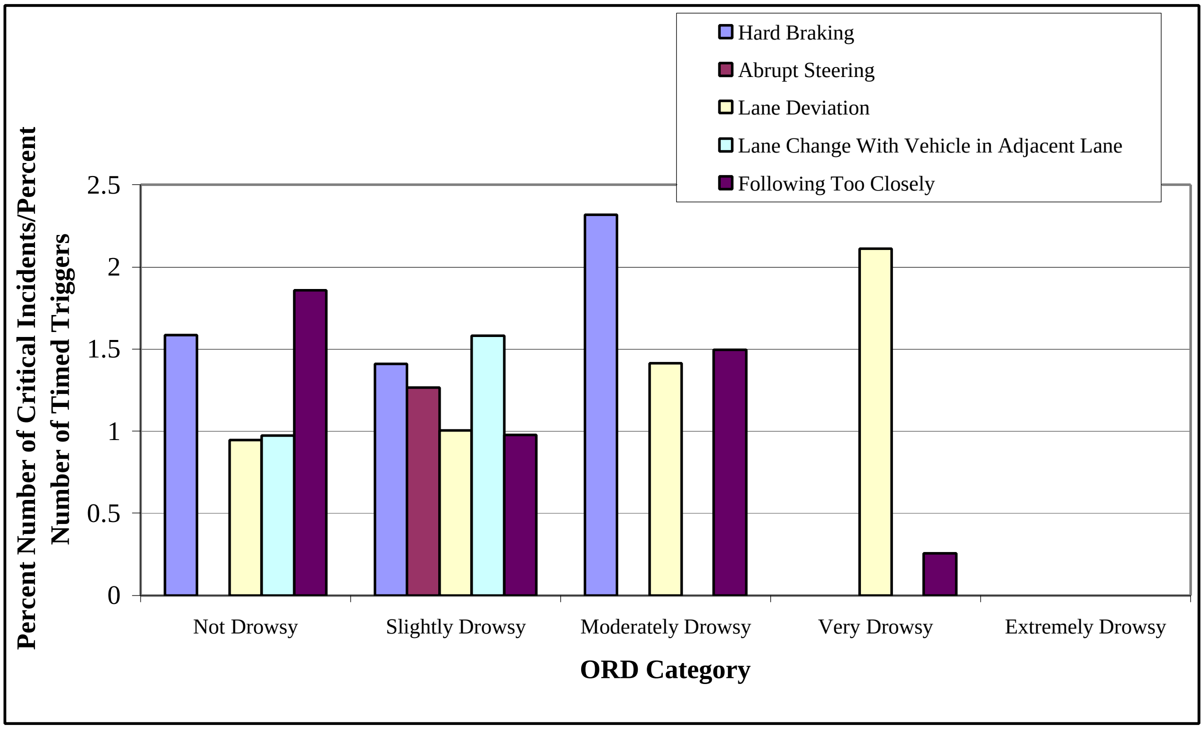

**Figure 117. Ratio of incident occurrence to timed-triggers, as a function of the incident triggers and the ORD rating, accounting for exposure for team drivers**

For single drivers, shown in Figure 118, the result that stands out is the ratio for “abrupt steering” in the “extremely drowsy” category. This ratio of over 20.0 was much larger than expected. The steering trigger was activated when the driver made a sudden, jerky movement with the steering wheel. The next largest trigger ratio was for the “change lanes with a vehicle in adjacent lanes” trigger in the “very drowsy” category. Comparing the findings from the team and single drivers, it becomes evident that incidents involving single drivers were greatly affected by their level of drowsiness, which then translated into dangerous driving behaviors (i.e., behaviors that resulted in a vehicle trigger). Team drivers did not seem to demonstrate extreme drowsiness and, perhaps as a result, did not exhibit these same dangerous behaviors.

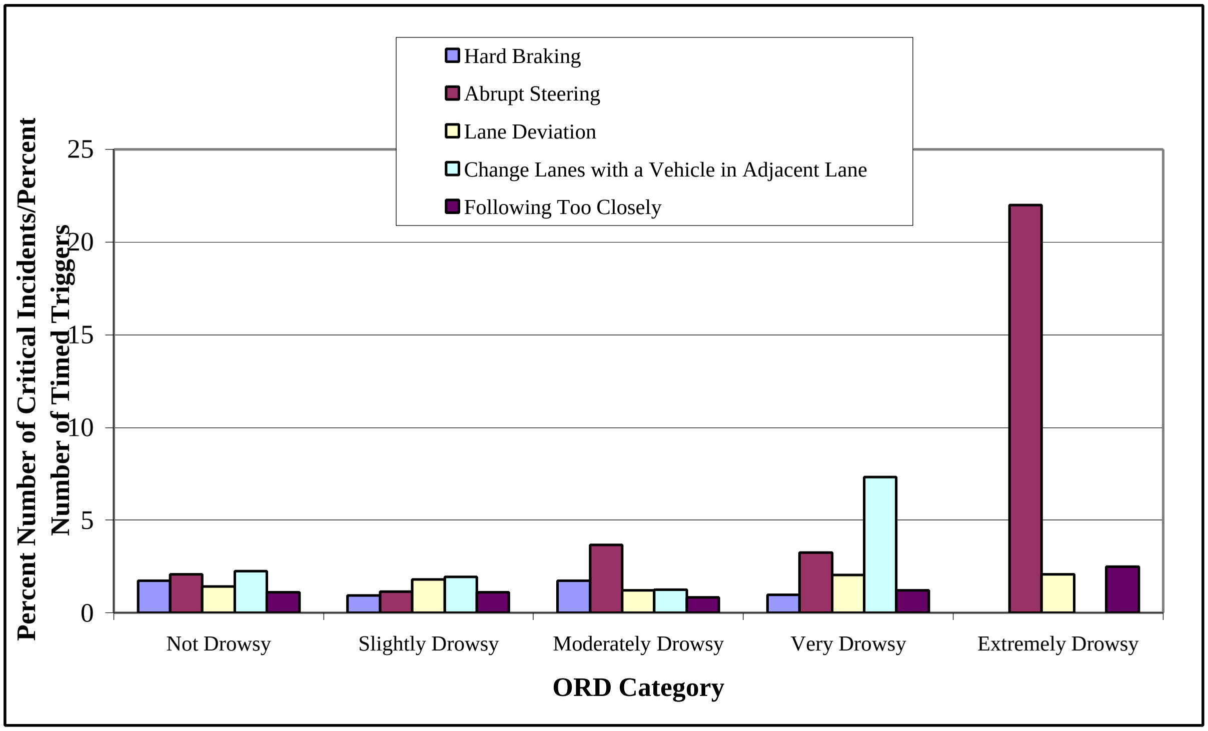

**Figure 118. Ratio of incident occurrence to timed-triggers, as a function of the incident triggers and the ORD rating, accounting for exposure for single drivers**

## Discussion

The purpose of this objective was to examine critical incidents as a function of driver alertness/drowsiness. The characteristics of critical incidents, in terms of the drowsiness rating associated with the incidents, the Day of Trip that incidents occurred, the Hour of Day that incidents occurred, the severity of the incidents, and the trigger type that initiated the incidents, were all considered.

The analyses conducted in support of this objective resulted in several interesting findings. One such finding was that single drivers were found to have a higher frequency of critical incidents than team drivers at every level of drowsiness, and a significantly higher number of incidents for the “very drowsy” and “extremely drowsy” categories. When the amount of single driver data that were collected was accounted for (exposure), the ratio of critical incidents to timed-triggers in the "extremely drowsy" category was far greater than one would have expected *a priori*.

What are the implications of these results? It is apparent that drowsiness plays a key role in the critical incidents that occur with long-haul drivers. Single drivers, to a greater degree than team drivers, seemed to on occasion push themselves and drive even when they were judged to be "extremely drowsy." The data from the team drivers indicated that team drivers were not immune to the negative effects of drowsiness. However, unlike single drivers, team drivers can be relieved from their driving duties before drowsiness significantly impacts their performance.

Analyses that were conducted on the Day of Trip as a function of the drowsiness ratings associated with critical incidents that occurred yielded two important findings. First, in looking at the frequency of critical incidents across the day of the drive, it was found that the frequency of incidents in the "not drowsy" category diminished for single drivers after the fourth day of driving. In addition, there were a relatively higher number of incidents for single drivers in the "extremely drowsy" category on days 5 and 8. One interpretation of these results is that the impact of drowsiness on single drivers was greater as the trip went on. For team drivers, on the other hand, this did not seem to be the case. It is suggested that for long trips of extended driving, the team driving system likely reduces the impact that fatigue has on a driver's performance. It may have been the case that, without a relief driver present, the single drivers in the study became increasingly fatigued. The result of this cumulative fatigue may have been an increase in the number of incidents that occurred in the latter days of the trip where the driver was classified as "extremely drowsy."

Analyses were conducted to determine if the number and type of critical incidents were affected by a driver's level of drowsiness and the time of day. One result indicated that single drivers were more alert in the morning and gradually become fatigued during the day, whereas team drivers maintained a constant level of fatigue throughout the 24-hour clock. This provides more evidence for the reduced impact of fatigue on team drivers than on single drivers during long haul trips.

Analyses were also conducted to determine the relationship of the critical incident severity levels to the drivers' level of drowsiness. As with many of the other findings presented in this objective, the results from these analyses illustrated the significant impact that drowsiness had on single drivers and the limited effect it had on team drivers. For example, single drivers were found to be "extremely drowsy" in almost 2.5 times as many incidents than were expected. Additionally, the data from single drivers indicated that, for the most severe incidents that were recorded (Near Collision), the "very drowsy" category included over 2.5 times as many incidents than were expected. For both single and team drivers, the two severity ratings that included the majority of recorded incidents, but were the least severe (Driver Error/Hazard Present and Driver Error/No Hazard Present), also showed an impact of drowsiness. Taken together, these findings highlight the negative safety-related effects of being drowsy on the job. Not surprisingly, drivers who are drowsy cannot react to situations as reliably as when they are alert. The results from these analyses showed that drowsiness impacts not only the driver's likelihood of causing an incident, but also his/her ability to appropriately react to the mistakes of other drivers.

The final set of analyses examined the relationship of critical incident trigger types to the drowsiness levels. Several interesting findings resulted from these analyses. Perhaps the most intriguing finding was that single drivers in the "extremely drowsy" category were involved in over 20 times as many "abrupt steering" incidents than were expected. This was the largest ratio for any trigger type in any drowsiness category (including "not drowsy") and was much larger than expected. The second largest trigger type ratio for single drivers, of approximately 5.5, was for the "change lanes with a vehicle in adjacent lane" deviation trigger, and this also occurred in the "very drowsy" category. In comparison, for team drivers across all drowsiness categories, "hard braking" was the predominant trigger with a ratio of 2.5 and occurred in the "moderately drowsy" category. Also, the "lane deviation" trigger occurred over 2.0 times in the "very drowsy" category. It is noteworthy that this was the only trigger for team drivers with a ratio greater than 2.0 in any drowsiness category. The very large ratio of "abrupt steering" incidents in the "extremely drowsy" category for single drivers, and the more minimal drowsy-related triggered incidents that occurred for team drivers, implies that drowsiness affected single drivers to a much larger degree than team drivers. The drowsiness experienced by single drivers translated into unsafe driving behaviors, or behaviors that resulted in a vehicle trigger. This was not the case for team drivers.

In summary, the findings from the analyses conducted in this objective strongly suggest that single drivers are greatly affected by drowsiness, which in turn compromises their ability to safely operate their vehicles. The benefits of reducing drowsiness are highlighted by the team driving operation. Unlike extremely tired single drivers, who may have felt compelled to continue to drive even when it was dangerous to do so, team drivers always had a relief driver present. As such, any individual driver in a team operation had no similar compulsion to operate the vehicle when he/she was extremely tired. From the data collected here, it is apparent that the team driving operation translates into fewer bouts of drowsiness, fewer critical incidents, and, in general, safer trucking operations.

## CONCLUSIONS AND RESEARCH IMPLICATIONS

The primary goals of this research were to determine:

1. If sleep quantity and quality differed between truck drivers sleeping at home and truck drivers sleeping in stationary and moving sleeper berths.
2. If driver alertness was affected by differences in sleep quality or other variations in the trucking environment or process.
3. If driving performance was affected by any differences in driver alertness, sleep quality, or other variations in the trucking environment.

These primary goals were discussed individually and in combination via the seven research objectives identified in the previous section. In this section, major conclusions and recommendations that address each of these three major goals are drawn from the seven research objectives, as applicable. Implications of this research are also presented in this section for each of the following issues:

- Differing types of trucking operations (singles vs. teams).
- Driver screening, driver training, and fatigue management programs.
- Hours-of-service regulations.
- Fatigue monitoring and warning devices.
- Sleeper berth design.

A closing section providing recommendations for future research is also included.

### FACTORS AFFECTING SLEEPER BERTH SLEEP QUANTITY AND QUALITY

Sleeping in either a stationary or moving sleeper berth was shown to adversely affect sleep quality and quantity when compared to the home sleep data. Sleep quality, in particular, was lower in a moving sleeper berth relative to a stationary sleeper berth or home sleep. Team drivers generally acquired more sleep (greater than one hour per day on average) than did single drivers, with single drivers reporting six hours of sleep per 24-hour period and team drivers reporting just over seven hours per 24-hour period. There were a number of measures, both objective and subjective, which indicated that the quality and depth of sleep was worse on the road, particularly for team drivers. Based upon these findings, it appears that the team drivers made up for a lower quality of sleep by having longer periods of rest.

The results also indicated that team drivers had significantly more sleep disturbances than did single drivers. When the environmental factors were considered, it was found that many of the sleep disturbances that occurred for single drivers could not be attributed to an environmental factor. In contrast, team drivers, who slept while the vehicle was in motion, were disturbed by the effects of vibration and noise of the moving truck. This finding has design implications for sleeper berths and indicates that, when the truck is in motion, greater attention should be paid to reducing the amount of vibration and noise that invades the sleeper berth.

## FACTORS AFFECTING DRIVER ALERTNESS

The effects of lower sleep quality described above apparently resulted in a greater tendency for team drivers to be “somewhat drowsy” or “moderately drowsy” relative to single drivers. In addition, single drivers were rated as “not drowsy” more often, probably due to the fact that they were generally getting a higher quality of sleep. However, of the 20 “very/extremely drowsy” episodes captured by Observer Ratings of Drowsiness, 16 were from single drivers.

Throughout various analyses of the data in this report, it appeared that single drivers tended to push themselves to continue driving on occasion when they were very tired. In contrast, team drivers appeared to effectively rely on their relief drivers to avoid instances of extreme drowsiness while driving. A primary issue regarding this study was whether or not team drivers were more fatigued since they may not have gotten a high enough quality of sleep in a moving sleeper berth truck. This was indeed the case, at least in the majority of the comparison cases. Even so, these findings suggest that team drivers are not at the greatest risk for extreme fatigue while driving.

It is important to note that, in general, there were relatively few instances of drivers being “very/extremely drowsy” while driving. Of the over 1,000 observations collected and analyzed during this part of the study, 2.2 percent of the trained Observer Ratings of Drowsiness (ORD) and 4.7 percent of self-reports (Karolinska scale ratings) indicated that the drivers were either “very drowsy” or “extremely drowsy.” Given the large sample size, these numbers are probably reasonably representative of the population. Furthermore, the low numbers of ORD and Karolinska self-assessments is in line with other research findings. Wylie *et al.* (1996) had 4.9% of reviewed video data judged “drowsy” and 2.5% of objective EEG data recorded during driving was assessed as “polysomnographcially drowsy”. Thus, for every 50 trucks on the road, one or two are driven by drivers who are very tired.

One of the strongest contributing factors for driving alertness overall was shown to be Hour of Day. On average, the highest Observer Ratings of Drowsiness occurred between 12 midnight and 5 a.m. This result is consistent with the demonstrated effects of circadian rhythms on alertness in many other applications.

When Length of Trip was considered for each of the two groups of drivers, it was found that single drivers had more frequent numbers of “moderately to extremely drowsy” ORD ratings than did team drivers on the first day of a trip. This may have indicated that single drivers were pushing themselves more than team drivers, who had the luxury of switching drivers if one of them became fatigued. It may also indicate, as was found by Hanowski and his colleagues (Hanowski *et al.,* 2000) in a study of Local/Short Haul drivers, that drivers were coming to work tired as a result of activities on their days off. Thus, the issue of “sleep hygiene” (i.e., the degree to which drivers come to work well-rested) also appears to be an issue in long-haul trucking, as has been noted by other researchers (e.g., Wylie et al., 1996). The effects of poor sleep hygiene may have been less of an issue for team drivers since they could trade-off their shifts even at the beginning of a trip.

On day 8 of a trip, team drivers were rated “moderately to very drowsy” more often than single drivers. This may indicate some effects of cumulative fatigue due to lower sleep quality of team drivers. It is possible that even the beneficial effect of switching drivers eventually loses its advantage as both drivers in a team eventually experience fatigue due to cumulative sleep loss over a very long trip.

The alertness analyses also discovered a Length of Shift by Day of Trip interaction, with very long shifts on days 2, 3, and 8 of a trip resulting in reduced alertness. A shift is defined as the amount of time a driver drove without taking more than a 20-minute break. This result has important implications for hours-of-service regulations. Further analysis indicated that there were a number of hours-of-service violations that occurred with drivers driving between 11 and 15 hours. Approximately 60 percent of these cases involved single drivers. What impact did these violations have on driver drowsiness? For single drivers, the lowest alertness ratings occurred late in the second, third, and fifth shifts of the day. A closer look at these shifts found that each involved an hours-of-service violation. Because drivers were found to drive up to 16 hours on the first day and shift of the trip without any apparent negative effects, it is suggested that these low alertness ratings resulted from drivers driving for long shifts over multiple days. Not surprisingly, it is also suggested that this combination of long shifts and multiple days of driving created the most significant drowsiness problem for drivers.

## FACTORS AFFECTING CRITICAL INCIDENTS AND DRIVER ERRORS

A primary purpose of this study was to assess any differences in driving performance as measured by the type and severity of triggered critical incidents such as Collisions, Near Collisions, and driver errors.

A primary finding of this study was that single drivers had many more critical incidents at all levels of severity than did team drivers. The difference was very large with ratios of between 4:1 and 2.5:1 depending on the trigger severity level. The overall difference was not limited to a few drivers, as has been the case with other similar studies (e.g., Hanowski *et al.,* 2000). Eight of the single drivers had more incidents than *any* of the team drivers. A possible explanation would be that single drivers are suffering a performance decrement due to sleep dept. Recall that single drivers obtain, on average, six hours of sleep a night, compared to seven hours for team drivers. This result would concur with findings by Balkin *et al.* (2000), who found that even a relatively small reduction in average nighttime sleep duration by short and long-haul drivers (from 7.93 to 6.28 hours) resulted in measurably decremented performance on a PVT task. Of course, this does not account for the fact that team drivers reported a much lower *quality* of sleep. Analyses of other possible alternative explanations for these differences (including age, experience, and company) showed that no systematic differences were present. A final possibility regarding this finding is that single drivers drive significantly more aggressively than team drivers. Based on focus group results for this project (Neale *et al.*, 1998a), a plausible explanation is that team drivers drive more carefully so that their partners can get a higher quality of sleep and/or are not alarmed by their driving.

An interesting note is that the teams who participated were driving together by choice, either because they were a regular team or because they wanted to participate in the study. None of the teams were in a “forced” driving arrangement. One could speculate whether a forced team might have more critical incidents relative to a team that was together by choice.

In looking at only the most severe of the critical incidents, including 2 Collisions and 22 Near Collisions, it was found that a few of the single drivers were greatly over-represented (as was found by Hanowski and his colleagues for Local Short haul operations). Seven of the 24 severe incidents were caused by one single driver, and 13 of the 24 incidents were caused by four single drivers. No team driver had more than one severe critical incident. These results show that a driver “screening” process could potentially help reduce risk in long-haul trucking (where drivers are required to undergo additional scrutiny prior to permanent licensing or to travel with on-board monitoring systems). Alternatively, a longer observation period for probationary drivers may be warranted.

The severe critical incident analysis also found that 4 of the 24 severe incidents were caused by extreme (i.e., “head-bobbing”) fatigue. This finding confirms both the presence and risk of these levels of fatigue in the long-haul trucking industry. The only interesting pattern regarding these four events was that three of them occurred with single drivers.

Another important finding related to driving performance was that the frequency of critical incidents and driver errors varied significantly by the Hour of Day. However, contrary to what might be expected based upon the results described above, the largest number of incidents (even corrected for exposure) occurred in the late afternoon/early evening hours. It was apparent from this analysis that interaction with a much heavier level of traffic had a greater impact upon the occurrence of critical incidents (and most likely the greatest impact on crash risk overall) than did fatigue due to circadian rhythm effects.

The results of this analysis also revealed interesting findings relative to the hours-of-service violations that occurred during this study. One of the most interesting aspects of this analysis is that, in general, there were very few critical incidents or driver errors of any kind during these periods. In fact, in 22-hour-long periods where a total of three drivers drove over 14 hours in a single shift, there were *no instances* of a driver error or critical incident. This is in contrast to an average of over 2.0 critical incidents per driver-hour during the first hour of a shift (i.e., over 44 critical incidents would have been expected based upon this average instead of *zero*). Thus, it appears that these drivers were driving very carefully to either compensate for fatigue or because they knew they were well beyond the regulation and did not want to risk being stopped by law enforcement officials.

The analyses conducted to assess the relationship between driver alertness and driving performance showed several important findings. One such finding was that single drivers were found to have a higher frequency of critical incidents than team drivers at every level of drowsiness, and a significantly higher number of incidents in the “very drowsy” and “extremely drowsy” categories. When the data were corrected for hours of driving (exposure), the critical incidents/hour in the “extremely drowsy” category were far greater for single drivers than one would have expected *a priori*. What are the implications of these results? First, it is apparent that drowsiness plays a key role in the critical incidents that occur with long-haul drivers. Single drivers, to a greater degree than team drivers, again seemed to push themselves on occasion and drove even when they were judged to be “extremely drowsy.” The data from the team drivers indicated that they were not immune to the negative effects of drowsiness. However, unlike single drivers, team drivers apparently utilized the capability to be relieved from their driving duties by their partners before drowsiness significantly affected their performance.

Analyses that were conducted on the Day of Trip as a function of the drowsiness ratings associated with critical incidents yielded two important findings. First, in looking at the frequency of critical incidents across the day of the drive, it was found that the frequency of incidents in the “not drowsy” category diminished for single drivers after the fourth day of driving. In addition, there were a relatively higher number of incidents in the “extremely drowsy” category for single drivers on days 5 and 8. One interpretation of these results is that the impact of drowsiness on single drivers was greater as the trip went on. For team drivers, on the other hand, this did not seem to be the case based upon this analysis. It is suggested that for long trips of extended driving, the team driving system likely reduces the impact that fatigue has on a driver’s performance (at least up to day 8, as was found indicated in the previous section). It may have been the case that, without a relief driver present, the single drivers in the study became increasingly drowsy while driving due to cumulative fatigue. The result of this cumulative fatigue may have been the cause of the increase in the number of incidents that occurred in the latter days of the trip where the driver was classified as “extremely drowsy.”

Analyses were conducted to determine if the number and type of critical incidents were affected by a driver’s level of drowsiness and the time of day. One result indicated that single drivers were more alert in the morning and gradually become fatigued during the day, whereas team drivers maintained a relatively constant level of alertness throughout the 24-hour clock. This provides more evidence for the reduced impact of fatigue on teams of drivers than on single drivers during long-haul trips.

Analyses conducted to determine the relationship of the critical incident severity levels to the drivers’ level of drowsiness illustrated the significant impact that drowsiness had on single drivers and the limited effect it had on team drivers. For example, single drivers were found to be “extremely drowsy” in almost 2.5 times as many incidents than were expected based upon driving-time exposure. Additionally, the data from single drivers indicated that, for the most severe incidents that were recorded (i.e., Near Collisions), the “very drowsy” category included over 2.5 times as many incidents than were expected, again based upon exposure. For both single and team drivers, the severity ratings that included the majority of recorded incidents, but were the least severe (i.e., driver errors), also showed an impact of drowsiness. Taken together, these findings serve to emphasize the negative safety-related effects of being drowsy on the job. The results from these analyses showed that drowsiness impacts not only the driver’s likelihood of causing a collision, but also his/her ability to appropriately react to the mistakes of other drivers.

Time of Day also had a major effect upon the probability of a critical incident; however, based upon the effects of fatigue alone, this was not as one would hypothesize. The most critical incidents and driver errors occurred in the late afternoon/early evening hours, which corresponded to an evening “rush hour.” It is clear that the presence of other traffic has a much larger effect on the occurrence of these safety surrogates (and most likely crash risk) than does the presence of fatigue overall.

## IMPLICATIONS FOR TYPE OF OPERATION: SINGLES VS. TEAMS

Team drivers in this study were generally very successful in avoiding circumstances of extreme drowsiness. Despite evidence pointing to the fact that they get a lower quality of sleep in a moving sleeper berth, team drivers appear to compensate by spending more time sleeping (or at least resting) relative to single drivers, and by utilizing their backup drivers effectively.

Conversely, the findings of this study strongly suggest that single drivers are greatly affected by drowsiness, which in turn compromises their ability to safely operate their vehicles. The benefits of reducing drowsiness are highlighted by the team driving operation. Unlike extremely tired single drivers, who may have felt compelled to continue to drive even when it was dangerous to do so, the individual drivers in a team operation generally had no similar compulsion to operate the vehicle when they were extremely tired. From the data collected here, it is apparent that the team driving operation translates into fewer bouts of drowsiness, fewer critical incidents, and, in general, safer trucking operations.

An interesting phenomenon was present regarding hours-of-service regulations and team drivers. Four of the 13 teams tested as part of this study were married couples. In three of the four cases, the husbands drove the vast majority of the time while the wives only drove for short periods several times per day. This resulted in relatively extreme cases of HOS violations, with the husbands often driving 15 to 17 hours per day.

## IMPLICATIONS FOR DRIVER SCREENING, DRIVER TRAINING, AND FATIGUE MANAGEMENT

Other studies (e.g., Hanowski *et al.,* 2000) have found that a relatively small percentage of drivers account for most unsafe acts. Thus, the potential exists to improve trucking safety through mechanisms such as driver screening/monitoring, driver training, or driver fatigue management. The results of this study support the findings of this prior work, but only in the case of single drivers.

The single drivers in this study had many more critical incidents at all levels of severity as compared to team drivers. This difference was very large at all trigger severity levels. In looking at only the most severe of the critical incidents, over one-half of the incidents were caused by four single drivers. This result is similar to that found by Wylie *et al.* (1996). No team driver had more than one severe critical incident.

In addition, single drivers were involved in four times the instances of “very/extremely drowsy” observer ratings than were team drivers. It appeared throughout various analyses of the data in this report that single drivers tended to push themselves to drive on occasions when they were very tired.

In contrast to single drivers, team drivers appeared to drive much less aggressively, make fewer errors, and rely effectively on their relief drivers to avoid instances of extreme drowsiness while driving. In effect, it appears that team drivers undergo a natural "screening" process. This was indicated by a number of the truck drivers during the focus groups conducted earlier in this project. Drivers indicated that team drivers must be both considerate of their resting partner and trustworthy with regard to their driving ability. Thus, the level of "acceptance" necessary to be a successful team driver seems to serve as an effective screening criterion.

Based upon these results, it is recommended that research in the areas of driver screening/monitoring, driver training and fatigue management be enhanced. Clearly, if systems and procedures could be developed to identify and either screen or rehabilitate the relatively few drivers that account for the greatest risk in trucking, the potential exists for a large positive impact in the trucking industry.

## HOURS-OF-SERVICE VIOLATIONS

As found by Wylie *et al.* (1996), there were relatively few instances (about 2.2 percent) of "extreme drowsiness." Most of these instances were experienced by single drivers, and there was a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive. Thus, it appears to be the combination of long driving times and multiple days that provide the greatest concern. Several results point to the presence of cumulative fatigue; thus, the length of shifts in the later stages of a trip must be carefully considered.

The hours beyond the regulation (i.e., greater than 10 hours of driving in one shift) did not show an increase in critical incidents or driver errors. In fact, there was a substantial decrease in the rate of critical incidents during some of the more extreme violations. However, one should exercise great caution when interpreting these results to mean that the hours-of-service should be expanded. For example, it seems likely that the drivers were making a point to drive more carefully and cautiously *because* they were operating outside of the regulation and did not want to get stopped by law enforcement officials. Alternatively, they may have only risked driving outside of the regulations because they felt alert and knew that they could continue to drive safely. Expanding the permissible driving hours could then reduce safety by driver decision-making with respect to driving longer hours. That is, drivers may not compensate by driving more safely or only when very alert during long drives if the long drives are *legal* in the first place.

Overall, Time of Day was a very strong contributing factor for driving fatigue. This result is not unexpected given the demonstrated powerful effects of circadian rhythms. On average, the highest Observer Ratings of Drowsiness occurred between 12 midnight and 5 am. However, Time of Day also had a major effect upon the probability of a critical incident, but not as one would hypothesize based upon the finding above. The most critical incidents and driver errors occurred in the late afternoon/early evening hours. In contrast, very few incidents/errors occurred in the late night/early morning hours even when Time of Day was corrected for exposure. It is apparent that the presence of other traffic has a much larger affect on crash risk than does the presence of fatigue overall. This finding has important implications with regard to any consideration to limit truck driving to certain hours of the day. That is, while there is a clear fatigue effect due to Time of Day, any control that would force truck drivers to drive more during daylight hours could *increase* crashes instead of reduce them.

## IMPLICATIONS FOR SLEEPER BERTH DESIGN

There were a number of findings as part of this study that indicated that the quality and depth of sleep was worse on the road, particularly for team drivers. Team drivers have significantly more sleep disturbances than do single drivers. When the environmental factors were considered, it was found that many of the sleep disturbances that occurred for single drivers could not be attributed to an environmental factor. For team drivers, who sleep while the vehicle is in motion, factors such as vibration and noise affected their sleep. Lighting and temperature aspects of the environment did not appear to be much of a factor.

These findings suggest that while the vehicle was in motion, the noise and motion environment in the sleeper berth degraded the drivers' sleep. This finding has design implications for sleeper berths and indicates that, when the truck is in motion, greater attention should be paid to reducing the amount of vibration and noise that invade the sleeper berth. In particular, more effective noise abatement between the cab and the sleeper berth could improve sleep quality, perhaps relatively inexpensively. Improvement in the vibration/motion environment is a much more difficult problem, but also has potential to improve sleep if practical.

## RECOMMENDATIONS FOR FUTURE RESEARCH

Based upon the above conclusions, the following additional research activities are recommended.

### A Larger-Scale, More General, Naturalistic Study of Long-Haul Trucking

As described throughout this report, this study provided many useful findings in regard to long-haul trucking. The study used innovative, naturalistic data collection techniques that proved very successful in their implementation. Technology has now advanced to the point where a larger scale naturalistic study could be undertaken to provide even more answers to questions about trucking operations both related to, and in addition to, the fatigue issue.

### Investigations into Innovative Methods for Identifying, Screening, Training, and/or Rehabilitating Drivers Who Pose the Greatest Risk to the Driving Public

As this and other studies have shown, perhaps the single greatest possible trucking safety benefit could be gained by effectively removing or rehabilitating the relatively few drivers who constitute the majority of the safety risk. There are a number of innovative ways that a program might accomplish this activity, including:

- On-board, driver-monitoring systems for novice or trainee drivers to instill correct behavior and perhaps provide a screening criterion.
- Education and training programs to teach drivers and dispatchers about the risk factors associated with fatigue over a shift and day of drive.
- Education of drivers and dispatchers on the importance of sleep hygiene (i.e., coming to work well rested).

- Methods to help drivers self-identify and avoid fatigue, specifically tailored for both team and single drivers.

### Research to Investigate Hours-of-Service Alternatives and Their Effect on Driver Alertness and Driving Performance

Such research should include comprehensive investigations of all of the factors that would influence either a potentially positive or negative safety impact of a change in the regulations, including:

- Longer hours for shorter trips or for days early in a trip.
- Improved enforcement methods.
- Longer trips allowed in combination with improved enforcement tools such as electronic logbooks.
- Longer shift and hour-per-day allowances for team drivers.

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# APPENDIX A: FORMS AND SURVEYS

## A.1. INFORMED CONSENT FORM

## VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

### *Informed Consent for Participants of Investigative Projects*

**TITLE OF THE PROJECT:** IMPACT OF SLEEPER BERTH USAGE ON LONG-HAUL DRIVER FATIGUE

**INVESTIGATORS:** THOMAS DINGUS, JOHN CASALI, VICKI NEALE, GARY ROBINSON, & STEVEN BELZ

### I. THE PURPOSE OF THE RESEARCH

The purpose of this research is to evaluate the impact of sleeper berth usage on long-haul commercial driver fatigue and to assess the role of sleep quality and quantity in relation to driving performance and safety. This will be determined by collecting on-road behavior and performance data from long-haul drivers during their workday.

### II. PROCEDURES

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

1. Read and sign this Informed Consent Form *(if you agree to participate).*
2. Consent to a Driving Record Check.
3. Wear, for the length of your participation, a sleep-monitoring device.
4. Complete a 'Once-a-Day' survey daily.
5. Complete a 'Wake-up' survey after each and every period of sleep.
6. Participate in a training session in which you will learn about specific features of the experimental vehicle and other experimental apparatus.

The experiment will last for the period of your scheduled haul. It is important for you to understand that we are collecting data from many long-haul 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:

1. The normal risk of an accident associated with driving a truck as you usually do.

2. The slight additional risk of an accident that might possibly occur while pressing a button to indicate that a critical incident has occurred.

3. 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:

1. Drivers will be trained on how to operate the critical incident button.

2. 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.

3. None of the data collection equipment interferes with any part of the driver's normal field of view.

4. The addition of the data collection systems to the experimental vehicle in no way affects the operating or handling characteristics of the experimental vehicle.

## 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 the long-haul trucking industry, 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, cameras will be videotaping various scenes associated with the driving task. This will periodically include a view looking from the front of the vehicle back toward you as well as 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. Tom Dingus and Dr. John Casali, the Principle Investigators for the project. Dr. Vicki Neale, project manager, Dr. Gary Robinson, senior research associate, and Mr. Steve Belz, 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)) and is intended to protect your privacy. You should take notice of this certificate and read it carefully.

## VI. COMPENSATION

You will be paid for participating in this study at the rate of $0.05 per mile driven in the Center's tractor. You will also be paid $10.00 for each day of home-sleep data collected. In addition, you will be paid a "bonus" of $100.00 for using the sleep monitoring systems and completing all required paperwork. You will be paid at the end of your voluntary participation in this study for the portion of the experiment that you complete. Payment will be made to you in the form of a check that will be mailed to you by Virginia Tech.

## 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 payment. 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. RESPONSIBILITY FOR INSURANCE

The Center for Transportation Research shall insure the tractor. The trailer and its respective contents shall be insured against collision and other incident while the trailer is attached to the tractor. Once unhitched, insurance for the trailer and its contents becomes the responsibility of the owner. Further, the Center for Transportation Research is limited to collision and the like, insurance protecting against stolen, vandalized, damaged, or spoiled goods are the responsibility of the driver or driver's employer.

## X. SUBJECT'S RESPONSIBILITIES

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

1. To adhere to all laws regarding operation of a class 8 tractor including those pertaining to alcohol and drug use,
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.

## XI. 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:

| | |
|---|---|
| Thomas A. Dingus, Principle Investigator | (540) 231-8831 |
| **John G. Casali, Co-Principle Investigator** | **(540) 231-6656** |
| Vicki L. Neale, Project Manager | (540) 231-5578 |
| Gary Robinson, Senior Research Associate | (540) 231-2680 |
| Steven M. Belz, Graduate Research Assistant | (540) 231-6656 |
| H. T. Hurd, Director of Sponsored Programs | (540) 231-528 |

## A.2. GENERAL INFORMATION QUESTIONNAIRE

### GENERAL SURVEY

**OFFICE USE ONLY**

***Participant Identification:* ________**
***Single / Team – 1 / 2***

**PERSONAL**

1. **Birth Date:** ______ / ______ / ______ (Month / Day / Year)

2. **Gender**: ☐ Male
☐ Female

3. **Street Address:** ____________________________________________________

4. **City:** ____________________

5. **Zip Code:** ____________________

6. **Phone Number:** ____________________ (Home) – Leave Message? ☐ Yes ☐ No
____________________ (Work) – Leave Message? ☐ Yes ☐ No
____________________ (Wireless / Cellular) – Leave Message? ☐ Yes ☐ No

7. **Union:** ? Yes ? No

**DRIVING EXPERIENCE**

1. **License Type:** ☐ Class A

2. Endorsements:
☐ Air Brake
☐ Hazardous Materials
☐ Tanker
☐ Double / Triple Trailers
☐ Passenger
☐ Other: ________________________

3. Which state issued your license? ____________________

4. What is your license number? _______________________

5. How long have you held a Class A commercial driver's license? ____________________

6. What types of cargo do you have experience hauling (check all that apply)?
☐ Dry Goods / Box
☐ Refrigerated
☐ Tanker
☐ Hazardous Materials
☐ Flatbed
☐ Flatbed - oversize
☐ Other: ___________________

7. On average, what is the length of your average trip? ____________________ Miles

____________________ Days

8. On average, how long are your breaks between trips? ____________________ Days

9. When was the last time you were on the road for at least six consecutive days?

10. Do you drive a regular (same trip, same few trips) or irregular schedule?
☐ Regular
☐ Irregular

11. What percentage of the nights that you are on the road do you spend in the sleeper berth?

12. When did you first start using a sleeper berth?

13. How often do you load or unload your own cargo?
☐ Always
☐ Frequently
☐ Sometimes (about half the time)
☐ Occasionally
☐ Never

14. What types of cargo do you have experience loading / unloading (check all that apply)?

☐ Dry Goods / Box
☐ Refrigerated
☐ Tanker
☐ Hazardous Materials
☐ Flatbed
☐ Flatbed - oversize
☐ Other: ____________________

15. What type of tractor do you most frequently drive?

16. How long have you been driving as part of a team?

17. If you are currently driving as a part of a team, how long or how many trips have you driven with your current partner? ____________ years/months __________# of trips

**MEDICAL**

1. Do you have difficulty getting to sleep?

   ☐ No – please continue with the next question
   ☐ Yes – please answer the following question

   1A. How often do you experience difficulty?

   ☐ All of the Time
   ☐ Frequently
   ☐ Sometimes
   ☐ Infrequently
   ☐ Never

2. Do you frequently wake in the middle of a sleep period?

   ☐ No – please continue with the next question
   ☐ Yes – please answer the following questions

   2A. How many times do you wake each 'night' or sleep period? __________

   2B. How often do you experience difficulty getting back to sleep?

   ☐ All of the Time
   ☐ Frequently
   ☐ Sometimes
   ☐ Infrequently
   ☐ Never

3. Do you wake earlier than you would like or had planned?

   ☐ No – please continue with the next question
   ☐ Yes – please answer the following question

   3A. How often do you experience difficulty getting back to sleep?

   ☐ All of the Time
   ☐ Frequently
   ☐ Sometimes
   ☐ Infrequently
   ☐ Never

4. What medication are you currently taking (include all prescription and non-prescription medication, symptoms you are taking the medications for, and doses)?

5. Have you ever been diagnosed with a sleep disorder? ☐ No
☐ Yes (Please list and describe)

6. Have you ever seen a doctor about not being able to fall asleep or stay asleep?

☐ No – please continue with the next question
☐ Yes - please answer the following question

6A. What did your doctor tell you was the reason for your sleep difficulties?

7. Please place a check mark next to any of the following that you have experienced, on a regular basis, related to your sleep? NOTE: We are asking if you have experienced these but also if anyone else (such as a spouse or partner) has reported them to you.

_____ Snoring that disturbs others
_____ Choking
_____ Stopped breathing
_____ Tightness in chest
_____ Sputtering / gagging
_____ Difficulty breathing
_____ Difficulty concentrating
_____ Irresistible urge to sleep during the day
_____ Gasping
_____ Morning headaches
_____ Congested nose or allergy
_____ Waking with coughing fits
_____ Throat dry when wake up
_____ Forgetfulness
_____ Sleepwalking
_____ Sleeptalking
_____ Severe recurrent nightmares or night terrors
_____ Grinding teeth
_____ Kicking or twitching legs
_____ Acting out your dreams
_____ Loss of muscle tone when experiencing strong emotion (while awake)

8. Have you been diagnosed with any of the following? If so, please place a checkmark next to the appropriate description and describe below.

_____ High Blood Pressure
_____ Liver Problems
_____ Kidney Problems
_____ Thyroid Problems
_____ Stroke
_____ Heart Attack
_____ Congestive Heart Failure
_____ Seizures
_____ Serious head injury (lost consciousness)
_____ Condition requiring brain surgery
_____ Any major psychiatric condition (e.g. depression, manic depress., PTSD, schizophrenia)
_____ Alcoholism or drug addiction
_____ Chronic fatigue syndrome
_____ Fibromyaligia
_____ Any chronic pain that interferes with sleep
_____ Heart Arrhythmia (slow or fast heart rate, arterial fibrillation?)

9. Have you ever taken any of the following medications? If so, please place a checkmark next to the appropriate medication and describe diagnosis / dosage / duration of prescription below.

**SLEEP MEDICATION**
_____ Ambien
_____ Klonopin
_____ Restoril
_____ Halcion
_____ Dalmane
_____ Seconal
_____ Nembutal,
_____ Seconal,
_____ Antihistamines for sleep (e.g., Benedryl, Vistaril, Unisom)
_____ Herbal Relaxants (e.g., Kava)

**ANXIOLYTICS**
_____ Klonopin
_____ Xanax
_____ Buspar
_____ Valium
_____ Ativan
_____ Serax
_____ Librium

**PSYCHOSTIMULANTS**
_____ Ritalin
_____ Dexedrine
_____ Adderall
_____ Cylert
_____ Methamphetamine
_____ Ephedrine
_____ Cocaine
_____ Sudafed
_____ Pseudoephedrine
_____ Herbal Stimulants (e.g., Ma Huang)

**ANTIDEPRESSANTS**
_____ Prozac
_____ Paxil
_____ Zoloft
_____ Luvox
_____ Celexa
_____ Elavil
_____ Pamelor
_____ Doxepin
_____ Amitryptiline
_____ Nortryptiline
_____ Desipramine
_____ Imipramine
_____ St. John's Wort

**MOOD STABILIZERS**
_____ Lithium
_____ Depakote
_____ Depakene
_____ Tegretol
_____ Neurontin
_____ Lamictal

**ANTIPSYCHOTICS**
_____ Risperdal
_____ Zyprexa
_____ Clozaril
_____ Seroquel
_____ Haldol
_____ Trilafon
_____ Thorazine
_____ Stelazine
_____ Mellaril

## A.3. ONCE-A-DAY SURVEY

## ‘ONCE-A-DAY’ SURVEY

**OFFICE USE ONLY**

***Participant Identification:*** ________
***Single / Team – 1 / 2***

**DATE:** ________________________________

**TIME:** ______________________ **AM / PM EST**

*This is the "once-a-day survey". 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 navigating to your destination or finding a place to stop.

0 100
Very Low 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.

0 100
Very Low 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?

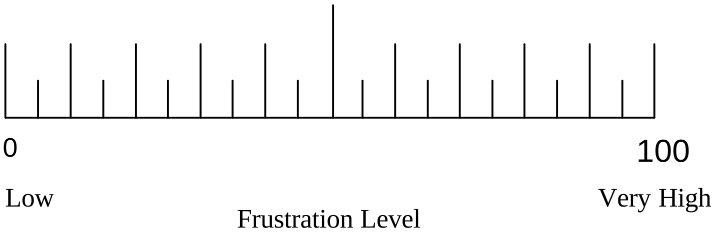
0 100
Very Low Very High
Degree of Success

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?

0 100
Very Low Very High
Effort Level

*Please continue the survey on the back of this sheet.*

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



7. What, if anything, caused you stress today? (select as many as apply by checking the appropriate boxes)

☐ Time pressure
☐ Weather-related
☐ Family stress
☐ Customer-related
☐ Traffic-related
☐ Dispatcher
☐ Partner
☐ Other: ___________________________
☐ None

8. Did you unload/load your trailer today?

☐ NO – please continue with the next question
☐ YES – please answer the following questions

8A. What kind of load was it?

☐ Partial load
☐ Full load

8B. How long did it take you to load or unload? (in hours and minutes)

_________ HOURS ________ MINUTES

8C. How did the loading/unloading affect you, did you feel?

☐ Fatigued
☐ Invigorated
☐ Other: ____________________________

9. Did you purposely stop the truck to exercise today?

☐ NO
☐ YES – please answer the following question

9A. What type of exercise did you get? (check as many as apply)

☐ Leisurely walk
☐ Brisk walk
☐ Jog
☐ Run
☐ Strength building
☐ Other: _____________________________

*Thank you for completing the "once a day" survey. Please remember to complete the "wake up survey" after each period of sleep.*

## A.4. WAKE-UP SURVEY

## ‘WAKE-UP’ SURVEY

**OFFICE USE ONLY**

***Participant Identification: ________***
***Single / Team – 1 / 2***

**DATE:** ______________________________

**TIME:** ___________________________ **AM / PM EST**

*Please remember to rate your sleepiness on the Karolinska Scale before you proceed with the wake up survey. This is the wake up survey, please indicate your quality of sleep by answering the following questions:*

1. At what time did you settle down to sleep?___________________________AM / PM EST

2. What time did you fall asleep? ______________________________AM / PM EST

3. What time did you finally wake? ____________________________AM / PM EST

4. What time did you finally get up? ___________________________AM / PM EST

5. Was your sleep...(select one of the following by checking appropriate box)

   ☐ 1. Very light
   ☐ 2. Light
   ☐ 3. Fairly Light
   ☐ 4. Deep average
   ☐ 5. Fairly deep
   ☐ 6. Deep
   ☐ 7. Very deep

6. How many times did you wake up? (select one of the following by checking appropriate box)

   ☐ 0. Not at all
   ☐ 1. Once
   ☐ 2. Twice
   ☐ 3. Three times
   ☐ 4. Four times
   ☐ 5. Five times
   ☐ 6. Six times
   ☐ 7. More than six times

7. How much sleep did you have? (in hours and minutes)

   ___________ HOURS ___________ MINUTES

8. How well did you sleep? (select one of the following by checking appropriate box)

   ☐ 1. Very badly
   ☐ 2. Badly
   ☐ 3. Fairly badly
   ☐ 4. Fairly well
   ☐ 5. Well
   ☐ 6. Very well

*Please continue the survey on the back of this sheet.*

9. Of the options presented below, what if anything disturbed your sleep? (select as many as apply by checking the appropriate boxes)

☐ The heat
☐ The cold/draft
☐ The humidity
☐ The lack of ventilation
☐ Condensation
☐ Illumination
☐ Vibration
☐ Noise from the radio
☐ Noise from outside
☐ Trailer noise
☐ Illness
☐ Stimulants (caffeine etc)
☐ Stress due to time pressure
☐ Stress due to the weather
☐ Stress due to family
☐ Noise from loading/unloading
☐ Noise from the telephone
☐ Noise from the weather (e.g., thunder)
☐ Noise made by your driving partner
☐ Customer-related stress
☐ Traffic-related stress
☐ Dispatcher related stress
☐ Stress due to partner's driving
☐ Alcohol
☐ Coffee/caffeine
☐ Snoring
☐ Breathing disturbances
☐ Truck motion
☐ Other: ____________________________
☐ None

10. How clear headed did you feel after getting up? (select one of the following by checking appropriate box)

☐ 1. Still very drowsy
☐ 2. Still moderately drowsy
☐ 3. Still slightly drowsy
☐ 4. Fairly clear headed
☐ 5. Alert
☐ 6. Very Alert

11. How satisfied were you with the sleep you just had? (select one of the following by checking appropriate box)

☐ 1. Very unsatisfied
☐ 2. Moderately unsatisfied
☐ 3. Slightly unsatisfied
☐ 4. Fairly satisfied
☐ 5. Completely satisfied

12. Were you troubled by waking prematurely, being unable to get off to sleep again?

☐ YES
☐ NO

13. How much difficulty did you have in getting off to sleep (falling asleep)? (select one of the following by checking appropriate box)

☐ 1. None or very little
☐ 2. Some
☐ 3. A lot
☐ 4. Extreme difficulty

14. How long did it take you to fall asleep? (in hours and minutes)

___________ HOURS ___________ MINUTES

*Thank you for completing the "wake up survey". Please remember to complete the "once a day" survey later today.*

## A.5. ACTIVITY LOG

## HOME SLEEP - KAROLINSKA

**OFFICE USE ONLY**

Participant Identification: ________
Single / Team – 1 / 2

Please complete this form ***prior to going to sleep*** ***and*** ***upon waking***.

1. Please check one:

   ☐ Going to Sleep
   ☐ Waking Up

2. Date: _______________

3. Time: _______________ AM / PM

4. Please complete the following scale

### KAROLINSKA SLEEPINESS SCALE

Here are some descriptors about how alert or sleepy you might be feeling right now.

Please read them carefully and the **CIRCLE** the number that best corresponds to the statement describing how you feel at the moment.

| | |
|---|---|
| 1 | Extremely alert |
| 2 | |
| 3 | Alert |
| 4 | |
| 5 | Neither alert nor sleepy |
| 6 | |
| 7 | Sleepy – but no difficulty remaining awake |
| 8 | |
| 9 | Extremely sleepy, fighting sleep |

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## APPENDIX B: OBJECTIVE 1 ANOVA TABLES

Table B-1. ANOVA Summary Table for Subjective Sleep Time (Question 7), Collapsed Across Days

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SUBJECTIVE SLEEP TIME** | | | | | |
| **DrivType** | **1** | **33.1173** | **33.1173** | **5.12** | **0.0355** |
| Location | 1 | 1.8617 | 1.8617 | 0.33 | 0.5727 |
| DrivType*Location | 1 | 4.8982 | 4.8982 | 0.87 | 0.3635 |
| Subj(DrivType) | 19 | 122.8410 | 6.4653 | | |
| Subj*Location(DrivType) | 19 | 107.3638 | 5.6507 | | |

* **Bold** indicates significance at *p*<0.05

Table B-2. ANOVA Summary Table for Subjective Sleep Time (Question 7), Day By Day

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SUBJECTIVE SLEEP TIME** | | | | | |
| **DrivType** | **1** | **51.1929** | **51.1929** | **6.55** | **0.0280** |
| Loc_Day | 11 | 43.7290 | 3.9754 | 0.78 | 0.6583 |
| DrivType*Loc_Day | 11 | 35.4747 | 3.2250 | 0.63 | 0.7981 |
| Subj(DrivType) | 19 | 171.9399 | 9.0495 | | |
| Subj*Loc_Day(DrivType) | 174 | 885.1471 | 5.0871 | | |

* **Bold** indicates significance at *p*<0.05

Table B-3. ANOVA Summary Table for REM Percent for Driver Type and Location (Home vs. OTR)

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>REM PERCENT** | | | | | |
| **Location** | **1** | **4013.8640** | **4013.8640** | **9.48** | **0.0082** |
| DrivType *Location | 1 | 1067.5496 | 1067.5496 | 2.52 | 0.1346 |
| DrivType | 1 | 923.5079 | 923.5079 | 3.41 | 0.0784 |
| Subj (DrivType) | 22 | 5962.3880 | 271.0176 | | |
| Subj*Location(DrivType) | 14 | 5927.3796 | 423.3843 | | |

* **Bold** indicates significance at *p*<0.05

Table B-4. ANOVA Summary Table for Subjective Sleep Quality (Question 8), Collapsed Across Days

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | **$p$ value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SLEEP QUALITY** | | | | | |
| DrivType | 1 | 0.6787 | 0.6787 | 0.24 | 0.6283 |
| **Location** | **1** | **7.5702** | **7.5702** | **4.46** | **0.0481** |
| DrivType*Location | 1 | 0.8870 | 0.8870 | 0.52 | 0.4783 |
| Subj(DrivType) | 19 | 53.2606 | 2.8031 | | |
| Subj*Location(DrivType) | 19 | 32.2185 | 1.6957 | | |

* **Bold** indicates significance at $p<0.05$

Table B-5. ANOVA Summary Table for Subjective Sleep Quality (Question 8), Day by Day

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | **$p$ value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SLEEP QUALITY** | | | | | |
| DrivType | 1 | 0.7640 | 0.7640 | 0.25 | 0.6211 |
| Loc_Day | 11 | 12.8052 | 1.1641 | 1.20 | 0.2918 |
| DrivType*Loc_Day | 11 | 5.0782 | 0.4617 | 0.47 | 0.9171 |
| Subj(DrivType) | 19 | 57.4832 | 3.0254 | | |
| Subj*Loc_Day(DrivType) | 180 | 175.0376 | 0.9724 | | |

* **Bold** indicates significance at $p<0.05$

Table B-6. ANOVA Summary Table for Nightcap Awakenings for Driver Type and Location

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | **$p$ value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>NUMBER OF AWAKENINGS** | | | | | |
| **Location** | 1 | 1.4942 | 1.4942 | 0.94 | 0.3596 |
| **DrivType*Location** | **1** | **22.1312** | **22.1312** | **13.99** | **0.0057** |
| **DrivType** | **1** | **42.4649** | **42.4649** | **5.86** | **0.0257** |
| Subj (DrivType) | 19 | 137.7813 | 7.2516 | | |
| Subj*Location (DrivType) | 8 | 12.6549 | 1.5819 | | |

* **Bold** indicates significance at $p<0.05$

Table B-7. ANOVA Summary Table for Location and Number of Awakenings per Average Sleep Length (Question 6)

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: MEAN NUMBER OF AWAKENINGS** | | | | | |
| **Location** | **1** | **0.0158** | **0.0158** | **17.75** | **0.0029** |
| **DrivType*Location** | **1** | **0.0231** | **0.0231** | **25.94** | **0.0009** |
| **DrivType** | **1** | **0.0142** | **0.0142** | **6.58** | **0.0190** |
| Subj (DrivType) | 19 | 0.0411 | 0.0022 | | |
| Subj*Location(DrivType) | 8 | 0.0071 | 0.0009 | | |

* **Bold** indicates significance at *p*<0.05

Table B-8. ANOVA Summary Table for Reported Number of Awakenings (Question 6), Collapsed Across Days

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: SUBJECTIVE NUMBER OF AWAKENINGS** | | | | | |
| DrivType | 1 | 3.7612 | 3.7115 | 0.93 | 0.3467 |
| Location | 1 | 0.0340 | 0.0340 | 0.02 | 0.8887 |
| DrivType*Location | 1 | 1.9486 | 1.9489 | 1.15 | 0.2962 |
| Subj(DrivType) | 19 | 75.7467 | 3.9867 | | |
| Subj*Location(DrivType) | 19 | 32.0856 | 1.6887 | | |

* **Bold** indicates significance at *p*<0.05

Table B-9. ANOVA Summary Table of Mean Awakenings per minutes of sleep for Driver Type and Location

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: NUMBER OF AWAKENINGS PER MINUTES OF SLEEP** | | | | | |
| DrivType | 1 | 0.0000 | 0.0000 | 0.44 | 0.5169 |
| Location | 1 | 0.0000 | 0.0000 | 1.34 | 0.2608 |
| DrivType*Location | 1 | 0.0001 | 0.0001 | 2.64 | 0.1208 |
| Subj(DrivType) | 19 | 0.0008 | 0.0000 | | |
| Subj*Location(DrivType) | 19 | 0.0004 | 0.0000 | | |

* **Bold** indicates significance at *p*<0.05

Table B-10. ANOVA Summary Table for Reported Number of Awakenings (Question 6), Day By Day

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SUBJECTIVE NUMBER OF AWAKENINGS** | | | | | |
| DrivType | 1 | 8.6439 | 8.6439 | 1.83 | 0.1917 |
| Loc_Day | 11 | 12.4866 | 1.1351 | 1.20 | 0.2922 |
| **DrivType*Loc_Day** | **11** | **20.4307** | **1.8573** | **1.96** | **0.0350** |
| Subj(DrivType) | 19 | 89.6056 | 4.7161 | | |
| Subj*Loc_Day(DrivType) | 179 | 169.7893 | 0.9485 | | |

* **Bold** indicates significance at $p<0.05$

Table B-11. ANOVA Summary Table of Nightcap Sleep Latency for Driver Type and Location

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SLEEP LATENCY** | | | | | |
| DrivType | 1 | 13021.7156 | 13021.7156 | 2.62 | 0.1296 |
| DrivType*Location | 1 | 12487.4089 | 12487.4089 | 2.51 | 0.1370 |
| DrivType | 1 | 1156.7365 | 1156.7365 | 0.27 | 0.6087 |
| Subj(DrivType) | 19 | 81129.6124 | 4269.9796 | | |
| Subj*Location(DrivType) | 13 | 64633.9869 | 4971.8452 | | |

* **Bold** indicates significance at $p<0.05$

Table B-12. ANOVA Summary Table for Time to Fall Asleep (Question 14), Collapsed Across Days

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>TIME TO FALL ASLEEP** | | | | | |
| DrivType | 1 | 0.4371 | 0.4371 | 1.54 | 0.2302 |
| **Location** | **1** | **0.2829** | **0.2827** | **7.81** | **0.0116** |
| DrivType*Location | 1 | 0.0293 | 0.0263 | 0.73 | 0.4051 |
| Subj(DrivType) | 19 | 5.4041 | 0.2844 | | |
| Subj*Location(DrivType) | 19 | 0.6885 | 0.0362 | | |

* **Bold** indicates significance at $p<0.05$

Table B-13. ANOVA Summary Table for Time to Fall Asleep (Question 14), Day By Day

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:<br>TIME TO FALL ASLEEP** | | | | | |
| DrivType | 1 | 0.7918 | 0.7918 | 1.87 | 0.1876 |
| **Loc_Day** | **11** | **1.6099** | **0.1464** | **2.01** | **0.0299** |
| DrivType*Loc_Day | 11 | 0.7470 | 0.0679 | 0.93 | 0.5111 |
| Subj(DrivType) | 19 | 8.0503 | 0.4237 | | |
| Subj*Loc_Day(DrivType) | 180 | 13.1183 | 0.0729 | | |

* **Bold** indicates significance at $p<0.05$

Table B-14. ANOVA Summary Table for Depth of Sleep (Question 5), Collapsed Across Days

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable:**<br>**DEPTH OF SLEEP** | | | | | |
| DrivType | 1 | 1.9604 | 1.9604 | 0.29 | 0.5973 |
| Location | 1 | 8.1203 | 8.1203 | 2.55 | 0.1266 |
| DrivType*Location | 1 | 0.4035 | 0.4035 | 0.13 | 0.7256 |
| Subj(DrivType) | 19 | 128.9914 | 4.7890 | | |
| Subj*Location(DrivType) | 19 | 60.4293 | 3.1805 | | |

* **Bold** indicates significance at $p<0.05$

Table B-15. ANOVA Summary Table for Depth of Sleep (Question 5), Day By Day

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable:**<br>**DEPTH OF SLEEP** | | | | | |
| DrivType | 1 | 0.2999 | 0.2999 | 0.04 | 0.8512 |
| **Loc_Day** | **11** | **34.9400** | **3.1764** | **2.00** | **0.0310** |
| DrivType*Loc_Day | 11 | 10.6433 | 0.9676 | 0.61 | 0.8203 |
| Subj (DrivType) | 19 | 157.5917 | 8.2943 | | |
| Subj*Loc_Day(DrivType) | 180 | 286.3089 | 1.5906 | | |

* **Bold** indicates significance at $p<0.05$

Table B-16. ANOVA Summary Table for Alertness Upon Awakening (Question 10), Collapsed Across Days

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable:**<br>**AWAKENING ALERTNESS** | | | | | |
| DrivType | 1 | 0.0176 | 0.0176 | 0.00 | 0.9459 |
| Location | 1 | 0.2332 | 0.2332 | 0.16 | 0.6963 |
| DrivType*Location | 1 | 0.5224 | 0.5224 | 0.35 | 0.5601 |
| Subj(DrivType) | 19 | 70.6296 | 3.7173 | | |
| Subj*Location(DrivType) | 19 | 28.2125 | 1.4849 | | |

* **Bold** indicates significance at $p<0.05$

Table B-17. ANOVA Summary Table for Alertness Upon Awakening (Question 10), Day by Day

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable:**<br>**AWAKENING ALERTNESS** | | | | | |
| DrivType | 1 | 0.5351 | 0.5351 | 0.11 | 0.7438 |
| Loc_Day | 11 | 5.3211 | 0.4837 | 0.41 | 0.9504 |
| DrivType*Loc_Day | 11 | 6.5587 | 0.5962 | 0.51 | 0.8981 |
| Subj(DrivType) | 19 | 92.4341 | 4.8650 | | |
| Subj*Loc_Day(DrivType) | 180 | 212.4041 | 1.1800 | | |

* **Bold** indicates significance at $p<0.05$

Table B-18. ANOVA Summary Table for Sleep Satisfaction (Question 11), Collapsed Across Days

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:**<br>**SLEEP SATISFACTION** | | | | | |
| DrivType | 1 | 0.8409 | 0.8409 | 0.57 | 0.4585 |
| Location | 1 | 0.8674 | 0.9674 | 0.64 | 0.4332 |
| DrivType*Location | 1 | 0.3173 | 0.3173 | 0.23 | 0.6337 |
| Subj(DrivType) | 19 | 27.9044 | 1.4687 | | |
| Subj*Location(DrivType) | 19 | 25.7017 | 1.3527 | | |

* **Bold** indicates significance at $p$<0.05

Table B-19. ANOVA Summary Table for Sleep Satisfaction (Question 11), Day by Day

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:**<br>**SLEEP EFFICIENCY** | | | | | |
| Location | 1 | 0.3345 | 0.3345 | 0.15 | 0.7038 |
| DrivType*Location | 11 | 9.6755 | 0.8796 | 1.80 | 0.6409 |
| DrivType | 11 | 8.3968 | 0.7633 | 0.69 | 0.7438 |
| Subj(DrivType) | 19 | 42.6542 | 2.2450 | | |
| Subj*Loc_Day(DrivType) | 179 | 197.0481 | 1.1008 | | |

* **Bold** indicates significance at $p$<0.05

Table B-20. ANOVA Summary Table for Sleep Efficiency for Driver Type and Location

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:**<br>**SLEEP EFFICIENCY** | | | | | |
| **Location** | **1** | **1.3302** | **1.3302** | **6.85** | **0.0213** |
| **DrivType*Location** | **1** | **1.2448** | **1.2448** | **6.41** | **0.0250** |
| DrivType | 1 | 0.1003 | 0.1003 | 0.67 | 0.4238 |
| Subj(DrivType) | 19 | 2.8529 | 0.1502 | | |
| Subj*Location (DrivType) | 13 | 2.5246 | 0.1942 | | |

* **Bold** indicates significance at $p$<0.05

## APPENDIX C: OBJECTIVE 3 ANOVA TABLES

Table C-1. ANOVA Summary Table for Driver Type, Hour of day, and Length of Trip

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: ORD** | | | | | |
| DriverType | 1 | 0.0216 | 0.0216 | .36 | 0.5522 |
| Subj (DriverType) | 25 | 1.4849 | 0.0594 | | |
| Length of Trip | 7 | 0.1040 | 0.0149 | 0.82 | 0.5706 |
| DrivType*Length of Trip | 7 | 0.0571 | 0.0082 | 0.45 | 0.8655 |
| Subj*Length of Trip(DriverType) | 76 | 1.3702 | 0.0180 | | |
| **HourOfDay** | **23** | **1.3113** | **0.0570** | **4.57** | **<.0001** |
| DriverType*HourOfDay | 23 | 0.2049 | 0.0089 | 0.71 | 0.8310 |
| Subj*HourOfDay(DriverType) | 292 | 3.6431 | 0.0125 | | |
| HourOfDay*Length of Trip | 143 | 1.2805 | 0.0090 | 0.94 | 0.6276 |
| Driver Type*HourOfDay*Length of Trip | 83 | 0.0653 | 0.0079 | 0.82 | 0.7946 |
| Subj*HourOfDay *Length of Trip (Driver Type) | 59 | 0.5635 | 0.0096 | | |

*** Bold** indicates significance at $p<0.05$

Table C-2. ANOVA Summary Table for Driver Type, Hour of day, and Length of Trip

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: KAROLINSKA** | | | | | |
| **DriverType** | **1** | **113.7012** | **113.7012** | **5.42** | **0.0283** |
| Subj (DriverType) | 25 | 524.6059 | 20.9842 | | |
| Length of Trip | 7 | 7.1294 | 1.0185 | 0.33 | 0.9377 |
| DriverType*Length of Trip | 7 | 16.8160 | 2.4022 | 0.79 | 0.6010 |
| Subj*Length of Trip(DriverType) | 126 | 385.5404 | 3.0598 | | |
| **HourOfDay** | **23** | **125.9077** | **5.4742** | **3.40** | **<.0001** |
| DriverType*HourOfDay | 23 | 42.3524 | 1.8414 | 1.14 | 0.2953 |
| Subj*HourOfDay(DriverType) | 438 | 706.1307 | 1.6122 | | |
| HourOfDay*LengthOfTrip | 161 | 184.7986 | 1.1478 | 1.00 | 0.5090 |
| DriverType*HourOfDay*LengthOfTrip | 137 | 194.4819 | 1.4196 | 1.23 | 0.0736 |
| Subj*HourOfDay *Length of Trip(DriverType) | 292 | 336.8430 | 1.1536 | | |

*** Bold** indicates significance at $p<0.05$

Table C-3. ANOVA Summary Table for Driver Type and Shift

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: LENGTH OF SHIFT** | | | | | |
| DriverType | 1 | 43817.466 | 43817.466 | 1.07 | 0.3109 |
| Subj(DriverType) | 25 | 1024155.652 | 40966.226 | | |
| Shift | 3 | 79863.726 | 26621.242 | 0.91 | 0.4443 |
| **Shift*DriverType** | **3** | **259408.192** | **86469.397** | **2.94** | **0.0406** |
| Subj* Shift(DriverType) | 58 | 1706000.894 | 29413.809 | | |

* **Bold** indicates significance at *p*<0.05

Table C-4. ANOVA Summary Table for Driver Type and Shift

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: ORD** | | | | | |
| DriverType | 1 | 0.0006 | 0.0006 | 0.01 | 0.9112 |
| Subj(DriverType) | 25 | 1.1723 | 0.0469 | | |
| Shift | 3 | 0.0815 | 0.0272 | 2.51 | 0.0697 |
| Subj* Shift(DriverType) | 50 | 0.5421 | 0.0108 | | |
| Shift*DriverType | 3 | 0.0086 | 0.0029 | 0.27 | 0.8497 |

* **Bold** indicates significance at *p*<0.05

Table C-5. ANOVA Summary Table for Driver Type and Shift

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: KAROLINSKA** | | | | | |
| DriverType | 1 | 16.3402 | 16.3402 | 3.09 | 0.0912 |
| Subj(DriverType) | 25 | 132.4024 | 5.2960 | | |
| Shift | 3 | 1.7915 | 0.5971 | 0.40 | 0.7532 |
| Subj* Shift(DriverType) | 56 | 83.5056 | 1.4912 | | |
| Shift*DriverType | 3 | 1.5015 | 0.5005 | 0.34 | 0.7996 |

* **Bold** indicates significance at *p*<0.05

Table C-6. ANOVA Summary Table for Shift by Length of Trip

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: Time Length** | | | | | |
| Length of Trip | 7 | 407548.8890 | 58221.2700 | 1.39 | 0.2128 |
| Subj | 26 | 204113.3870 | 78504.3610 | | |
| Subj*Length of Trip | 140 | 5850960.1080 | 41792.5720 | | |
| **Shift** | **3** | **361293.2450** | **120431.0820** | **4.95** | **0.0038** |
| Subj*Shift | 61 | 1483222.0110 | 24315.1150 | | |
| Length of Trip*Shift | 21 | 1028685.5540 | 48985.0260 | 1.38 | 0.1383 |
| Subj*Length of Trip*Shift | 124 | 4385685.2720 | 35368.4300 | | |

* **Bold** indicates significance at $p<0.05$

Table C-7. ANOVA Summary Table for Shift by Length of Trip

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: ORD** | | | | | |
| Length of Trip | 7 | 0.0491 | 0.0070 | 0.87 | 0.5300 |
| Subj | 26 | 0.9035 | 0.0347 | | |
| Subj*Length of Trip | 102 | 0.8190 | 0.0080 | | |
| **Shift** | **3** | **0.1012** | **0.0337** | **3.73** | **0.0170** |
| Subj*Shift | 50 | 0.4524 | 0.0090 | | |
| Length of Trip*Shift | 17 | 0.0766 | 0.0045 | 0.31 | 0.9943 |
| Subj*Length of Trip*Shift | 38 | 0.5558 | 0.0146 | | |

* **Bold** indicates significance at $p<0.05$

Table C-8. ANOVA Summary Table for Shift by Length of Trip

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: KAROLINSKA** | | | | | |
| Length of Trip | 7 | 5.8788 | 0.8398 | 0.49 | 0.8398 |
| Subj | 26 | 174.3608 | 6.7062 | | |
| Subj*Length of Trip | 135 | 230.811 | 1.7102 | | |
| Shift | 3 | 0.4672 | 0.1557 | 0.15 | 0.9285 |
| Subj*Shift | 59 | 60.7878 | 1.0303 | | |
| **Length of Trip*Shift** | **21** | **48.9144** | **2.3293** | **2.19** | **.0060** |
| Subj*Length of Trip*Shift | 87 | 92.3594 | 1.0616 | | |

* **Bold** indicates significance at $p<0.05$

Table C-9. ANOVA Summary Table for Shift by Hour by Shift

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: ORD** | | | | | |
| **Hour of Shift** | **15** | **0.3017** | **0.0201** | **2.08** | **0.0126** |
| Subj | 26 | 2.3481 | 0.0903 | | |
| Subj*Hour of Shift | 183 | 1.7691 | 0.0097 | | |
| Shift | 4 | 0.2691 | 0.0673 | 2.19 | 0.0814 |
| Subj*Hour of Shift*Shift | 167 | 1.3000 | 0.0078 | | |
| **Hour of Shift*Shift** | **31** | **0.4260** | **0.01374** | **1.77** | **0.0124** |
| Subj*Shift | 56 | 1.7177 | 0.0307 | | |

* **Bold** indicates significance at *p*<0.05

Table C-10. ANOVA Summary Table for Shift by Hour by Shift

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: KAROLINSKA** | | | | | |
| **Hour of Shift** | **23** | **59.5657** | **2.5898** | **1.87** | **0.0114** |
| Subj | 26 | 485.1530 | 18.6598 | | |
| Subj*Hour of Shift | 218 | 301.6419 | 1.3837 | | |
| Shift | 5 | 18.7487 | 3.7497 | 0.73 | 0.6067 |
| Subj*Hour of Shift*Shift | 246 | 316.1969 | 1.2854 | | |
| Hour of Shift*Shift | 36 | 51.5082 | 1.4308 | 1.11 | 0.3114 |
| Subj*Shift | 64 | 330.7145 | 5.1674 | | |

* **Bold** indicates significance at *p*<0.05

# APPENDIX D: OBJECTIVE 4 ANOVA TABLES

Table D-1. ANOVA Summary Table of Sleep Time by Driver Type and Maximum ORD

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: SUBJECTIVE SLEEP TIME** | | | | | |
| **DrivType** | **1** | **219283.8783** | **219283.8783** | **6.90** | **0.0154** |
| MaxORD | 4 | 94283.6168 | 23570.9042 | 1.13 | 0.3742 |
| DrivType*MaxORD | 3 | 63169.3734 | 21056.4578 | 1.01 | 0.4120 |
| Subj(DrivType) | 22 | 699321.1280 | 31787.3240 | | |
| Subj*MaxORD(DrivType) | 18 | 375917.4630 | 20884.3035 | | |

* **Bold** indicates significance at $p<0.05$

Table D-2. ANOVA Summary Table of Sleep Time by Driver Type and Median ORD

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: SUBJECTIVE SLEEP TIME** | | | | | |
| **DrivType** | **1** | **115005.5501** | **115005.5501** | **4.41** | **0.0475** |
| Med ORD | 2 | 1429.1841 | 714.5921 | 0.03 | 0.9659 |
| DrivType* Med ORD | 2 | 6435.2137 | 3217.6068 | 0.16 | 0.8575 |
| Subj(DrivType) | 22 | 574275.1208 | 26103.4146 | | |
| Subj* Med ORD (DrivType) | 7 | 143313.4191 | 20473.3456 | | |

* **Bold** indicates significance at $p<0.05$

Table D-3. ANOVA Summary Table of Sleep Time by Driver Type and Maximum Karolinska Rating

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: SUBJECTIVE SLEEP TIME** | | | | | |
| **DrivType** | **1** | **266464.2469** | **266464.2469** | **11.93** | **0.0021** |
| Max Kar | 2 | 7006.1293 | 3503.0646 | 0.27 | 0.7633 |
| DrivType* Max Kar | 2 | 13255.5847 | 6627.7923 | 0.52 | 0.6033 |
| Subj(DrivType) | 24 | 535979.9399 | 22332.4975 | | |
| Subj* Max Kar (DrivType) | 21 | 268842.1845 | 12802.0088 | | |

* **Bold** indicates significance at $p<0.05$

Table D-4. ANOVA Summary Table of Sleep Time by Driver Type and Median Karolinska Rating

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:**<br>**SUBJECTIVE SLEEP TIME** | | | | | |
| DrivType | 1 | 78946.2634 | 78946.2634 | 3.08 | 0.0926 |
| Med Kar | 2 | 25738.9914 | 12869.4957 | 1.89 | 0.2938 |
| DrivType* Med Kar | 1 | 5337.7766 | 5337.7766 | 0.79 | 0.4407 |
| Subj(DrivType) | 23 | 589452.9360 | 25628.3885 | | |
| Subj* Med Kar (DrivType) | 3 | 20386.2246 | 6795.4082 | | |

* **Bold** indicates significance at $p<0.05$

Table D-5. ANOVA Summary Table of Sleep Quality by Driver Type and Maximum ORD

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:**<br>**SLEEP QUALITY** | | | | | |
| **DrivType** | **1** | **6.1687** | **6.1687** | **10.99** | **0.0031** |
| MaxORD | 3 | 4.3900 | 1.4637 | 1.98 | 0.1538 |
| DrivType*MaxORD | 3 | 1.6431 | 0.5477 | 0.74 | 0.5423 |
| Subj(DrivType) | 22 | 12.3454 | 0.5612 | | |
| Subj*MaxORD(DrivType) | 18 | 13.3348 | 0.7408 | | |

* **Bold** indicates significance at $p<0.05$

Table D-6. ANOVA Summary Table of Sleep Quality by Driver Type and Median ORD

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable:**<br>**SLEEP QUALITY** | | | | | |
| **DrivType** | **1** | **2.7116** | **2.7116** | **4.10** | **0.0551** |
| MedORD | 2 | 2.0713 | 1.0357 | 2.24 | 0.1773 |
| DrivType* MedORD | 2 | 1.3821 | 0.6910 | 1.49 | 0.2884 |
| Subj(DrivType) | 22 | 14.5452 | 0.6611 | | |
| Subj* MedORD(DrivType) | 7 | 3.2398 | 0.4628 | | |

* **Bold** indicates significance at $p<0.05$

Table D-7. ANOVA Summary Table of Sleep Quality by Driver Type and Maximum Karolinska

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SLEEP QUALITY** | | | | | |
| DrivType | 1 | 4.1391 | 4.1391 | 2.98 | 0.0971 |
| MaxKar | 2 | 0.1581 | 0.0791 | 0.10 | 0.9072 |
| DrivType* MaxKar | 2 | 1.8450 | 0.9225 | 1.14 | 0.3383 |
| Subj(DrivType) | 24 | 33.3314 | 1.3888 | | |
| Subj* MaxKar(DrivType) | 21 | 16.9694 | 0.8081 | | |

* **Bold** indicates significance at *p*<0.05

Table D-8. ANOVA Summary Table of Sleep Quality by Driver Type and Median Karolinska

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>SLEEP QUALITY** | | | | | |
| DrivType | 1 | 0.0007 | 0.0007 | 0.00 | 0.9829 |
| MedKar | 2 | 3.3329 | 1.6664 | 6.73 | 0.0778 |
| DrivType* MedKar | 1 | 0.0206 | 0.0206 | 0.08 | 0.7917 |
| Subj(DrivType) | 23 | 32.8922 | 1.4301 | | |
| Subj* MedKar (DrivType) | 3 | 0.7427 | 0.2476 | | |

* **Bold** indicates significance at *p*<0.05

Table D-9. ANOVA Summary Table of Nightcap REM Percent for Maximum ORD

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>REM PERCENT** | | | | | |
| ORD_Cat_Max | 3 | 0.0871 | 0.0290 | 0.33 | 0.8075 |
| DrivType | 1 | 0.2047 | 0.2047 | 2.30 | 0.1485 |
| DrivType*ORD_Cat_Max | 2 | 0.0977 | 0.0489 | 2.02 | 0.1534 |
| Subj (DrivType) | 16 | 1.4216 | 0.0889 | | |
| Subj*ORD_Cat_Max (DrivType) | 6 | 0.5354 | 0.0892 | | |

* **Bold** indicates significance at *p*<0.05

Table D-10. ANOVA Summary Table of Nightcap REM Percent for Median ORD

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>REM PERCENT** | | | | | |
| ORD_Cat_Med | 2 | 0.0584 | 0.0292 | 0.20 | 0.8277 |
| **DrivType** | **1** | **0.4926** | **0.4926** | **7.64** | **0.0138** |
| DrivType*ORD_Cat_Med | 2 | 0.0412 | 0.0206 | 0.90 | 0.4182 |
| Subj (DrivType) | 16 | 1.0310 | 0.0644 | | |
| Subj*ORD_Cat_Med (DrivType) | 4 | 0.5889 | 0.1472 | | |

* **Bold** indicates significance at *p*<0.05

Table D-11. ANOVA Summary Table of Nightcap REM Percent for Maximum Karolinska

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>REM PERCENT** | | | | | |
| KAR_Cat_Max | 2 | 0.0229 | 0.0115 | 0.18 | 0.8356 |
| DrivType | 1 | 0.1699 | 0.1699 | 2.76 | 0.1159 |
| DrivType*KAR_Cat_Max | 2 | 0.0239 | 0.0120 | 0.41 | 0.6698 |
| Subj (DrivType) | 16 | 0.9834 | 0.0615 | | |
| Subj*KAR_Cat_Max (DrivType) | 9 | 0.5627 | 0.0625 | | |

* **Bold** indicates significance at *p*<0.05

Table D-12. ANOVA Summary Table of Nightcap REM Percent for Median Karolinska

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable:<br>REM PERCENT** | | | | | |
| KAR_Cat_Med | 1 | 0.0681 | 0.0681 | 7.59 | 0.1104 |
| DrivType | 1 | 0.0449 | 0.0449 | 0.87 | 0.3635 |
| DrivType*KAR_Cat_Med | 1 | 0.0136 | 0.0136 | 0.39 | 0.5334 |
| Subj (DrivType) | 16 | 0.8212 | 0.0513 | | |
| Subj*KAR_Cat_Med (DrivType) | 2 | 0.0180 | 0.0090 | | |

* **Bold** indicates significance at *p*<0.05

# APPENDIX E: OBJECTIVE 5 ANOVA TABLES

Table E-1. ANOVA Summary Table for Critical Incident Rate for Driver Type and Time

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: CRITICAL INCIDENT RATE** | | | | | |
| **DrivType** | **1** | **532.5104** | **532.5104** | **8.49** | **0.0074** |
| **Time** | **23** | **197.0231** | **8.5662** | **1.93** | **0.0062** |
| DrivType*Time | 23 | 86.0578 | 3.7416 | 0.84 | 0.6750 |
| Subj(DrivType) | 25 | 1568.1609 | 62.7264 | | |
| Subj*Time(DrivType) | 480 | 2127.5186 | 4.4323 | | |

* **Bold** indicates significance at $p<0.05$

Table E-2. ANOVA Summary Table for Critical Incident Rate for Driver Type and Time

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: DRIVER ERROR RATE** | | | | | |
| **DrivType** | **1** | **417.9795** | **417.9795** | **8.27** | **0.0081** |
| **Time** | **23** | **147.0241** | **6.3924** | **1.59** | **0.0405** |
| DrivType*Time | 23 | 68.5844 | 2.9819 | 0.74 | 0.8011 |
| Subj(DrivType) | 25 | 1263.8024 | 50.5521 | | |
| Subj*Time(DrivType) | 480 | 1925.5205 | 4.0115 | | |

* **Bold** indicates significance at $p<0.05$

Table E-3. ANOVA Summary Table for Number of Critical Incident Rate for Each Segment of Day

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: MEAN RATES OF CRITICAL INCIDENTS PER HOURS DRIVEN** | | | | | |
| **DrivType** | **1** | **427.8273** | **427.8273** | **7.83** | **0.0097** |
| **Segment** | **3** | **93.3894** | **31.1298** | **4.23** | **0.0083** |
| DrivType*Segment | 3 | 12.6255 | 4.2085 | 0.57 | 0.6358 |
| Subj(DrivType) | 25 | 1365.8308 | 54.6332 | | |
| Subj* Segment (DrivType) | 71 | 523.1208 | 7.3679 | | |

* **Bold** indicates significance at $p<0.05$

Table E-4. ANOVA Summary Table for Number of Critical Incidents per Hour of Single Shift

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: RATE OF CRITICAL INCIDENTS PER HOUR OF SHIFT** | | | | | |
| Hour of Shift | 23 | 123.5116 | 5.3701 | 1.05 | 0.4039 |
| **DrivType** | **1** | **287.1991** | **287.1991** | **4.40** | **0.0462** |
| Subj(DrivType) | 25 | 1632.3531 | 65.2941 | | |
| Drivtype*Hour of Shift | 11 | 46.3749 | 4.2159 | 0.83 | 0.6150 |
| Subj*Hour of Shift(DrivType) | 202 | 1032.0610 | 5.1092 | | |

Table E-5. ANOVA Summary Table for Number of Critical Incidents per Hour of Single Shift

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: RATE OF DRIVER ERRORS PER HOUR OF SHIFT** | | | | | |
| Hour of Shift | 23 | 103.1743 | 4.4858 | 0.95 | 0.5370 |
| **DrivType** | **1** | **221.4677** | **221.4677** | **4.10** | **0.0537** |
| Subj(DrivType) | 25 | 1351.0910 | 54.0436 | | |
| Drivtype*Hour of Shift | 11 | 43.1376 | 3.9216 | 0.83 | 0.6129 |
| Subj*Hour of Shift(DrivType) | 202 | 957.6266 | 4.7407 | | |

Table E-6. ANOVA Summary Table for Critical Incidents per Hour for Hour of Day and Driver Type

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---:|---:|---:|---:|---:|
| **Dependent Variable: RATE of CRITICAL INCIDENTS PER Total HOURS of DRIVING/DAY** | | | | | |
| Hour of Drive | 23 | 208.7850 | 9.0776 | 1.28 | 0.1814 |
| DrivType | 1 | 311.8246 | 311.8246 | 4.19 | 0.0513 |
| Subj(DrivType) | 25 | 1861.1497 | 74.4460 | | |
| DrivType*Hour of Drive | 18 | 116.1604 | 6.4534 | 0.91 | 0.5704 |
| Subj*Hour of Drive(DrivType) | 304 | 2163.0174 | 7.1152 | | |

* **Bold** indicates significance at $p<0.05$

Table E-7. ANOVA Summary Table Driver Errors per Hour for Hour of Day and Driver Type

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: RATE of DRIVER ERRORS PER Total HOURS of DRIVING/DAY** | | | | | |
| Hour of Drive | 23 | 190.2972 | 8.2738 | 1.34 | 0.1407 |
| DrivType | 1 | 247.9559 | 247.9559 | 4.00 | 0.0563 |
| Subj(DrivType) | 25 | 1547.9967 | 61.9199 | | |
| DrivType*Hour of Drive | 18 | 119.1299 | 6.6183 | 1.07 | 0.3817 |
| Subj*Hour of Drive (DrivType) | 304 | 1897.9035 | 6.1839 | | |

* **Bold** indicates significance at $p<0.05$

Table E-8. ANOVA Summary Table for Number of Critical Incidents per Hour per Hour of Shift

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: CRITICAL INCIDENTS PER SHIFT HOUR** | | | | | |
| Shift | 5 | 7.1728 | 1.4346 | 0.79 | 0.5638 |
| **DrivType** | **1** | **106.3219** | **106.3219** | **10.45** | **0.0034** |
| Subj(DrivType) | 25 | 254.4216 | 10.1769 | | |
| Drivtype*Shift | 3 | 10.0149 | 3.3383 | 1.83 | 0.1510 |
| Subj*Shift*DrivType | 63 | 115.0147 | 1.8256 | | |

* **Bold** indicates significance at $p<0.05$

Table E-9. ANOVA Summary Table for Driver Error per Hour per Hour of Shift

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: DRIVER ERRORS PER SHIFT HOUR** | | | | | |
| Shift | 5 | 4.8307 | 0.9661 | 0.57 | 0.7191 |
| **DrivType** | **1** | **81.9106** | **81.9106** | **10.58** | **0.0033** |
| Subj(DrivType) | 25 | 193.5125 | 7.7404 | | |
| Drivtype*Shift | 3 | 8.4002 | 2.8001 | 1.67 | 0.1834 |
| Subj*Shift*DrivType | 63 | 105.9033 | 1.6810 | | |

* **Bold** indicates significance at $p<0.05$

Table E-10. ANOVA Summary Table for Critical Incident Rate for Day of Trip and Driver Type

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: CRITICAL INCIDENT RATE** | | | | | |
| **DrivType** | **1** | **247.5276** | **247.5276** | **7.96** | **0.0093** |
| DayNo | 7 | 31.2514 | 4.4645 | 0.61 | 0.7486 |
| Subj(DrivType) | 25 | 777.8897 | 31.1156 | | |
| DrivType*DayNo | 7 | 38.3346 | 5.4764 | 0.75 | 0.6337 |
| Subj*DayNo(DrivType) | 133 | 976.7598 | 7.3441 | | |

* **Bold** indicates significance at $p<0.05$

Table E-11. ANOVA Summary Table for Driver Error Rate for Day of Trip and Driver Type

| Source of Variation | df | SS | MS | F value | *p* value* |
|---|---|---|---|---|---|
| **Dependent Variable: DRIVER ERROR RATE** | | | | | |
| DayNo | 7 | 29.9303 | 4.2758 | 1.02 | 0.4183 |
| DrivType | 1 | 153.3792 | 153.3792 | 6.61 | 0.0165 |
| Subj(DrivType) | 25 | 579.8816 | 23.1953 | | |
| DrivType*DayNo | 7 | 15.0857 | 2.1551 | 0.52 | 0.8217 |
| DayNo*Subj(DriveType) | 133 | 556.0877 | 4.1811 | | |

*** Bold** indicates significance at $p<0.05$

# APPENDIX F: OBJECTIVE 6 ANOVA TABLES

Table F-1. ANOVA Summary Table for Subjective Sleep Time for Driver Type and Severity Rating

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: Subjective Sleep Time** | | | | | |
| Severity | 4 | 4253.60 | 1063.40 | 0.15 | 0.9629 |
| DrivType*Severity | 3 | 37350.82 | 12450.27 | 1.73 | 0.1769 |
| DrivType | 1 | 194391.40 | 194381.4047 | 1.32 | 0.2613 |
| SUBJ(DrivType) | 25 | 3678241.61 | 147129.67 | | |
| SUBJ*Severity(DrivType) | 39 | 280807.65 | 7200.20 | | |

Table F-2. ANOVA Summary Table for Subjective Sleep Quality for Driver Type and Severity Rating

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: Subjective Sleep Quality** | | | | | |
| Severity | 4 | 1.55 | 0.388 | 0.66 | 0.6232 |
| DrivType*Severity | 3 | 0.28 | 0.094 | 0.16 | 0.9213 |
| DrivType | 1 | 10.31 | 10.31 | 2.09 | 0.1622 |
| SUBJ(DrivType) | 23 | 113.65 | 4.94 | | |
| SUBJ*Severity(DrivType) | 35 | 20.55 | 0.59 | | |

Table F-3. ANOVA Summary Table for REM Percent for Driver Type and Severity Rating

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: REM Percent** | | | | | |
| Severity | 4 | 0.18 | 0.044 | 0.52 | 0.7250 |
| DrivType*Severity | 3 | 0.49 | 0.16 | 1.90 | 0.1505 |
| DrivType | 1 | 0.0098 | 0.0098 | 0.02 | 0.8819 |
| SUBJ(DrivType) | 22 | 9.56 | 0.43 | | |
| SUBJ*Severity(DrivType) | 31 | 2.69 | 0.087 | | |

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## APPENDIX G: OBJECTIVE 7 ANOVA TABLES

Table G-1. ANOVA Summary Table for Driver Type, Segment of Day and ORD Category

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: Percent Number of Critical Incidents Per ORD Category Per Segment of Day Per Subject/ Percent Number of Timed Triggers per ORD Category Per Segment of Day Per Subject** | | | | | |
| DrivType | 1 | 0.3674 | 0.3674 | 0.83 | 0.3706 |
| **Segment** | **3** | **1.6356** | **0.5452** | **4** | **0.0110** |
| DrivType*Segment | 3 | 0.6727 | 0.2242 | 1.64 | 0.1872 |
| ORD | 2 | 0.5479 | 0.2740 | 0.71 | 0.5025 |
| DrivType*ORD | 2 | 0.7407 | 0.3703 | 0.96 | 0.3982 |
| Segment*ORD | 6 | 6.5162 | 1.0860 | 1.79 | 0.1447 |
| Subj(DrivType) | 28 | 12.4235 | 0.4437 | | |
| Subj*Segment(DrivType) | 69 | 9.4103 | 0.1364 | | |
| Subj*ORD(DrivType) | 23 | 8.8860 | 0.3863 | | |
| DrivType*Segment*ORD | 2 | 2.9601 | 1.4801 | 2.45 | |
| Subj*Segment*ORD(DrivType) | 23 | 13.9182 | 0.6051 | | |

* **Bold** indicates significance at *p*<0.05

Table G-2. ANOVA Summary Table for Driver Type, Severity Rating and ORD Category

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: Percent Number of Critical Incidents Per ORD Rating Per ORD Category Per Subject / Percent Number of Timed Triggers Per ORD Category Per Subject** | | | | | |
| DrivType | 1 | 1.4708 | 1.4708 | 2.71 | 0.1110 |
| **Severity** | **3** | **25.6455** | **8.5485** | **11.54** | **<0.0001** |
| DrivType*Severity | 3 | 1.5180 | 0.5060 | 0.68 | 0.5678 |
| **ORD Level** | **4** | **10.3834** | **2.5958** | **2.81** | **0.0376** |
| DrivType*ORD Level | 3 | 2.4470 | 0.8157 | 0.88 | 0.4576 |
| **Severity*ORD** | **10** | **16.2603** | **1.6260** | **4.30** | **0.0027** |
| Subj(DrivType) | 28 | 15.2019 | 0.5429 | | |
| Subj*Svrty(DrivType) | 38 | 28.1386 | 0.7405 | | |
| Subj*ORD(DrivType) | 41 | 37.8513 | 0.9232 | | |
| DrivType*Svrty*ORD | 3 | 1.8817 | 0.6272 | 1.66 | |
| Subj*Svrt*ORD(DrivType) | 20 | 7.5637 | 0.3782 | | |

* **Bold** indicates significance at $p<0.05$

Table G-3. ANOVA Summary Table for Driver Type, Incident Type and ORD Category

| **Source of Variation** | **df** | **SS** | **MS** | **F value** | ***p* value*** |
|---|---|---|---|---|---|
| **Dependent Variable: Percent Number of Critical Incidents Per ORD Per Trigger Type Per Subject / Percent Number of Timed Triggers Per ORD Per Subject** | | | | | |
| DrivType | 1 | 0.3760 | 0.3760 | 0.21 | 0.6478 |
| **Incident Type** | **8** | **450.7661** | **56.3458** | **74.69** | **<0.0001** |
| DrivType*Inc_Type | 7 | 6.0974 | 0.8711 | 1.15 | 0.3404 |
| **ORD** | **4** | **34.5885** | **8.6471** | **7.61** | **0.0001** |
| DrivType*ORD | 3 | 1.6021 | 0.5340 | 0.47 | 0.7049 |
| **Inc_Type *ORD** | **18** | **37.5855** | **2.0881** | **8.44** | **<0.0001** |
| Subj(DrivType) | 28 | 49.3844 | 1.7637 | | |
| Subj* Inc_Type (DrivType) | 68 | 51.3012 | 0.7544 | | |
| Subj*ORD(DrivType) | 40 | 45.4542 | 1.1364 | | |
| DrivType* Inc_Type *ORD | 6 | 3.2254 | 0.5357 | 2.1653 | |
| Subj* Inc_Type *ORD(DrivType) | 34 | 8.4113 | 0.2474 | | |

* **Bold** indicates significance at $p<0.05$

# REFERENCES

Ajilore, O., Stickgold, R., Rittenhouse, C.D., and Hobson, J.A. (1995). Nightcap: Laboratory and home-based evaluation of a portable sleep monitor. *Psychophysiology,* 32, 92-98.

Akerstedt, T. and Gilberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience, 52*, 29-37.

Balkin, T., Thome, D., Sing, H., Thomas, M., Redmond, D., Wesensten, N., Williams, J., Hall, S., and Belenky, G. (2000). *Effects of sleep schedules on commercial motor vehicle driver performance.* (Report No. DOT-MC-00-133). Washington, DC: Department of Transportation Federal Motor Carrier Safety Administration.

Brunier, G., Graydon, J. (1996). A comparison of two methods of measuring fatigue in patients on chronic haemodialysis: Visual analogue scale. *International Journal of Nursing Studies,* 33 (3), 338-348.

Collins, D.J., Neale, V.L., and Dingus, T.A. (1999). *Driver performance when using an in-vehicle signing information system considering adverse weather, visibility condition, and age*. Proceedings of the Intelligent Transportation Society of America 9th Annual Meeting and Exposition (CD-ROM). Washington, D.C.: Intelligent Transportation Society of America.

Gilberg, M., Kecklund, G., and Akerstedt, T. (1994). Relations between performance and subjective ratings of sleepiness during a night wake. *Sleep,* 17(3), 236-241.

Grace, R., Byrne, V.E., Bierman, D.M., Legrand, J.M., Gricourt, D.J., Davis, R.K., Staszewski, J.J., and Carnahan, B. (1999). A drowsy driver detection system for heavy vehicles. *Proceedings of the ocular measures of driver alertness conference,* Herndon, VA.

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

Hanowski, R.J., Wierwille, W.W., Garness, S.A., and Dingus, T.A. (2000). *Impact of local/short haul operations on driver fatigue, final report*. (Report No. DOT-MC-00-203). Washington, DC: U.S. Department of Transportation, Federal Motor Carriers Safety Administration.

Herscovitch, J. and Broughton, R. (1981). Sensitivity of the stanford sleepiness scale to the effects of cumulative partial sleep deprivation and recovery oversleeping. *Sleep,* 4, 83-92.

Johnson, L.C., Freeman, C.R., Spinweber, C.L., and Gomez, S.A. (1991). Subjective and objective measures of sleepiness: The effect of benzodiazepine and caffeine on their relationship. *Psychophysiology,* 28, 65-71.

Neale, V.L., Robinson, G.S., Belz, S.M., Christian, E.V., and Dingus, T.A. (1998a). *Impact of sleeper berth usage on driver fatigue, Task 1: Analysis of trucker sleep quality.* (Report No. DOT-MC-00-204). Washington, DC: Federal Motor Carrier Safety Administration.

Neale, V.L., Robinson, G.S., Dingus, T.A., and Davis, R.E.L. (1998b). Long-haul drivers' perspective on sleeper berth usage and fatigue in the trucking industry. *SAE Technical Paper Series, 982784*. Warrendale, PA: SAE International.

Pinel, J.P.J. (1997). *Biopsychology.* Boston, Mass: Allyn and Bacon.

Transportation Research Board (1997). *Highway capacity manual, special report 209* (3rd Edition). Washington, DC: National Research Council.

Silvestri, R., Pace-Schott, E.F., Gersh, T., Stickgold, R., Salzman, C., and Hobson, J.A. (in press). Effects of fluvoxamine and paroxetine on sleep structure in normal subjects: A home based nightcap evaluation during drug administration and withdrawal. *Journal of Clinical Psychiatry,* 62.

Skipper. J.H. and Wierwille, W.W. (1986). An investigation of low-level stimulus-induced measures of drowsiness. In: A.G. Gale, et al. (Eds.) Visions in Vehicles. Elsevier Science Publishers B.V. (North Holland Press): Amsterdam: 139-148.

Stickgold, R., Pace-Schott, E., Hobson, J.A., Neale, V.L., and Dingus, T.A. (1999). On-road sleep and vigilance monitoring with the "nightcap." *Proceedings of the Second International Truck and Bus Safety Symposium* (77-98). Knoxville, TN: The University of Tennessee Transportation Center.

Wierwille, W.W., Ellsworth, L.A., Wreggit, S.S., Fairbanks, R.J., Kirn, C.L. (1994). *Research on vehicle based driver status/performance monitoring: Development, validation, and refinement of algorithms for detection of driver drowsiness.* Contract final report DOT HS 808 247: National Highway Traffic Safety Administration.

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. and Hanowski, R.J. (1998*). Impact of local/short haul operations on driver fatigue: Recommended instrumentation and data to be collected for lane changing and backing – White paper addendum to Task 2 report.* (Report No. DTFH61-96-C-00105). Blacksburg, VA: Virginia Tech Transportation Institute.

Winters, J.J. (1998). *An Investigation of Auditory Icons and Brake Response Times in a Commercial Truck-Cab Environment.* Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., Mackie, R.R. (1996). *Commercial motor vehicle driver fatigue and alertness study: Project Report.* (Report No. DTFH61-89-C-096). Washington, DC: Federal Motor Carrier Safety Administration.

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