AN ON-ROAD INVESTIGATION OF SELF-RATING OF ALERTNESS AND TEMPORAL SEPARATION AS INDICATORS OF DRIVER FATIGUE IN COMMERCIAL MOTOR VEHICLE OPERATORS.

by

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(ABSTRACT)

This on-road field investigation employed, for the first time, a completely automated, trigger-based data collection system capable of evaluating driver performance in an extended duration real-world commercial motor vehicle environment. The complexities associated with the development of the system, both technological and logistical and the necessary modifications to the plan of research are presented herein

This study, performed in conjunction with an on-going three year contract with the Federal Highway Administration, examined the use of self-rating of alertness and temporal separation (minimum time-to-collision, minimum headway, and mean headway) as indicators of driver fatigue. Without exception, the regression analyses for both the self-rating of alertness and temporal separation yielded models low in predictive ability; neither metric was found to be a valid indicator of driver fatigue. Various reasons for the failure of self-rating of fatigue as a valid measure are discussed. Dispersion in the data, likely due to extraneous (non-fatigue related) factors (*e.g.*, other drivers) are credited with reducing the sensitivity of the temporal separation indicators.

Overall fatigue levels for all temporal separation incidents (those with a time-to-collision equal to or less than four seconds) were found to be significantly higher than for those randomly triggered incidents. On this basis, it is surmised that temporal separation may be a sensitive indicator for time-to-collision values greater than the 4-second criterion employed in this study.

Two unexpected relationships in the data are also discussed. A ‘wall’ effect was found to exist for minimum time-to-collision values at 1.9 seconds. That is, none of the participants who participated in this research effort exhibited following behaviors with less than a 1.9-second time-to-collision criterion. In addition, based upon the data collected for this research, anecdotal evidence suggests that commercial motor vehicle

operators do not appear to follow the standard progression of events associated with the onset of fatigue.

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“Out of clutter, find simplicity.
From discord, find harmony.
In the middle of difficulty, lies opportunity”

Albert Einstein

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Although the spine of this document may bear a single name, a dissertation is never the sole work of a single individual. Indeed, others have offered their professional experience and expended a great deal of time and effort in order to enhance the quality of this research. Specifically, I would like to thank my Chairman, Dr. John Casali for his friendship, guidance, and direction in the development of this research. I would also like to thank Dr. Gary Robinson for his encouragement and invaluable assistance throughout this research process. Special thanks are also due to Dr. Tom Dingus, Dr. Brian Kleiner, Dr. Albert Prestrude, and Dr. Tonya Smith-Jackson for their worthwhile advice and service to my graduate committee.

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PREFACE

Due to a variety of unforeseen complexities with this research, the data resulting from this research effort were not of the quality, nor of the timetable, originally envisioned. This shortcoming is largely due to the complexities associated with the cutting edge development of a trigger-based data collection system. As a result, it was determined the current data set could not sustain the implementation of the experimental methodology originally proposed since a higher level of validity was required than found to exist within the data set. For example, it was not possible to evaluate change in driving performance over the course of a ten-day period if data existed only for the two and a half days of the trip for any participant. Similarly, comparisons between different fatigue and alertness measures cannot be ascertained when, in the data set, data exist only for one of the relevant measures.

That a system capable of performing consistently could not be developed within the originally anticipated timeframe is a certain disappointment to this author and others working on the project. However, the revised course of action for this dissertation was chosen after carefully considering the strengths and limitations of the available data and their potential for contributing to quality research. Further, it is envisioned, once the data collection system issues are resolved, the resulting data set will support the originally proposed data analysis methods.

It is worth further mentioning the actual course of events describing the manner in which this research has unfolded is not being hidden through submission of a revised research plan that makes no mention of the issues necessitating deviation from the original course of action. Instead, chronicled herein is the original course of action and review of supporting literature and a description of the issues that arose necessitating change to this course of action. In doing so, it is the intention of the author to offer to those engaged in similar research a record of the challenges experienced by those involved in this project that they may learn from these endeavors.

INTRODUCTION

Problem Statement

The costs incurred as a result of traffic congestion and accidents on the nation's roadway system are staggering. In excess of $100 billion annually is attributed to lost productivity due to traffic congestion. Costs associated with traffic accidents – many of which occur as a result of excessive traffic congestion - total an additional $70 billion annually (IVHS America, 1992). Financial cost alone cannot indicate the costs associated with traffic accidents; in 1994, over 40,000 individuals lost their lives in motor vehicle accidents, an average of one person every thirteen minutes (NHTSA, 1996).

Driver fatigue is recognized as a major causal factor in accidents involving long-haul commercial drivers. The development of an on-board driver performance/fatigue monitoring system could potentially assist drivers in identifying the onset of fatigue. Such a system would monitor drivers on their ability to perform this complex, visually intensive manual control tracking task where, in addition to keeping the vehicle within the confines of the roadway, drivers must continuously avoid collisions with other vehicles, pedestrians, and other impediments that may lie in their path of travel. A set of formidable issues exists which must be addressed before the successful deployment of such a system is possible. The research described herein sought to progress further the evaluation of two prospective dependent measures as possible indicators of driver fatigue.

Purpose

This dissertation research seeks to determine:

1) whether self-assessment of fatigue is a valid indicator of driver fatigue, and

2) whether temporal separation, as measured by time to collision and headway, is a valid indicator of driver fatigue.

Experimental Approach and Objectives

In order to minimize the influence of the experimenter's presence, the current research employed a field study in order to collect data in a real world environment that was as naturalistic, unobtrusive, and non-invasive as possible. Toward this end, automated data collection systems embedded within two instrumented Class 8 commercial tractors collected data during thirty-six real world, revenue-producing trips. Experimenters were not present at any time during the trip, which varied between six and ten days in length depending on the load and transportation requirements of the company employing the participant driver.

The following research claims form the cornerstone of this dissertation research seek to identify and further evaluate suitable measures for inclusion in a vehicle-based fatigue monitoring system.

Hypothesis 1: Self-assessment of fatigue is a valid indicator of driver fatigue.

Hypothesis 2: Temporal separation, as measured by time to collision and headway, is a valid indicator of driver fatigue.

Dissertation Overview

As previously stated, the purpose of this research is twofold. First, this document chronicles the originally proposed course of action and a description of the issues that arose necessitating change to this course of action. Second, the empirical portion of this dissertation focuses on the assessment of time-to-collision and self-assessment of fatigue as valid indicators of driver fatigue. In order to meet both of these goals, this dissertation begins with a critical review of six large-scale studies related to fatigue and commercial motor vehicle operations. Subsequent to this review, the results of recently conducted focus groups designed to elicit driver input into the cause of fatigue are presented. An operational definition of fatigue was then established in light of the insights presented by the reviewed literature and focus groups. Subsequently, a suitable subset of the available metrics for assessing fatigue were generated relative to their ability to meet the stated objective: achieving a comprehensive collection of field data in a naturalistic, unobtrusive, and non invasive manner.

Following a review of the pertinent literature, the originally proposed course of action is presented succeeded by a discussion of the issues necessitating its eventual replacement. Subsequently, the current research objectives and hypotheses are presented. A review of the experimental apparatuses, presentation of the experimental design and related experimental procedures follows. Results of the data analyses, a discussion of their significance, conclusions reached, and suggestions for future work close the dissertation.

REVIEW OF SELECTED STUDIES

Fatigue, as it relates to the commercial motor vehicle operator, has been the topic of substantial research. In an effort to maximize the efficiency of the current research effort, it is prudent to review some of the prominent research related to this area. Six large-scale studies related to fatigue, each representing a variety of independent and dependent variables, are critically reviewed. With the intention of identifying the most efficient and effective procedures, methods, and salient factors for the current research effort, each of these studies is reviewed in turn.

Study 1: A Study in the Relationships among Fatigue, Hours of Service, and Safety of Operations of Truck and Bus Drivers

Human Factors Research, Inc. published results from one of the first major studies evaluating fatigue and commercial motor vehicle operators in 1972 (Harris, Mackie, Abrams, Buckner, Harabedian, O'Hanlon, and Starks). The relationships among fatigue, hours-of-service, and safety of truck and bus drivers were investigated through the use of surveys, analysis of accident data, and an experimental investigation. Harris *et al*. (1972) summarized the results of their research efforts by drawing several conclusions based upon their findings.

- Driver performance errors increased and drivers experienced significant decreases in the psychophysiological arousal within the current (10-hour) driving time limit.
- The marginal effectiveness of rest breaks on driver performance and psychophysiological arousal; the first break (occurring after approximately 3 hours of driving) produced the highest level of recovery while the second (occurring after 6 hours of driving) provided somewhat less recovery and the third and final break (occurring after approximately 9 hours of driving) provided almost no recovery.
- Drivers who utilized the sleeper berth appeared to recover less completely from breaks than did relay drivers.
- A cumulative effect of reduced psychophysiological arousal was noted for drivers who spent several successive days on duty.
- The effects of prolonged driving were more pronounced for drivers over 41 years of age.

Survey responses. A survey of 548 professional drivers from twenty major cities was conducted in an effort to identify significant variables associated with driver characteristics, various types of commercial motor vehicle operations, accident experience, and attitudes towards the Department of Transportation regulations. Of the 548 drivers surveyed, 148 were bus drivers, 202 were owner-operators, 100 were common carriers, and 98 were contract carriers (common carriers are for-hire to the general public; whereas, contract carriers are limited to carrying the goods for a specific shipper or group of shippers). One hundred officials within the trucking industry (*e.g.*, director of safety, director of operations) and several officials from the Teamsters and United Transportation Unions also participated in the survey.

Harris *et al*. (1972) evaluated and compared a number of variables (driver age, experience, workday schedule, daily length of drive, accident experience, unrecorded stops, knowledge of drug use, and type of operation) with type of carrier (owner-operator, common carrier, private carrier, and bus company). While the survey results, taken as a whole, provide a reasonably comprehensive description of driver demographics, the current research effort is focused on identifying factors relevant to fatigue. Consequently, the discussion will focus only on the variables related to work schedule and trip length, the variables most commonly associated with fatigue. Additionally, the discussion will be limited to owner-operators, common carriers, and private carriers; bus operations will not be discussed.

The most common work schedule reported by the majority of drivers was the 70-hour/8-day schedule, the maximum allowable under Department of Transportation (DOT) regulations. Approximately 64 percent of owner-operators, 63 percent of common carriers, and 41 percent of private/contract carriers reported using this option. A 60-hour/7-day schedule was the next most common schedule (~25%) reported, followed by a 40-hour-per-week schedule (~3%). Variable schedules and schedules which did not coincide with any of the aforementioned categories comprised approximately 17 percent of the responses.

The length of a typical driver's workday was determined through evaluation of the last full day of operations for each driver surveyed. Based upon this information, the typical truck driver worked an average of nine hours: seven hours driving and two hours performing other 'on-duty' functions. Approximately 30 percent of drivers surveyed informally reported driving in excess of nine hours and being on-duty for periods exceeding ten hours, thereby exceeding then-legal limits. Since this information was not reflected in the analysis of the logbooks, the information garnered from the logbooks is likely to be conservative.

The differences between daily median mileage driven by owner-operators (369 miles), common carriers (371 miles), and private/contract carriers (353 miles) were not significant. The mileage covered by drivers employed in two-driver sleeper-team operations (403 miles) was found to be significantly greater than that for either the one-driver sleeper (370 miles) or single-driver relay operations (328 miles). Further, the distance traveled also differed significantly between the one-driver sleeper and the single-driver relay operations. Approximately five percent of the drivers within each group were found to engage in continuous driving operations exceeding 500 miles daily, regardless of the presence of sleeping accommodations.

Drivers under the age of 30 were found to drive significantly further than were drivers in the middle (31-40 years) and older (41 years and older) age groups. The median distance traveled by those under the age of 30 was 366 miles, versus 287 and 320 miles for the middle and older categories, respectively. Harris *et al*. (1972) offered two possible explanations for this difference: 1) the large number of younger drivers engaged in sleeper-berth operations, or 2) speculation that many younger drivers feel they are able to drive for longer periods of time without being affected by fatigue.

When asked to order an experimenter-identified list of possible contributors to fatigue, drivers ranked poor ventilation and long str*etc*hes of roadway without hills or curves as the primary and secondary contributors to fatigue; high levels of vibration and noise, and low levels of traffic followed thereafter. Drivers were also requested to identify any additional factors they felt contributed to driver fatigue. The factors most often identified as such included bad weather, heavy traffic, slow traffic, tourists, and campers (recreational vehicles). Road conditions, heat, bright sun, mechanical trouble, driving too long, not sleeping prior to driving, and oncoming lights were also reported as contributing to fatigue. Younger drivers specifically mentioned conditions such as 'lack of music/radio,' 'boredom,' and 'under-powered trucks' as factors contributing to fatigue more often than older drivers. This age-related disparity may suggest that younger drivers are more prone to inattention and boredom than older drivers.

Drivers were also requested to describe what actions, if any, they took on a regular basis to cope with fatigue. The most common answer was to 'stop, pull over, and sleep.' Stopping for food or drink was also reported as a popular option for combating fatigue. Additional methods reported included stopping and walking around, stopping to rest (but not sleep), getting fresh air (rolling down the window), cold water on hands and face, switching drivers, smoking/chewing gum, and stopping driving prior to the onset of fatigue.

Analysis of accident data. Three carriers provided data for the second portion of the study: a major common carrier, a large private carrier, and a major bus company. The accident data were subject to an 'exposure limit hypothesis' (Harris, *et al.*, 1972). This hypothesis led to the construction of an empirically-derived probability function relating the probability of a company experiencing an accident to the total amount of time its drivers spent driving. Significant departures from this probability function were proposed to indicate that some outside factor (*e.g.*, fatigue) played a role in accident causation. This hypothesis depended on the notion that drivers become increasingly fatigued as driving time increases and does not account for periods of recovery and increased alertness. Thus, according to the hypothesis, as driving time increases so too would the probability of an accident occurring as the result of fatigue.

Results from the data analysis (Harris, *et al.*, 1972) provided by the common carrier were found to deviate significantly ($p < 0.001$) from the probability function. Fatigue, some other causal factor, or statistical anomaly could potentially have explained this deviation; no effort was made to isolate and identify the causal factor. The accident data from the private/contract carrier did not deviate significantly from the expected probability function.

In addition to fatigue, six other hypotheses were considered; these hypotheses addressed variables that may have influenced deviations from the expected probability function for the accidents reported. Only the common carrier provided enough data to support these analyses. None of the proposed variables (type of collision, ratio of preventable to non-preventable accidents, hours on duty prior to accident, regular vs. irregular duty cycle, daylight vs. non-daylight, and driver's age) were found to be significant.

Several criticisms of the flawed 'exposure limit hypothesis' exist. First, the 'exposure limit technique' is a macro-level technique and should include more companies than the limited application it received in this study. While deviations from an expected probability function can be calculated, determining the cause of the deviation without some prior, in-depth knowledge of the situation surrounding the accident is suspect.

Additionally, the complex phenomenon of fatigue and fatigue onset is subject to fluctuations in arousal level due to recovery (from breaks) or periods of increased alertness (*e.g.*, arousal due to a transient environmental stimulus such as 'rumble strips' or another vehicle's horn). The 'exposure limit hypothesis' presumes fatigue as a monotonically decreasing function; an assumption which cannot be supported given the occurrence of arousal and recovery. Further, Harris *et al*. (1972) did not report the specific method for determining significance, making it difficult to ascertain the nature and therefore the validity of the analyses performed and the conclusions drawn from therein. Finally, the majority of these analyses were conducted for a single common carrier, the results from which may not represent the industry as a whole.

Experimental investigation. The field study was designed to investigate the effect of prolonged driving under operational conditions on the performance and functioning of drivers operating within the Department of Transportation regulations. Performance, physiological and subjective measures were evaluated as indices of changes in driver status (*e.g.*, change in fatigue levels). Over 200 runs were observed; however, only 195 of these were included for data analysis because some of the data were lost due to equipment failures. One hundred fifty-nine of the 195 runs were completed in trucks whereas the remaining 36 were completed in buses. A total of 30 different routes were chosen (15 relay, 7 sleeper, and 8 bus) for inclusion in the study.

Independent variables were divided into two categories: control and manipulated. Manipulated variables included Type of Operation (truck relay, bus relay, truck short sleeper, truck long sleeper), On-Duty Time, Driving Time, Rest Breaks, and Cycle Run, Time of Day, and Driver Characteristics (including age, experience, duration of pre-run rest and sleep periods, and nature of activities during rest breaks). Control variables included Surface Conditions (dry, wet, ice, snow, frost), Road Type (concrete, asphalt, unpaved, number of lanes, divided or not, bridge), Road Conditions (smooth, rough, jolting), Weather (clear, rain, snow, sleet, fog, windy), and Traffic Events (vehicles approaching from rear, left, right, or ahead in same lane; being passed on left or right; own vehicle passing on left or right).

Dependent measures were derived from performance variables, physiological variables, and subjective reports. Performance variables included steering wheel reversal rate, variability in speed control, brake activation, and driver error (lane drift error, speeding/tailgating/signaling errors, judgmental errors). Physiological variables included heart rate and heart rate variability. Subjective measures included self-ratings of both fatigue and alertness (Figure 2, page 55). The dependent variables found to be the most consistent indicators of the time spent on the road included: trends in heart rate, lane drift frequency, self-report of fatigue, and steering wheel reversal rate.

Trends in heart rate were found to be the most consistent indicators of the effects of time on the road and were generally found to be significant ($p < 0.10$). As predicted, the level of arousal decreased as a function of time on the road. A decreased state of arousal is consistent with an increased state of fatigue.

Lane drift frequency was hypothesized to increase as a function of fatigue. Though found to be significant ($p < 0.10$), the expected trend was realized for the first eight hours of the trip, after which lane drift was found to decrease until the end of the trip. Since most of the runs in the experiment ended in urban areas where lane drift occurs less frequently, the decrease in lane drift is not surprising. The reliability of this measure is somewhat questionable as the experimenter accompanying the driver manually collected lane drift frequency data. It is not unreasonable to presume that the experimenter, like the drivers they were observing, would become fatigued and thus be less reliable and accurate in their data collection efforts.

Drivers, as a self-report of fatigue, completed an 11-point scale (Figure 2, page 55). Both relay and sleeper drivers reported increased feelings of fatigue further into their respective trips. Self-ratings of fatigue for the sleeper drivers were consistently higher than those for relay runs; however, the differences were not significant. Harris *et al*. (1972) provided no evidence that the current self-reports of fatigue and alertness had been tested or validated; consequently, the effectiveness of these scales and the value of the results derived from them are suspect.

Steering wheel reversal rate was hypothesized to decrease as a function of time on the road or driver fatigue. While found not to be a consistent or significant indicator of the effects of time on the road, the trend was frequently observed. High individual variability, however, was thought by the researchers to be the factor that limited the utility of this measure.

Summary. Due to the limited scope of the existing accident data, the related analyses did not produce any further insights into the proximate cause of fatigue and fatigue-related accidents. The experimental portion of the study identified heart rate and lane drift frequency as the dependent variables most sensitive to the effects of time on the road. It is important to recognize, however, that the methodology employed required an experimenter to be present to collect the data, which may have resulted in lessening the effects of fatigue. Furthermore, measurement of heart rate required the driver to be wired to a data collection device, a relatively obtrusive measure that may have caused unintentional arousal and served as a persistent reminder to the drivers they were being observed. Therefore, other dependent measures not found to be particularly sensitive to detecting fatigue in this study may prove to be effective measurement tools in situations where an experimenter is not present. The survey of commercial drivers identified several important factors that drivers felt to be fatigue-related, including:

- Work schedule
- Daily hours worked
- Trip length
- Cab environment (*e.g.*, poor ventilation, noise, vibration)
- Traffic volume (excessively high or low volumes of traffic)
- Weather (*e.g.*, bad weather, glare from sun)

Through surveying drivers, reviewing accidents, and performing an experimental evaluation of the factors affecting fatigue, this study represents the first major effort to systematically evaluate some of the factors affecting truck driver fatigue. Many of the criticisms discussed within this review are attributable to the somewhat limited technology and literature resources available in the late 1960s and early 1970s. Subsequent advances in microelectronics and a more highly developed body of fatigue-related literature contribute to an increased ability to monitor and study the effects of commercial driver-fatigue.

Study 2: Heat, Noise, and Vibration in Relation to Driver Performance and Physiological Status

Human Factors Research, Inc. published the results of a second study evaluating environmental factors related to fatigue and commercial motor vehicle operators in 1974 (Mackie, O'Hanlon, and McCauley, 1974). Three experiments were conducted to determine the effects of heat, noise, and vibration on the driving performance, subjective feelings of alertness and fatigue, and the physiological symptoms of stress among drivers. Since the overwhelming majority of commercial motor vehicles are currently equipped with air conditioning systems, the issue of heat stress is less salient in the current day than it was in 1974. Consequently, only the experiment comprising the portion of the study focusing on the effects of noise and vibration will be discussed.

Measurement of noise and vibration. Noise levels were measured using a Bruel and Kjaer, Model #2209, Impulse Precision Sound Level Meter, and a Bruel and Kjaer, Model #4145, one-inch condenser microphone equipped with an anti-wind device. The guidelines for measuring the sound level in truck cab interiors, outlined in SAE J336, were followed. An observer riding along in the cab with the driver, verbally recorded the Sound Pressure Level (SPL) measurements based upon the "slow" scale, approximately once an hour using a magnetic tape recorder. Unfortunately, while these measurements were made over a variety of different roadway and truck cab conditions experienced by commercial motor vehicle operators, they fell short of representing a true integrated measure of the noise environment experienced by the study's participants.

Pre- and post-test audiograms were conducted using a Grason-Stadler, Model #1703, automatic audiometer. The subject was allowed to practice for several minutes prior to the actual test and the left ear was always tested first. Audiometric tests began two to seven minutes after the cessation of truck cab noise and were conducted in the quietest facilities available at the time, generally below 50 dBC. Since temporary threshold shift is formally defined as the hearing threshold two minutes after cessation of noise exposure (Ward, 1976), some caution should be exercised when comparing these results with results from other studies where the timing of the tests was more stringently controlled.

Vibration in each of the three major axes, x, y, and z, was measured using two Bruel and Kjaer triaxial accelerometers, Model #4340. One of the accelerometers was attached to a metal plate inside a small aluminum box affixed to the driver's seat as close as possible to the human-seat interface. The second accelerometer was affixed to the floor of the cab adjacent to the driver's seat. The first accelerometer measured the vibration imparted to the driver, whereas, the second accelerometer measured the vibration of the truck. Both signals were amplified and recorded on magnetic tape, and subsequently transferred to a strip-chart for analysis.

Effect of noise and vibration. The purpose of the this experiment was to determine the effects of noise and vibration on the operators' driving performances as well as their physiological and subjective indicators of fatigue and alertness. Independent variables included Noise and Vibration. The experiment was a full-factorial between subjects design with three levels of each independent variable represented. However, several of the cells were not included in the analyses because the experimenters felt they were not meaningful (*e.g.*, low noise and high vibration, or high noise and low vibration). As a result, only five of the nine cells were evaluated. Further, two of the conditions (low vibration/low noise and medium vibration/medium noise) were imported from a previous experiment (not discussed herein) and were of within-subjects design.

Differences in noise level (69.5 dBA – 89 dBA) and vibration were achieved through the use of a then-modern (1974 model) passenger car with a heavy-duty suspension system traveling on smooth roadways (low noise, low vibration) and tractor-trailer combination vehicles with relatively hard seats traveling on some of the roughest highways in the United States (high noise, high vibration). Dependent measures included blood pressure, heart rate, heart rate variability, EEG, adrenaline and noradrenaline excretion, oxygen consumption, ventilation (breathing) rate, hearing level, steering wheel reversal, variations in speed control, technical errors (*e.g.*, speeding, tailgating, failure to signal), lane drifts, and subjective rating of fatigue.

One of the most important implications of this research was the identification of measures influenced by noise and vibration. While vibration and noise levels have both been found to influence fatigue directly, it is also important to recognize that noise and vibration similarly affect many of the dependent measures frequently used to detect fatigue. The following dependent variables were found to be the most sensitive indicators of the effects of noise, vibration, and time spent on the road: blood pressure, heart rate, EEG, oxygen consumption and ventilation, subjective ratings of alertness and fatigue, and steering wheel reversal rate.

Prior to discussing each of the measures reported by Mackie *et al.* (1974) as being the most sensitive indicators of the effects of noise, vibration, and time spent on the road it is only prudent to mention the possible impact of this flawed design. While it is not uncommon to reuse data from one experimental design in another (in fact, such practice may represent the most efficient design of experiments), it is extremely unusual to incorporate cells from a within-subjects design into another, between-subjects design. A between-subjects design tends to elicit very large error effects when compared with a within-subjects design since a within-subject design takes advantage of block homogeneity. Block homogeneity occurs when each subject acts as his or her own control (*i.e.*, forms a block). Therefore, within-subjects (block) designs are generally considered more efficient than between-subjects (block) design. This difference in block homogeneity is likely to bias the error term between the two imported conditions when compared to the remaining design. Realistically, the magnitude of the bias is likely to be relatively small; however, without the original data it is impossible to determine the precise effect this practice had on the outcome of the experiment. By comparison, however, the impact of incorporating within-subject cells into a between-subjects experimental design is considerably less questionable than incorporating a couple of between-subjects cells into a within-subjects experimental design.

A trend towards lower systolic blood pressure for higher levels of noise and vibration was observed ($p < 0.10$). It was expected that blood pressure would increase as noise and vibration levels increased. Mackie *et al*. (1974) suggest that the unexpected results may reflect the differences between the drivers rather than the different noise/vibration levels.

Another unexpected result occurred when significant differences of Alpha+Beta power were noted between the four noise/vibration conditions ($p < 0.05$). This was principally attributed to the lower levels of Alpha+Beta power shown by the drivers of the passenger vehicle than of the trucks.

Oxygen consumption was chosen as a measure of the metabolic activity and was expected to increase involuntarily over time as a result of increased vibration. This hypothesis was confirmed as oxygen consumption ($p < 0.05$) and ventilation rate ($p < 0.10$) for truck drivers was found to increase approximately 25 percent and 9 percent, respectively, over the course of a trip. Automobile drivers did not experience a similar increase in oxygen consumption.

Drivers indicated they became fatigued more quickly while driving a truck than an automobile; it is uncertain whether this increase in fatigue was caused by the increased noise and vibration levels in a truck, the inherently greater difficulty of driving a truck, or some combination of these two factors. No significant differences were found with respect to the different vibration conditions. A trend towards decreased alertness and increased fatigue as a function of time on the road for all four noise/vibration conditions was found to be significant ($p < 0.01$).

Significant differences between steering wheel reversal rates for the four noise/vibration environments were also found. Increased vibration resulted in more steering wheel reversals. Steering wheel reversals as a function of time was also significant ($p < 0.01$), with more steering wheel reversals occurring later in the trip.

Summary. A portion of the study conducted by Mackie *et al*. (1974) consisted of an on-the-road experimental study to evaluate the effects of noise and vibration on driver performance, fatigue, and alertness. Factors related to driving performance and fatigue that were influenced noise and vibration include:

- Blood pressure
- Heart rate
- EEG
- Oxygen consumption and ventilation rate
- Subjective ratings of alertness and fatigue
- Steering wheel reversal rate

Concerns threatening the validity of the dependent measures, specifically pertaining to the issues surrounding the development of the subjective fatigue and alertness scales, persist. Primary criticism was directed towards the inclusion of these instruments void of a discussion describing their testing and validation. Without testing and validation of subjective scales, there was no way to determine whether the responses are truly indicative of the levels intended by the experimenter. Another flaw of this incarnation of sleep and fatigue scales was their reliance on lengthy descriptors at the scale extremes while providing little or no information at the other, clearly labeled divisions.

As with Harris *et al*. (1972), Mackie *et al*. (1974) were limited by the technology available in the early 1970s. Much of the criticism directed towards the shortcomings of the objective dependent measures is directed, not towards what measures were made, but rather towards the data collection methods and how the measurements were made. The techniques employed would be considered obtrusive by today's standards most likely influenced the results. The presence of an experimenter likely lessened (rather than increased) the effects of fatigue and may have affected some of the dependent measures. Additionally, using an automobile in the low noise/low vibration condition (since a truck meeting these requirements had not yet been developed) may likely be inconsistent with the driving demands required by a larger vehicle (*e.g.*, combination tractor-trailer).

In addition to the concerns that could be attributed to technological shortcomings, this research effort is fraught with a number of issues pertaining to the experimental design and development which should be enumerated. Overall, there was some concern about the consistency and appropriateness of statistical terminology and language throughout the report. The designation of significance occurs when the p-value (measured level of significance) representing a data set is less than or equal to some alpha-level (predetermined criterion level of significance). Mackie *et al*. (1974) were occasionally unclear in their discussion as they referred to significance occurring at multiple levels of alpha. Many researchers regard this as an unconventional and inappropriate technique. While some researchers prefer to utilize multiple criterion levels of alpha for differentiating between different levels of significance (*e.g.*, recognizing that a much stronger phenomenon is required to generate a p-value of 0.00001 than would be required to produce a p-value of 0.01; both of which would be considered significant when the alpha criterion is set to 0.05), these individuals utilize precise language which represents their consideration of multiple-alpha criterion; such language was not conveyed by Mackie *et al* (1974). Additionally, mixing between and within subject cells as they did in the second experiment is another questionable research technique. Similarly, there is some question as to the overall appropriateness of the independent/dependent variables in the second experiment and perhaps the underlying reasoning used to interpr*et al*l of the results generated by the study. The second experiment was of a between-subjects design, yet Mackie *et al*. (1974) attribute the significance of the blood pressure dependent measure with an unexpected magnitude to differences between the participants, rather than the experimental conditions to which they were assigned. If differences between the participants existed capable of generating this difference, these differences call into question the significance, or lack thereof, of each dependent measure used in this study; what other measures may have been affected by the differences between participants, rather than the conditions to which they were exposed? Finally, after determining significance, appropriate post-hoc tests were not conducted (or at least not discussed) to determine the precise nature of the significance.

Through further on-road experimentation, this study does offer some insight into the factors affecting driver performance, which are related to driver fatigue. While several criticisms have been raised, the most severe are attributable to the somewhat limited technology and resources available in the early 1970s. Despite these shortcomings, this study was the first major attempt to evaluate the effects of heat stress, noise levels, and vibration with regard to driver performance.

Study 3: Strategies to Combat Driver Fatigue in the Long Distance Road Transport Industry

In 1994 the Australian National Occupational Health and Safety Commission (Williamson, Feyer, Friswell, and Leslie, 1994) published a report investigating methods to reduce on-road fatigue on long-distance trips by varying work practices. The study involved both on-road and off-road monitoring of the driver's level of fatigue, alertness, and arousal using measures of each of these dimensions. The experimental design was devised to rule out factors related to individual drivers such as level of experience, general health, and lifestyles as causes of fatigue. Twenty-seven subjects, driving the same route, participated in a repeated-measures design intended to evaluate each of three work practices.

The first work practice was staged driving - in staged driving, two drivers began their trips from different points, met at a point roughly half-way into their trip, exchanged loads, and then returned to their point of origin. Flexible driving was the second work practice evaluated – here drivers were allowed to arrange the work/rest schedule of their trip according to their own body state, regardless of the hours of service regulations. The third method, control trips, involved single drivers traveling from point of origin to point of destination; all hours of service regulations were adhered to.

Results from this study suggest that "controlling the hours of work within a trip may not be as important as controlling the overall scheduling framework in which the trip occurs in order to better manage accumulated fatigue" (Williamson *et al*., 1994, page 1). Two major findings were conveyed as supporting this conclusion:

- The 12-hour trip was found to be fatiguing, regardless of how the work was arranged
- Drivers who are tired at the start of a trip are likely to experience an increase in the fatiguing effects of that trip.

Williamson *et al*. (1994) argued within the confines of a 12-hour trip these findings present evidence the affects of cumulative fatigue may eclipse the effects of short-term (acute) fatigue.

Performance measures. In order to objectively evaluate the impact on driver fatigue of staged driving and the leniency afforded drivers of the flexible driving work practice, several measures of driver performance and functioning were collected. Measures collected included sensory performance tests such as Critical Flicker Fusion

(CFF) test, a perception test based on the detection of flicker onset/offset, a Simple Visual Reaction Time (SVRT) test, a vigilance test where drivers responded to a simple visual detection task, and an unstable tracking task. On road performance tests included a simple reaction time task based on the presentation of an auditory stimulus, steering wheel movement, and changes in forward truck velocity. Physiological measures were measured objectively through monitoring of the driver's heart rate and subjectively through the use of the Stanford Sleepiness Scale and a set of three Visual Analog Scales. Those measures found to be significant include steering wheel movement, heart rate, cognitive functioning task, vigilance, and the subjective assessment of sleepiness as reported through the Stanford Sleepiness Scale; these results are discussed herein.

Trends in steering wheel movement data presented by Williamson *et al*. (1994) appear to support previous research conducted by Safford and Rockwell (1967) and Wierwille and Muto (1981) where smaller and less variable steering wheel movements characterize an alert driver. Unfortunately, comparison of actual magnitude could not be made since Williamson *et al*. (1994) present their results in terms of encoder units rather than standard units of measurement. Steering wheel position was collected at a rate of 10 Hz. The overall pattern of results for steering wheel movements showed the steering wheel movements on staged and control trips decreased in magnitude across the trip, but for flexible trips, the magnitude of steering movements increased across the trip ($p < 0.01$). In addition, the frequency of steering wheel movement or steering variability did not vary significantly for any work practice. The two breaks did not appear to affect the magnitude of steering deviations in staged or flexible trips. For the control trips, however, the steering wheel movements increased significantly in magnitude after the first break ($p < 0.01$), but returned to their original levels shortly following the second break. While the magnitude of the steering deviation changed after breaks for one of the work practices, other performance measures were not any more, or less, variable as a result.

Using EKG and chest electrodes to obtain the heart rate data, this variable related to fatigue such that increased arousal level correlated with shorter interbeat intervals and lower variability in heart rate. The results showed drivers on flexible trips showed significantly larger interbeat intervals and more variability before the break than after the break ($p < 0.01$). Drivers on control trips showed no change in interbeat interval or variability after the break. Staged drivers had the lowest interbeat interval and variability before and after the break indicating highest alertness for this work practice. The second break did not benefit the drivers in any of the work practices. Both staged and flexible trip drivers showed increased interbeat intervals after the second break, and the control trip drivers had no significant change in interbeat intervals. The interbeat variability did not significantly change in any of the work practices.

The cognitive functioning task consisted of an auditory stimulus and an oral response. The driver responded by saying "yes" when he/she heard the signal. There were 30 trials unevenly spaced over a 15-minute period. The test was administered immediately before and after the trip, and then one-hour after departure and every two hours thereafter. If a break was taken, the test was administered one hour after the break and two hours thereafter.

Work practice and duration did not affect driver reaction time on this test. There was a significant relationship between mean reaction time and time of day and the standard deviation of reaction time and time of day ($p < 0.04$). Reaction time tended to be longer and more variable in the late afternoon and up to midnight than at other times; however, the results may have been confounded due to re-arousal that may have occurred during testing.

The ability of the driver to maintain a high performance level in the face of a tedious unchanging environment was measured by having the driver push a button on a box to turn a light off. The display contained five lights with a button beneath each and the driver's task was to press the button below the illuminated light. Overall performance on flexible and control trips did not differ. The mean reaction time in this task was significantly longer at the end of the trip than before the trip ($p < 0.002$). Staged trip drivers made significantly more errors than on control trips, with the fewest errors occurring on flexible trips ($p < 0.04$).

The Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, and Dement, 1973) was used in this study (Figure 2, page 55). This test focused on identifying increased feelings of subjective sleepiness. Significant main effects were found for type of trip ($p < 0.009$) and time of rating for fatigue ($p < 0.0001$). The interaction was not significant. The drivers generally rated themselves as being considerably more tired and progressively less alert towards the end of the trip than they had been at the beginning of the trip ($p < 0.0001$). One notable exception occurred as an increased number of staged drivers reported they were tired at the beginning of the trip ($p < 0.009$) than with any other trip type. This is most likely due to the fact that staged trips were the first trips scheduled in the study; where the higher levels of fatigue reported at the beginning of the trips were attributed to the demands and sleep/wake cycle of the previous working week. As the workload had been high for many drivers in the previous week, this may have led to higher fatigue in drivers even before they started a trip for this study. Scheduling prohibited a randomized or counter-balanced design. For 92% of the participants, the staged trip was the first trip taken; thus, it is likely that presentation order contributed as a confounding factor in this study. Further, it is difficult to separate the effects of staged driving from the occurrence of drivers who reported being tired at the beginning of their trip. Specifically, Williamson *et al*. (1994) reported that higher levels of fatigue were attributed to the demands of the previous week's sleep/wake cycle when the drivers were not participating in the study. Since staged trips were the first trips scheduled for 92% of the drivers, the lack of a randomized or counter-balanced presentation of treatment conditions create a confounding relationship between the effects of staged driving and the occurrence of drivers who reported being tired at the beginning of their trip.

Several additional performance measures were also recorded, but not found to be significant. These non-significant measures included forward speed monitoring, critical flicker fusion, simple manual reaction time, and an unstable tracking task. Of these measures, only forward speed monitoring was conducted while the vehicle was in motion; the remaining measures were conduced after the vehicle had come to a stop. It is likely that these measures were different enough from the driving task to elicit re-arousal, thus decreasing their effectiveness as dependent performance measures.

Summary. The study conducted by Williamson *et al*. (1994) demonstrated work practice had little effect on overall driver performance. More drivers reported being more tired at the end of the trip than at the beginning, regardless of how the trip was structured. This is not an unexpected result. The study also identified the following factors as being the sensitive to fatigue detection:

- Steering wheel position
- Heart rate
- Subjective assessment of fatigue (Stanford Sleepiness Scale)

It is important to reiterate some of the limitations of the current study. The results from the performance measures, specifically the vigilance task, were not collected while the driver was operating the vehicle. Consequently, re-arousal might have confounded the results; over the course of a trip, therefore, it is likely drivers were more fatigued than these tests indicate. The small sample size of this experiment coupled with the missing/lost data, may have resulted in the statistical tests not being as sensitive as they might have been otherwise. Additionally, the experimental design, altered to be more conducive to scheduling concerns, prohibited a randomized or counter-balanced design. Considering that 92% of the subjects first participated in the staged trip, which is also the trip identified as being the most fatiguing, it is very difficult to separate and quantify a participant's exposure to this condition versus their incidental (starting) level of fatigue. Thus, this confounding relationship casts considerable uncertainty around Williamson *et al*. (1994) assertion that drivers who are tired at the start of a trip are likely to experience an increase in the fatiguing effects of that trip. Finally, a very limited route selection (*i.e.*, Sydney to Melbourne, Australia) may limit the generalizability of the results.

Study 4: Review of Factors that Affect Fatigue in Heavy Truck Accidents

In 1995, the National Transportation Safety Board (NTSB, 1995a, 1995b) released a two-volume report on a study intended to identify the factors that affect fatigue in heavy truck accidents. The first volume contained the NTSB's analysis of the data along with its conclusions and recommendations. The second volume described and documented each of the accidents included in the report. The study addressed three major safety issues: 1) identifying the factors affecting fatigue-related accidents, 2) determining truck drivers' understanding of these factors, and 3) determining the adequacy of the current hours-of-service regulations.

The NTSB investigated 113 single-vehicle heavy truck accidents where the driver survived. The NTSB employed standard investigative and probable cause determination methods in order to accurately collect information pertinent to the truck drivers' duty and sleep patterns for the 96 hours preceding the accident. In six of the 113 accidents investigated, the NTSB was unable to establish this 96-hour duty/sleep history; therefore, the NTSB limited the investigation to the remaining 107 accidents. Each of these accidents was then reviewed to ensure the accident information, vehicle, and physical evidence were appropriately and consistently used to determine probable cause (fatigue, traveling too fast for conditions, mechanical/vehicle defects, load shift, poor weather conditions, roadway hazards).

From September 1992 through June 1993, authorities in Alabama, California, Georgia, New Jersey, North Carolina, and Texas notified the NTSB of single-vehicle truck accidents. These states were chosen because of their close proximity to NTSB regional offices, allowing the driver to be interviewed within a few hours of the accident. In addition to reconstructing the accident sequence based upon physical evidence, investigators interviewed each driver in order to reconstruct the 96 hours preceding the accident.

Once the 96-hour period preceding the accident had been established, each driver was asked to respond to a standard set of questions regarding his/her duty/sleep history, work activity, educational background, motor carrier operations, driver oversight, and medical history. The NTSB did not specifically collect information pertaining to drug and alcohol use or influence.

A panel of NTSB staff reviewed each accident report to ensure vehicle and physical evidence were appropriately and consistently applied in the determination of probable cause. Fatigue was determined to be the probable cause in situations when a driver admitted to having fallen asleep or dozing while driving, when a preponderance of physical evidence existed consistent with fatigue (*e.g.*, shallow departure angle from roadway, no corrective steering/braking inputs), or when information within the driver's 96-hour sleep/duty history suggested a reduced state of alertness. The non-fatigue-related accidents included all of those incidents in which the probable cause was not identified to be fatigue-related. Some factors affecting these accidents included speeding, driving too fast for conditions, mechanical defects, load shifts, poor weather conditions, and roadway hazards. NTSB (1995a, 1995b) summarized the key results of their research efforts by drawing several conclusions based upon their findings.

- Base upon the Board's sample, duration of the most recent sleep period, the amount of sleep within the last 24 hours, and split sleep patterns are the most critical factors in predicting fatigue-related accidents
- Truck drivers in non-fatigue related accidents obtained an average of 2.5 hours more sleep (8 hours) in their last sleep period than drivers who were involved in a fatigue-related accident (5.5 hours)
- Truck drivers in non-fatigue related accidents obtained an average of 2.4 hours more sleep (9.3 hours) in their last 24 hours than drivers who were involved in a fatigue-related accident (6.9 hours)
- Hours of service regulations do not currently provide the opportunity for drivers to obtain sufficient rest (8 continuous hours) because they do not account for the driver's personal needs (travel, eating, personal hygiene, recreation, or inability to fall asleep immediately during their 8-hour off-duty time period)
- Sleep accumulated in small blocks hinders recovery of performance abilities

- A higher incidence of fatigue-related accidents was noted for drivers with irregular schedules (67 percent) as opposed to those keeping a regular schedule (38 percent)
- Of the drivers involved in a fatigue-related accident, a larger percentage of drivers exceeded the hours of service regulations (82 percent) as opposed to those who had not exceeded regulations (18 percent)

Accident overview. In order to describe the nature of the accidents, the NTSB reported key characteristics describing the accidents, the drivers, the vehicles, and the motor carriers. The summaries presented for each characteristic are based upon the descriptive statistics derived from the determination of probable cause in each of the 107 accidents studied. Extrapolating these results to the larger population may not be warranted as they were derived for the 107 accidents reviewed, and not for the larger population.

Fatigue and time of day were ascertained to be probable causes in 58 percent (62 of 107) of the accidents reviewed. Sixty-five percent (70 of 107) of the accidents occurred between 10 PM and 8 AM; of which 74 percent (52 of 70) were fatigue related. Of the accidents occurring between 8 AM and 10 PM, only 27 percent (10 of 37) were fatigue related.

A seven-point scale, anchored at 1 (very clearly) and 7 (not very clearly), was used to ascertain driver alertness by determining how well drivers remembered the 5-minute period immediately preceding the accident. A second seven-point scale, anchored at 1 (fully alert) and 7 (completely exhausted), was used to determine how alert drivers felt before the accident occurred. Drivers involved in fatigue-related accidents generally rated their memory as being less clear and being less alert than drivers involved in non-fatigue-related accidents.

The effect of pay was also considered. Of the drivers paid by the mile, 65 percent (28 of 43) had a fatigue-related accident. Of the drivers paid by the load, 46 percent (13 of 28) had a fatigue-related accident. Only 27 percent (3 of 11) of the drivers who were paid by the hour were involved in a fatigue-related accident. These results suggest an effect of payment method on fatigue-related accidents. While these results may be suspect given the relatively small sample size, they are consistent with an earlier NTSB study (1990a, 1990b) on fatal-to-the-driver heavy truck crashes.

Differences between long-haul and short haul trips were also evaluated. Trips exceeding 500 miles one-way or those that required the driver to be away from home for more than one night were classified as long-haul; the remaining trips were classified as short-haul. Fifty of the 107 drivers included in this study were identified as a long-haul trip, of which 34 had a fatigue-related accident. Of the remaining 57 short-haul drivers 49 percent (28 of 57) were involved in a fatigue-related accident.

The effects of solo versus team driving were also considered. Ninety-eight of the 107 accidents involved single drivers; approximately 54 percent (53 of 98) were attributed to fatigue. Eight of the nine accidents involving team or co-drivers were found to be fatigue related.

Trip duration was also evaluated. Sixty percent of the drivers who had been away from home for one or more days (37 of 62) were involved in a fatigue-related accident. A more complete breakdown of trip duration and probable cause (fatigue vs. non-fatigue) was not presented. Drivers averaged 251 miles on the leg of the trip in which the accident occurred; individuals involved in fatigue-related accidents averaged 320 miles, while those involved in non-fatigue-related accidents averaged 154 miles.

Driver sleep location was also evaluated. Of the 107 drivers involved in accidents, 51 percent of those who slept at home (27 of 53) in their last sleep period prior to the accident were involved in a fatigue-related accident. Of the drivers who slept in the sleeper berth in their last sleep period prior to the accident, 67 percent (28 of 42) were involved in fatigue-related accidents. Both of the drivers who last slept in their truck cab experienced fatigue-related accidents.

Discriminant analysis. In addition to reporting these key characteristics, a multivariate discriminant analysis was performed to evaluate the relationship between a set of 18 predictor measures, shown in Table 1, to the probable cause of the accident (fatigue-related or non-fatigue-related). Time of day was not included since the majority of single-vehicle accidents in this study (a criterion for inclusion) occurred at night. Complete sleep/wake measures could not be computed for 20 of the 107 drivers due to days off; therefore, these items were also excluded from the discriminant analysis. Of the remaining 87 accidents included in the analysis, 51 were found to have fatigue as a probable cause, while 36 were found to be non-fatigue-related.

Results from the discriminant analysis identified the duration of the last sleep period, the total hours of sleep obtained during the 24 hour period prior to the accident, and split sleep patterns as a primary set of measures for predicting the occurrence of

TABLE 1

Predictor Measures Evaluated in a Multivariate Discriminant Analysis (adapted from NTSB, 1995a)

DESCRIPTION OF PREDICTOR MEASURES	
Number of hours on duty:	In past 24 hours In past 48 hours In most recent duty period
Number of hours driving:	In past 24 hours In past 48 hours In most recent duty period
Number of hours slept:	In past 24 hours In past 48 hours In most recent duty period
Number of hours:	Since last slept Driving since last slept On duty since last slept
Duty/sleep pattern:	Irregular duty Irregular sleep Irregular duty/sleep
Other schedule-related measures:	Inverted duty/sleep periods Split-sleep pattern Exceeded hours-of-service limits

fatigue-related accidents. Drivers in non-fatigue-related accidents slept an average of eight hours in the most recent sleep period preceding the accident whereas drivers involved in fatigue-related accidents were found to have received only 5.5 hours of sleep in their last sleep period. Within the 24-hour period preceding an accident, drivers involved in fatigue-related accidents were found to have received 6.9 hours of sleep compared to 9.3 hours of sleep for drivers in non-fatigue-related accidents.

Approximately 30 percent (26 of 88) of the drivers were found to have had split-sleep patterns. These 26 drivers averaged only eight hours of sleep in the 24-hours preceding the accident and obtained just 4 hours of sleep in their last sleep period. The results of the discriminant analysis suggest that individuals experiencing split-sleep schedules are at a greater risk of being involved in a fatigue-related accident; however, a specific breakdown of the 26 drivers who were identified as having split-sleep schedules was not presented.

A secondary set of measures was also identified as predicting, to a somewhat lesser extent, the occurrence of fatigue-related accidents. These secondary measures include exceeding hours-of-service limits, number of hours driving in the preceding 24 hours, number of hours on duty in the preceding 24 hours, duration of most recent driving period, and the number of hours driving since last sleep. Of the accidents investigated where the drivers were found to be in violation of the hours-of-service limits; specifically, these drivers had driven more than 10 hours or had been on duty for more than 15 hours prior to taking their 8 consecutive hours off-duty. Of those drivers who exceeded the hours-of-service regulations and were involved in an accident, approximately 82 percent (22 of 27) of the accidents were found to be fatigue-related. Fewer hours to obtain adequate rest are a direct implication of exceeding the hours-of-service requirements. The duration of the most recent sleep period for drivers exceeding hours of service limitations was shorter (4.7 versus 7.2 hours) for those who were not in violation of the hours of service regulations. Similarly, drivers in violation of the hours of service regulations received fewer hours of sleep in the preceding 24 hour period (6.1 versus 8.3 hours) than whose who were not in violation.

Because of the potential effect on a driver’s sleep schedule, two additional measures, irregular duty/sleep patterns and inverted duty/sleep schedule, were evaluated further despite not being identified as major predictors from the discriminant analysis. Seventy-three percent (64 of 88) of the drivers experienced irregular patterns of duty or sleep. Approximately 67 percent (43 of 64) of the drivers experiencing irregular patterns of duty or sleep were involved in fatigue-related accidents. By contrast, only 38 percent (9 of 24) of the drivers with regular patterns of duty and sleep were involved in fatigue-related accidents. Inverted duty/sleep periods are defined as a driver operating at a time when 24 hours previously the driver had been sleeping. Inverted duty/sleep schedules were experienced by 17 of the 107 drivers; all but one (94 percent) were found to be involved in fatigue-related accidents.

Summary. The study conducted by the NTSB (1995a, 1995b) offers considerable insight into the factors affecting fatigue in heavy truck accidents. The most salient factors identified by the discriminant analysis include:

- the duration of the most recent sleep period
- the total hours of sleep obtained during the 24 hours prior to the accident
- split-sleep patterns
- exceeding hours-of-service limits

In addition to the factors identified in the discriminant analysis, some of the descriptive statistics suggest factors worthy of investigation in future research efforts examining truck-driver fatigue. These include:

- time of day (*e.g.*, circadian rhythm)
- pay schedule
- long-haul vs. short-haul operations
- solo driver vs. team driver operations
- trip length
- sleep location
- subjective self-assessment of alertness
- irregular and inverted duty/sleep patterns

Several factors limit the overall generalizability and applicability of this study. First, the method for selecting the sample population was such that the sample cannot be considered representative of truck collisions in general or single-vehicle collisions in particular.   For example, only accidents occurring in six states (Alabama, California, Georgia, New Jersey, North Carolina, and Texas) were included in the study. While chosen on the basis of proximity to NTSB regional offices, extrapolation of these results to other geographic regions may not be appropriate as the geography and weather conditions of these states may not be representative of the rest of the country.

Additionally, only those accidents where the driver survived were included in the sample population; more serious accidents involving multiple vehicles or the death of the driver may not follow the same pattern or result from the same set of proximate causes. Furthermore, much of the information collected was dependent on the accuracy of the information provided by the driver and may have been hampered by memory and the general unwillingness of the driver to provide accurate (potentially self-incriminating) information.

Another limiting factor, given the nature of this study, is the relatively small sample size. In a review of this study, the University of Michigan, Transportation Research Institute (Waller, Edwards, Nicholson, and Sheridan, 1995) notes that the comparisons of long-haul versus short-haul drivers are made using only 42 long-haul and 40 short-haul drivers, for a combined population size of 82. They note that the sample size shrinks accordingly when factors such as missing information or some cases that do not fall neatly into one category or another are considered.

Employing the multivariate discriminant analysis as the method of analysis was another factor that may have introduced bias into the results (Waller *et al*., 1995). One assumption of linear discriminant analysis is the underlying assumption predictor variables have normal probability distributions. If predictor variables are dichotomous, rather than being normally distributed, discriminations are not optimal (Rencher, 1995) but are biased, even with large samples. The dependent measures, specifically those related to duty/sleep schedules, are a combination of dichotomous and continuous measures. Logistic regression is one method of analysis that may be more appropriate given the current situation as it permits the use of dichotomous predictor variables. Logistic regression alone, however, would not be sufficient to eliminate the possibility of bias in the estimation of predictor parameters; the existence of confounding factors needs to be addressed. If the existence of confounding factors (two variables are confounded when their effects on a response variable cannot be distinguished from each other) is ignored in the design of experiments, distortions in the estimation parameters can subsequently result (Anderson, 1980 as cited in Waller *et al*., 1995). In this situation, given the high level of similarity that exists in the definition of the factors (*e.g.*, as previously mentioned, a violation in the of hours of service is likely to affect the hours of sleep an operator can have within a 24-hour period) it is highly likely confounding exists. Adjustment for the confounding factors can be conducted by explicitly entering the factors into the experiment one at a time as independent variables.

In addition to the previously mentioned issues, which primarily focus on the conduct and analysis of the experiment, the recommendations put forth by NTSB (1995a) are also somewhat suspect as they are presented without substantial foundation. For example, in making a recommendation for an hours-of-service rest requirement, the reasoning presented nominally compares truck rest requirements to that of aviation flight crews and briefly mentions circadian rhythms, but does little to formally discuss these nominal comparisons and address the overall complexity of the problem.

Despite this substantial list of shortcomings, it is important to recognize this study was directed towards describing only single-vehicle truck collisions in which the driver survived. This study represents the first step towards identifying variables capable of predicting truck driver fatigue. However, these variables must now be more fully refined such that in situ detection of fatigue is possible in order to prevent vehicle accidents before they occur.

Study 5: Driver Fatigue and Alertness Study

Released in 1996 by the Federal Highway Administration, this report (Wylie, Schultz, Miller, Mitler, and Mackie, 1996) represents the largest and most comprehensive over-the road study ever conducted on driver fatigue and alertness in North America. The goal of the Driver Fatigue and Alertness Study was to 1) observe and measure the development and progression of driver fatigue and degradation of driver alertness, 2) develop countermeasures for reducing fatigue, and 3) investigate the feasibility of a potential system capable of monitoring or predicting driver alertness.

The study involved 80 healthy, drug and alcohol-free, male drivers, ages 25-65, from the U.S. and Canada. The subjects were divided into four groups of 20, and each group presented with one of the following treatment conditions:

- Condition 1: 10-hour “baseline” daytime: 10 driving-hour turnaround route, starting at approximately the same time each morning for 5 consecutive days.
- Condition 2: 10-hour “operational,” or rotating: 10-hour driving turnaround route, starting about 3 hours earlier each day for 5 consecutive days
- Condition 3: 13-hour nighttime start: 13-hour driving turnaround route, starting at about the same time each night for 4 consecutive nights
- Condition 4: 13-hour daytime start: 13-hour turnaround route, starting about the same time each day for 4 consecutive days.

Conditions 1 and 2 were conducted in the U.S. on routes between St. Louis and Kansas City, Missouri. Conditions 3 and 4 took place in Canada on routes between Montreal, Quebec, and Toronto, Ontario. Wylie *et al*. (1996) defined fatigue as the state of the drivers manifested by the following:

- Increased lapses of attention
- Increased information processing and decision making
- Increased reaction time to critical events
- More variable and less effmctive control response
- Decreased motivation to sustain performance
- Decreased psychophysiological arousal
- Increased subjective feelings of drowsiness
- Decreased vigilance
- Decreased alertness

Independent variables investigated included driving duration, the time of day driving was initiated, and the amount of sleep obtained. Driving time was manipulated to assess the relative influence of the amount of time spent on task performance by the driver. Starting time was varied systematically in order to assess the relationship between schedule regularity and circadian rhythms. The investigators also monitored sleep duration to permit interpretation of driving time and circadian rhythm effects. Wylie *et al*. (1996) summarized the key results of their research efforts as follows.

- Time of day was the most consistent factor influencing driver fatigue and alertness; Time of day exceeded was a better predictor of decreased driving performance than hours of driving (time on task) or the cumulative number of trips made
- The quantity of sleep obtained by the participants while participating in the study was low (mean of 5.2 hours, about 2 hours less than their self-described ideal)
- Efficient quality and normally structured sleep was found to prevail as judged by formal clinical criteria
- Expert subjective facial expression ratings were more sensitive than polysomnographic (PSG) measures in detecting drowsiness
- Poor correlation existed between driver subjective self-ratings of alertness/sleepiness and concurrent objective performance measures; drivers tended to rate themselves as more alert than the performance tests indicated
- No significant relationship was found between driver age and fatigue

Performance measures. The dependent measures were comprised of direct and indirect measures of driving performance, physiological measures, and subjective measures. Performance measures consisted of lane tracking, steering wheel movement, and speed and distance (headway) monitoring. Physiological measures consisted of body temperature, polysomnography, and quantitative electroencephalogram (QEEG). Subjective measures included self-assessment of fatigue and experimenter assessment of alertness using video-recorded images to assess driver eyelid closure and facial expression. Indirect performance measures included a battery of surrogate tests, including: code substitution (CS) test, critical tracking task (CTT) test, and the simple response vigilance task (SRVT) test. Of these measures, lane tracking, code substitution test, simple response vigilance test, eyelid closure and facial expression, and the subjective assessment of fatigue as detected by the Stanford Sleepiness Scale were the dependent variables found to be the most sensitive indicators of the factors affecting fatigue.

Lane tracking was collected every five seconds. Drowsiness (based on the subjective observation of the driver's face from the video record) was found to be associated with increased lane position variability in all four conditions, but was statistically significant only for the Condition 1, 10-hour daytime start ($p < 0.003$) and Condition 3, 13-hour nighttime start ($p < 0.00003$). Lane tracking performance was better during the shorter (10-hour vs. 13-hour trips) ($p < 0.05$). These results suggest lane-tracking variability had a significant relationship with increased driving hours and increased cumulative number of trips; such results suggest lane tracking may be a useful predictor of fatigue.

The Code Substitution Test (CST) was used to measure information processing, perceptual speed, and response selection speed. In the CST, a letter was displayed on a 9-inch VGA screen, located to the right of the driver slightly forward of the dash instruments. The subject responded to the letter presentation by pressing a numbered key corresponding to the displayed letter on the screen (the subject was required to depress a coded key also displayed on the VGA screen, in order to determine which letter corresponded to the appropriate numerical response). The test was repeated 4 times/day for Conditions 1 and 2 (10-hour shift), and 3 times/day for Conditions 3 and 4 (13-hour shift). Each test period lasted approximately three minutes. The fourth test was omitted for the Conditions 3 and 4 (13-hour shift) because it would have caused drivers to exceed allowable time on-duty limits. Because performance on the test diminished during the trips in all four conditions, the CST was said to be a sensitive predictor of behavior changes commonly associated with acute (within trip) fatigue and decreased alertness.

The Simple Response Vigilance Test (SRVT) required the driver to press a button as quickly as possible after a stimulus (three digits), appeared on a 9-inch VGA monitor (located to the right of the driver slightly forward of the dash instruments). The test measured reaction time, which is correlated with sustained attention or vigilance. Test performance diminished from the first to last trip in all four experimental conditions. In addition, the scores indicated poorer performance at the end of trips than at the start. Based on these results, the SRVT was said to be a sensitive predictor of both acute and cumulative (across trip) fatigue despite the tendency toward poor performance in daylight, and extensive missing data. Based on these results, the study concluded the SRVT was the best performance test index of cumulative fatigue.

Observers analyzed recorded images of subjects' eyelid closure and facial expression to determine whether drivers "appeared drowsy." This technique was based on studies conducted by Wierwille and Ellsworth (1994). In addition to determining drowsiness, the observers were required to complete a questionnaire that focused on the drivers' behavior, such as chewing, singing, whistling, using the CB, or if they had droopy eyelids. The results indicated a direct correlation between the video and both the lane tracking and steering wheel movement data. Judgments of video were found to be more sensitive in detecting drowsiness while driving than methods based on PSG (polysomnographic) measures.

Five times within each 24-hour period, drivers provided a subjective assessment of their level of fatigue using the Stanford Sleepiness Scale (Figure 1, page 42). Results indicated no correlation with the objective measures; however, the subjective ratings were found to be correlated with hours of driving and cumulative number of trips.

Several criticisms of the current study exist. Considering the research branch of the American Truckers Association (ATA), an industry organization representing the interests of the trucking industry, conducted the study, it is questionable as to whether the study was conducted in an unbiased manner. The results identified time of day as the predominant cause of fatigue; Wylie *et al*. (1996) subsequently recommended longer driving hours. It is not so much that time of day is identified as a major contributor that is cause for concern, but rather the ease with which Wylie *et al*. (1996) discounted the role of time on-duty. The findings of this study conflict with the findings of several previously published research studies (Harris *et al*., 1972; Williamson *et al*., 1994; and NTSB 1995a, 1995b) showing the amount of time on-duty crucially contributes to driver safety and crash risk. While other research efforts have identified time of day as a contributing factor, they have also identified time spent driving as being a major contributing factor to driver alertness and fatigue.

The failure to recognize time spent driving as a significant contributor to fatigue may have been the result of a flawed experimental design. The routes selected by the researchers were limited both in selection (St. Louis to Kansas City, and Montreal, Quebec, to Toronto, Ontario) and duration (4 to 5 consecutive days). These limitations established a regular route for the drivers and failed to address the larger topic of irregular route scheduling, an issue that affects many drivers. Further, these two routes are unlikely to represent the weather, road conditions, and geography encountered by the majority of drivers. Similarly, the duration of the trips was reasonably short and do not represent the driver who is on the road for a week or month at a time. Another design-related concern is none of the drivers drove a 'full schedule'. That is, none of the drivers in the study exceeded 52 hours/week; the current hours of service regulations establish a maximum of 60 hours in seven days or 70 hours in eight days. Finally, team drivers were omitted from the sample. These shortcomings contributed to the flawed nature of the experimental design and may limit the generalizability of the results presented by Wylie *et al*. (1996).

It is also important to recognize the following limitations of the study and their potential impact on the results. The general intrusiveness of the equipment is one such limitation. The video camera used to monitor facial expressions was placed immediately in front of the driver, constantly reminding him of its presence and potentially impacting his behavior. Additionally, the polysomnographic data required the attachment of electrodes to the driver's chest. This could be considered to be excessively intrusive, and unlikely to gain widespread driver support if implemented as part of a 'fatigue detection' system. The administration of the surrogate performance test battery could also be construed as a limiting factor since the test required a response from the driver, which may have produced an arousal effect. Additionally, a large amount of glare was associated with the CRT display that, as the authors noted, could also have affected the results. Further, much of the data collected in this study proved to be unusable due to reasons related to excessive quantity or poor quality. Finally, no measurements of noise or vibration were taken. These environmental factors may affect fatigue and alertness.

Changing measurement methods of some variables and adding new variables might allow more accurate assessment of driver alertness and fatigue.

Summary. The study conducted by Wylie *et al*. (1996) found a correlation between the drowsiness, average lane tracking standard deviation, code substitution, average sleep, and the percentage of night driving. The results indicated the following driver characteristics between 0000 and 0600 hours:

- Increased drowsiness (judged by driver's face)
- Increased lane tracking variation
- Decreased score on Code Substitution Test
- Decreased overall amount of sleep obtained

The strongest and most consistent factor influencing driver fatigue and alertness was found to be time of day. While driving time was not found to be as important as time of day, it should not be completely dismissed, as driving time was found to be highly correlated with elapsed time from trip start and self-ratings of fatigue. Increased self-ratings of fatigue were found to correlate with increased driving time.

The Driver Fatigue and Alertness Study provided a set of general conclusions and relationships on several key issues surrounding commercial motor vehicle driver fatigue. Of particular value was the finding drivers experience normally structured sleep while participating, expert subjective facial expression ratings were more sensitive than polysomnographic (PSG) measures in detecting drowsiness, and no significant relationship was found between driver age and the occurrence of fatigue. Unfortunately, issues of poor experimental design and conduct diminish the overall credibility of this research effort and applicability of the associated results.

Study 6: The Impact of Local/Short Haul Operations on Driver Fatigue

Completed in 1999 by the Federal Motor Carrier Safety Administration, this report (Hanowski, Wierwille, Garness, and Dingus, In Press) was focused on determining whether fatigue was an issue in local/short haul commercial motor vehicle operations. From this research, Hanowski *et al.* (In Press) determined 1) that fatigue was present immediately preceding driver involvement in at-fault critical incidents, and 2) fatigue was not found to be attributable to the factors associated with the job, but rather to those factors which occurred in an individual's non-work home life.

Because of the differences in focus in the participant population and associated job requirements between the research conducted by Hanowski *et al.* (In Press) and current research project, a detailed discussion of the study results is not included herein. Of particular interest, however, is the methodology and data instrumentation employed by Hanowski *et al*. (In Press). Hanowski *et al.* (In Press) employed the first *in situ* data collection effort using fully instrumented data collection vehicles focussing specifically on the trucking industry.

Data collection system. A “black box” data collection system was developed for the on-road data collection effort. These systems provided Hanowski *et al.* (In Press) with a reliable (for long data collection intervals (24 hours) with no researcher present) and unobtrusive method for collection of driver alertness measures, driver attention and performance measures, and near-accidents/critical incidents.

System activation occurred approximately fifteen seconds after the vehicle ignition was turned on. The system remained on as long as the ignition was on, and it shut down when the vehicle was turned off. In addition, the system had a ‘suspend mode’ in order to conserve videotape and hard drive space (i.e., so that when nothing was going on as when the vehicle was stopped, no data were collected). The data collection system consisted of a video camera system, usual system sensors, and unusual system sensors.

The video camera system was comprised of five video cameras. Each camera measured 2.92 cm (1.15 in) square by 0.635 cm (0.25 in) deep with apertures measuring 0.0794 cm (0.03125 in) in diameter were used to collect the video information. The first camera was a forward looking camera capturing the roadway scene, a second camera focussed on the driver's face, the third and fourth cameras were focussed capturing the left- and right-side rear-view mirror information, and a fifth camera recorded the traffic situation behind the vehicle.

The usual system sensors typical of the types of sensors used in past field studies (*e.g.,* Hanowski, 2000). These eight sensors collected data on driver behaviors related to the accelerator, service brakes, reverse gear, steering, directional signals, cab microphone, incident push-button, and accelerometers. In addition to the usual system sensors, several unique sensors, not previously incorporated in a vehicle data collection system were employed. These included a backing sensor system, driveshaft sensor system, and ambient illumination sensor. The backing sensor system detected the closing distance to any object as a function of time during backing maneuvers. The driveshaft sensor system was instrumented with a non-contact distance and velocity measurement system in order to determine distance and velocity. Finally, the ambient illumination system was calibrated to distinguish 8 levels of illumination, from total darkness to intense full sunlight.

While the system was active, data were gathered continuously as long as the engine of the vehicle was running (unless the system had entered the 'suspend mode'). In order to manage more efficiently the enormous quantities of data collected by this continuous approach, a channel of the data gathering process was dedicated to flagging or identifying critical incidents. The flags identified areas of the videotape for in-depth analysis.

The approximate triggering criteria employed in this study are shown below; Hanowski (2000) reports that slight adjustments were necessary in order to accommodate differences (*e.g.*, 'play' in steering wheel) between each of the vehicles (Hanowski, 2000, p. 37):

1. Longitudinal deceleration above 0.5g (intended to sense panic braking) OR
2. Longitudinal acceleration above 0.5g (intended to sense being hit in the rear) OR
3. Absolute lateral acceleration above 0.25g and longitudinal speed above 32.19 km/h (20 mph) (intended to pick up evasive maneuvers) OR
4. Absolute steering angle rate above 6.28 rad/sec and longitudinal speed above 32.19 km/h (20 mph) (intended to pick up panic steering) OR
5. Absolute lateral acceleration above 0.5g (intended to pick up side collisions) OR
6. Actuation of a critical incident pushbutton.
7. Turn signals were used as a means of determining passing events.
8. Reverse lights were used as a means of determining backing events.

Data reduction. In addition to automatic flagging of potential incidents through vehicle sensors and the critical incident button (driver identified critical incident), critical incidents were also identified through manual review of the videotapes. Hanowski (1999) reports that analyst review proved effective in identifying any remaining (yet undetected) incidents. Subsequent to this review, the analysts assessed driver drowsiness by evaluating relevant dependent measures Observer Ratings of Drowsiness, PERCLOS (fatigue, the proportion of time during the interval that the driver's eyes were closed or nearly closed.), EYETRANS (inattention, the number of eye transitions made by the driver over the three minute), and EYESOFF (inattention, the proportion of time that the driver's eyes were off the road during the three minute interval,). Eye glance reduction, written description (narrative) of the incidents, and digitization of the video data were also performed.

Summary. The study conducted by Hanowski *et al.* (2000) found that fatigue was present immediately preceding driver involvement in at-fault critical incidents; however, it was not found to be attributable to the factors associated with the job, but rather to those factors which occurred in an individual's non-work home life. Of particular interest, however, was the methodology and data instrumentation employed by Hanowski *et al*. (2000). This research represented considerable advancement in the state of the art of data collection and logging and represents a huge improvement over previous data collection efforts that required obtrusive data collection units or the presence of an experimenter during the performance of the task. Despite these advantages, however, the volume of data collected still represented a formidable obstacle and required considerable resources for reduction and analysis.

LONG-HAUL FOCUS GROUPS

In addition to those factors identified in the preceding review of five large-scale studies, Neale, Robinson, Belz, Christian, and Dingus (1998) employed focus group interviews in an effort to identify all relevant factors related to long-haul driver fatigue. Ten focus groups were held in eight cities, across seven states, between September, 1997, and February, 1998. The cities in which the focus groups were held were selected in an effort to represent, within the contiguous United States, a geographical cross-section of drivers employed by the long distance commercial trucking industry. The purpose of these sessions was to gain an understanding, from the drivers' perspective, of the issues affecting the quality and quantity of sleep drivers receive, as well as other issues that may affect drivers' levels of fatigue. The information gathered from the sessions was used to determine the controlled, manipulated, and dependent variables to be examined in the subsequent on-road study intended to assess the impact of sleeper berth usage on long-haul driver fatigue.

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 ½ years (ages were inadvertently not recorded for 8 of the 74 drivers). Both union and non-union drivers were represented; with 23 of the 24 union drivers participating in a single, union-only focus group. Single and team drivers, company drivers and owner-operators, and haulers of flatbeds, vans (singles, doubles, and triples), refrigerated units, and hazardous material were all represented.

Drivers' comments from the focus group are summarized into nine general areas: Team Driving, Equipment Issues, Facilities, Enforcement Issues, Private Driver Education, Terminus Issues, Company and Dispatcher Issues, Training Issues. Table 2 provides a brief summary of driver recommendations and comments for improving driver rest and reducing overall fatigue; a more thorough discussion of individual issues can be found in Neale *et al*. (1998).

While drivers identified these issues as affecting fatigue and quality of sleep, addressing each issue is clearly beyond the scope of the current research effort. Two major categories of issues, team driving and equipment, are particularly relevant and within the scope of the current research effort. These issues are salient, capable of being addressed in a study of this magnitude, and, if resolved, could provide a significant

TABLE 2

Summary of Driver Recommendations and Comments for Improving Driver Rest and Reducing Overall Fatigue

CATEGORY	EXPLANATION
Team Driving	Many drivers are incapable of obtaining quality rest in a moving vehicle; therefore, team drivers should be selected on the basis of their ability to sleep in a moving vehicle If teaming, drivers should be allowed to choose their driving partner such that it is someone they trust If teaming, drivers should know their schedules far enough in advance to allow the drivers to establish who will be driving first. This will enable the partner schedule to drive first to prepare by obtaining adequate rest prior to driving. If teaming, 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 may be assigned to different trucks. Improved noise insulation is needed between the cab and the berth. Better noise insulation is needed between the inside and outside of the cab. Better thermal insulation is needed for the tractor. Proper maintenance is required to ensure the quality of ride.
Facilities	Drivers need rest stops located at frequent, regular intervals. Rest stops should provide adequate parking. Safety measures to protect drivers while they are parked at rest areas and truck stops should be provided. Clean and safe facilities at which to shower should also be provided.
Enforcement Issues	Consistent enforcement of federal and state regulations should be supported. Allow trucks to travel at the same speed limit as private vehicles.
Private Driver Education	Private drivers should be educated in 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 loosing their place in line. Drivers should always have the option to sleep if they feel it is necessary as opposed to loading or unloading. If drivers are loading or unloading a vehicle, equipment necessary to do the task should be provided for them. Driver should be able to load and 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 that he or she must rest should be eliminated. For drivers on call, the company should provide enough notice to drivers to allow drivers to plan and obtain an adequate amount of sleep prior to driving. Drivers should have the time available to stop driving and sleep during particularly fatiguing driving times, which may be different for each driver.
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 the trainer gets adequate rest.

improvement for drivers. A more thorough discussion of the issues related to these specific categories follows.

Team Driving

Team versus single driving was identified as a very important issue for drivers regarding quality and quantity of sleep. Almost without exception, drivers expressed strong feelings in favor of or against team driving. Those drivers preferring team driving indicated they had little or no difficulty sleeping in a moving truck and were comfortable trusting their partner with their life. It is noteworthy many of the team drivers who were satisfied with a team arrangement were driving with their spouse.

Alternatively, of those drivers who did not like team driving, many stated they could not sleep in a moving truck. Several reasons were given, including a lack of confidence in their partner's ability to drive safely, a partner who could not drive smoothly (gear shifts, lane changes, braking maneuvers, and so forth must be executed flawlessly to avoid sudden vibrations of the sleeper compartment), and general lack of consideration by the non-driving partner (*e.g.*, volume on CB or radio too high). Another reason given for not obtaining a high quality sleep when team driving was directly attributable to sleep/wake cycles. Drivers commented sometimes they simply are not tired when it is their turn to sleep or that they must "wind down" or relax after driving prior to sleeping.

Scheduling also affects a driver's ability to obtain quality sleep. Team drivers indicated it is beneficial, when coming back to work after having a few days off, to have planned ahead of time who would drive first. In contrast, if both drivers were awake during the day and returned to work at night, one of the drivers would still have to drive up to 10 hours before being able to go to sleep. This is a particular problem for drivers who are on short notice "make-up teams," since they do not have the opportunity to make prior arrangements with their partners (single drivers experience a similar problem if they are unsure of their departure time). Another issue for team drivers occurs when driving in 10-hour shifts when the driver becomes tired before his/her 'shift' is over. In these circumstances, while the drivers may be tired, they are reluctant to stop driving since it is their 'turn' behind the wheel. When this occurs, some drivers indicated that they may stop to take a 15 to 20 minute "power nap" hunched over the steering wheel while others do not stop. In contrast, some teams (those with double bunks available, and married couples) reported trying to stop the truck for 4 to 6 hours each night so that both drivers could obtain at least a few hours of quality sleep.

Equipment Issues

In general, it was felt conventional and longer wheelbase trucks cabs created more comfortable sleeping quarters than did cabovers; however, cabovers and short wheel-base trucks in general were said to be easier to maneuver in confined spaces. Air-ride cabs were also said to be more comfortable for both driving and sleeping than spring-ride cabs. In addition, drivers mentioned several potential improvements for the design of truck cabs and sleeper berths. Equipment maintenance issues were also mentioned. Cleanliness of the cabs in situations where drivers may be assigned different tractors for each trip is said to have an effect on the drivers' attitude and ability to rest and sleep in the sleeper berth.

The subject of noise insulation was brought up on several occasions. One problem specific to team driving is the insufficient noise reduction between the truck cab and the sleeper berth. The drivers explained uninsulated walls or curtains were not sufficient to isolate the sleeping portion from the noise in the driver's compartment. Furthermore, the isolation of the tractor's interior from outside noise, both while the truck is stationary and moving, was said to be inadequate. Many drivers indicated when the truck is stationary, insulation from the outside noise is important for sleep. When the truck is moving, both the driver and, if teaming, the person sleeping, appreciate protection from the road noise.

The lack of thermal insulation in the truck cab was also mentioned repeatedly. Many drivers felt the walls of the sleeper berth compartment should be better insulated so a person in the sleeper berth does not have to sleep against a cold and possibly damp wall in colder climates. Also, some states and companies do not want drivers to let their trucks idle while they are stopped to sleep in rest areas or truck stops. For this reason, drivers believe trucks should be better insulated against both heat and cold. Drivers also suggested portable heating and air conditioning systems would be useful for those times when the truck should not be left idling. Related to this last point, the drivers thought the lack of separate heat and air conditioning systems in the cab and sleeper berth was problematic.

SLEEP

Much has been written about sleep. Consequently, a complete and comprehensive discussion of this topic is beyond the scope of this research effort. However, given the focus of this research effort, it is prudent given to briefly discuss three aspects related to sleep – sleep physiology, sleep quality, and several issues related to intrusive sleep onset.

Sleep Physiology

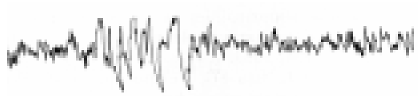
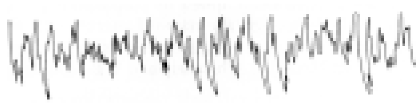
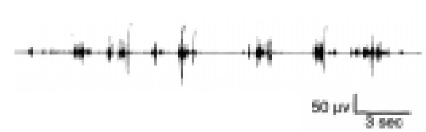
Sleep has been identified by such behaviors as stereotypic posture, reduced motility, reduced response to stimulation, and reversibility, among others (Ogilvie and Harsh, 1994). While such behaviors contribute to a reasonable and intuitive understanding of sleep, they fail to consider the changes in electrical activity within the brain that uniquely defines sleep. Changes in brain electrical activity occur as an individual transitions from wakefulness to sleep and back to wakefulness. These changes are physiological in nature and are frequently quantified through the use of electroencephalograms (EEG), electromyograms (EMG), and electrooculograms (EOG) with EEG measures being the most common.

Electroencephalograms (EEG) have been used to identify at least five stages of sleep in addition to the state of wakefulness. It is worth mentioning the cyclic nature accompanying the gradual transition from wakefulness to sleep. Carskadon and Dement (1994), Guyton and Hall (1996), Hobson (1989), Moorcroft (1989), and Ogilvie and Harsh (1994) each present a brief discussion of the different physiological and behavioral aspects associated with each of these stages. A graphical integration of the information presented in their respective works is shown in Table 3 while a descriptive integration follows.

Wakefulness. During this period, eye movements are relatively frequent and less erratic than those occurring during REM (Rapid-Eye-Movement) sleep. Fast, irregular, and low amplitude (voltage) beta (> 13 Hz) brain waves or somewhat slower, regular, alpha (8-12 Hz) waves of a moderate amplitude are characteristic of wakefulness. Presuming no other outside influences, muscle tone and reaction times are near ceiling performance levels.

TABLE 3

Stages of Sleep and Their Related Electroencephalogram, Electro-oculogram, and Electromyogram Characteristics (adapted from Carskadon and Dement, 1994 and Moorcroft, 1989).

SLEEP STAGE	ELECTROENCEPHALOGRAM (EEG)	ELECTRO-OCULOGRAM (EOG)	ELECTROMYOGRAM (EMG)
Wakefulness			
Stage 1, NREM			
Stage 2, NREM			
Stage 3, NREM			
Stage 4, NREM			
REM			

Stage 1 NREM. Stage 1, or sleep onset, is characterized by very light sleep or drowsiness; this stage usually lasts just a few minutes. Detection of this stage of sleep is difficult, as there are few physiological distinctions between wakefulness and Stage 1 sleep. EEG signals characteristic of sleep have not yet begun to develop; however, a mixture of relatively low voltage (50-100 MV), predominantly theta (4-7 Hz) waves are present. Further, muscle tone and reaction time decline during this stage. Finally, slow rolling eye movements of several seconds or more, as measured by EOG, are characteristic of this stage. If the sleeper is not disturbed by anyone or thing, he/she will quickly journey into Stage 2 sleep.

Stage 2 NREM. Stage 2 is characterized by a much deeper sleep than Stage 1. Towards the end of Stage 1 or the onset of Stage 2, dreamlike mental experiences may proliferate in a sleep-thought mode where vague thoughts and ideas drift through the sleeper's mind as the brain continues to process its own visual data. Convulsive muscle twitches accompanied by feelings of falling may occur during this stage as well. Eye movements are absent during this stage. EEG shows complex theta and delta (not exceeding 20%) waves in a sleep spindle (characterized by a burst of 12 to 14 Hz waves lasting at least 0.5 seconds) or 'k-complex' (characterized by a high amplitude sharp negative wave followed by a smaller, low amplitude positive wave where the total lasts at least 0.5 seconds). The amplitude of these waves range from 50-150 MV. If the sleeper remains undisturbed, Stage 3 sleep will follow.

Stages 3 & 4 NREM. Delta sleep, also known as Stages 3/4 are distinguished by low frequency (0.25-4) delta waves of relatively high voltage (100-200 MV). The continued occurrence of spindle waves and an occurrence of 20% to 50% delta waves characterize Stage 3. During this stage, the sleeper's muscles are relaxed and his/her heart rate has slowed. The sleeper's blood pressure is also falling and his/her breathing is steady and even. Stage 4 represents the deepest level of sleep and is very similar to Stage 3; however, it is characterized by an occurrence of greater than 50% delta waves. Individuals in Stage 3/4 sleep are very difficult to wake.

REM. REM (Rapid Eye Movement) is easily distinguished from the preceding stages and is the time during which the brain is most active, if not formally psychotic (Stickgold and Hobson, 1996). The cyclic nature of the sleep cycle indicates REM occurs about once every 90 to 100 minutes, is associated with vivid dreaming, and occupies approximately 25% of an individual's sleep time (more for children, less for older adults).

During REM, the motor and sensory systems are distinctively altered; fast, low voltage, and random sawtooth-like waveforms characterize the EEG. Specifically, the central motor neurons are activated, the result are evident by sharp EOG waveforms revealing twitches and REM. Similarly, the spinal motor neurons are deactivated or turned off during REM, yielding a temporary paralysis known as atonia. Consequently, muscle activity, as measured by EMGs, is small or non-existent. Additionally, the brainstem is activated by Ponto-Geniculo-Occipital (PGO) waves, providing considerable internal stimulation thereby fostering the occurrence of dreams while simultaneously blocking stimuli from the external environment. Other physiological responses during REM include an increase in heart and breathing rates accompanied by increased blood pressure.

Sleep cycle. The transition from wakefulness to sleep and back to wakefulness is cyclic in nature and shown in Figure 1. An individual transitions from wakefulness through the first and second stages of sleep and into a relatively long period of Delta or Stage 3/4 sleep, occasionally lasting 40 to 90 minutes. After approximately 90 to 100 minutes the sleeper transitions to REM sleep; the first REM period will last between five and 20 minutes. After that, the sleeper returns to Stage 2 sleep and then a deep Delta or Stage 3/4 sleep. Again, after a period of time, the sleeper's REM begins. The time period of each sleep cycle remains approximately the same (~90 minutes); however, as the sleep period progresses, the Delta sleep time decreases while REM time simultaneously increases with successive cycles, eventually lasting a half an hour or longer. The individual continues to cycle through REM and Stage 2 sleep until the sleeper is woken up. An average adult may complete four to five such cycles in a normal sleep period. Table 4 shows the time and percent allocation for the stages of sleep in a typical night's sleep for both healthy young adults and retired individuals.

Sleep Quality

Spiegel (1981) defines sleep quality as being predominantly a subjective assessment. It is not uncommon for individuals experiencing nearly identical nights of sleep, as recorded by EEG and similar physiological measures, to report experiencing two very different qualities of sleep. Generally, however, a subjectively good night of sleep when compared to a poor one, is often identified as having fewer periods of wakefulness, fewer sleep stage shifts, very little Stage 1 sleep, and increased REM sleep (Borbely, 1986; Moorcroft, 1989). The length of sleep, the quantity of Delta sleep, nor the REM /

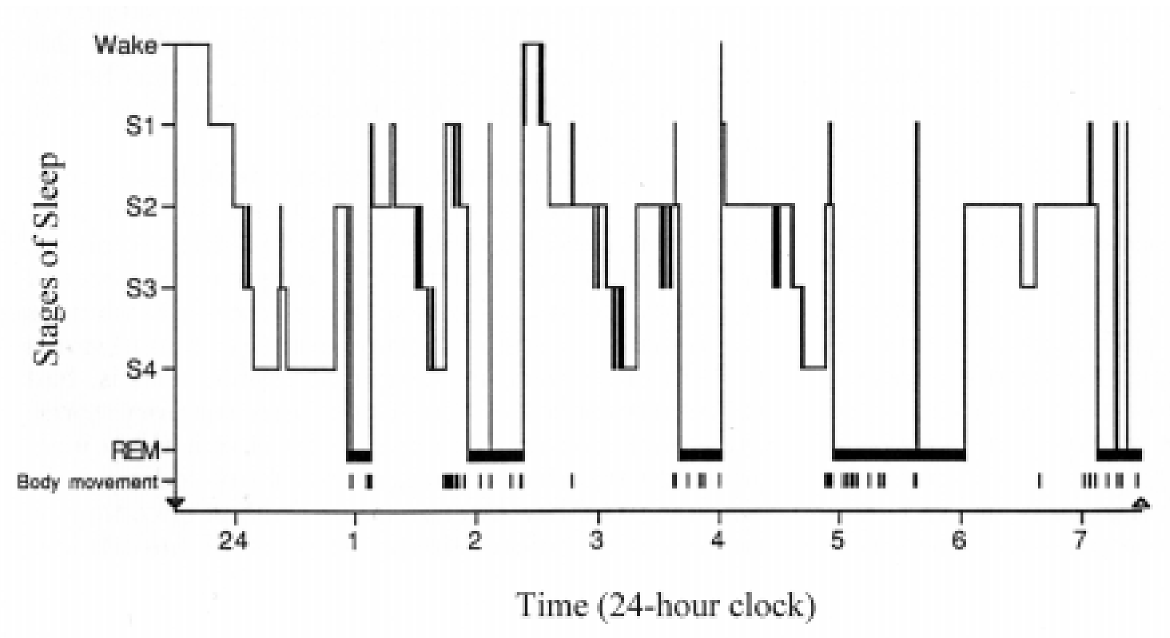


Figure 1. The cyclic transition from wakefulness to sleep and back across a single night of sleep for a normal young male adult (adapted from Carskadon and Dement, 1994).

TABLE 4

Sleep Stage Allocation in a Typical Night's Sleep for both Healthy Young Adults and Retired Individuals (adapted from Moorcroft, 1989).

	HEALTHY YOUNG ADULT	**HEALTHY RETIRED ADULT**
Time in Bed (hrs, min)	7 hrs, 21 min	7 hrs, 31 min
Total Time Asleep (hrs, min)	7 hrs, 4 min	6 hrs, 46 min
Time to Get to Sleep (min)	9	13
Number of Awakenings (> 30 s)	2	5 (♀ fewer)
Time Spent Awake (%)	1.2	8.5
Time Spent REM (%)	26	22.5
Time Spent Stage 2, NREM Sleep (%)	51	56
Time Spent Stage 3 / 4 (Delta), NREM Sleep (%)	16	5
REM Cycle (min)	105	100
Sleep Efficiency	0.96	0.88
Number of Sleep Stages	36	41

NREM sleep cycle length have been shown to be good predictors of an individual's quality of sleep (Moorcroft, 1989).

Psychological, environmental, and physiological stressors have been shown to be three primary contributors to poor sleep quality in normal, healthy sleepers (Moorcroft, 1989). Psychological stress can be positive or negative in context and may occur as a result of an event that has already occurred or in anticipation of one yet to transpire. Noise has been identified as one of the most prevalent and pervasive environmental stressors and has been shown to disrupt sleep even in individuals who have adapted to sleeping in noisy environments (Nakagawa, 1987). Temperature and barometric pressure have also been shown to be environmental stressors affecting sleep quality. Temperatures in excess of 75° F (24° C) have been shown to decrease sleep quality while simultaneously increasing sleepiness; increased sleepiness has also been reported during extreme changes in barometric pressure (Borbely, 1986; Moorcroft, 1989). Physical fitness (*e.g.*, exercise, weight gain/loss) and the presence of pain from injury have been identified as physiological stressors affecting the quality of sleep. Pain from injury has been shown to adversely affect sleep quality. Shorter, fragmented sleep has been associated with considerable weight loss, while a similar weight gain has been associated with longer, uninterrupted sleep (Moorcraft, 1989). The effects of exercise are mixed and depend largely on the characteristics of both the individual and the exercise being performed (Moorcraft, 1989).

Bonnet (1986) and Chase (1986) have been involved in determining the characteristics of a night's sleep that leads to increased levels of sleepiness on the subsequent day. Both researchers report the number of arousals occurring during sleep as being related to daytime drowsiness. Furthermore, they conducted an experiment in a controlled sleep lab where normal sleepers had their sleep interrupted briefly but frequently. The typical occurrence of sleep stages and their respective lengths were unaffected in this study as the arousals were designed to be extremely brief (between 2 and 10 seconds of state change). Results indicated that participants who were interrupted once a minute reported high levels of subjective sleepiness, while those participants interrupted once every five minutes reported much lower levels of subjective sleepiness. Consequently, poor sleep quality may be related to the frequent disruption of sleep continuity (Moorcroft, 1989).

Intrusive Sleep Onset

Alertness, fatigue, and drowsiness are interrelated and oft-confounded entities directly associated with an individual's arousal level and the occurrence of intrusive sleep onset. These quantities are very similar; however, nuances between meanings do exist and their distinctions are important. Levels of drowsiness, fatigue, and arousal are somewhat more evident in the physiological domain, while alertness pertains more directly to the psychological domain. For example, levels of alertness and arousal frequently parallel one another; as one quantity increases or decreases, so too does the other. Daydreaming, however, is one example of an exception to this relationship; an operator's arousal level may be quite high – that is, the driver demonstrates few of the classical physiological symptoms of drowsiness – but his/her level of alertness (and ability to respond to stimuli in the environment) may be quite low. Similarly, lower levels of alertness frequently accompany fatigue; however, the corollary is not always true. For example, the onset of boredom or similar phenomena may cause a decrease in alertness without a causing a corresponding increase in fatigue (it is worth noting prolonged boredom is associated with a decreased state of arousal and increased drowsiness and fatigue).

Intrusive sleep or drowsiness facilitates an individual's progression from wakefulness into Stage 1 sleep and beyond. During this time, an individual's mental facilities may or may not detect the perception of sleepiness itself (*e.g.*, dulled senses, feelings of tiredness) and may or may not notice degradation in their ability to successfully process data or perform a task. Regardless of an individual's ability to detect its onset, drowsiness or intrusive sleep onset may be operationally defined as "an undesirable decrease in arousal level to the point that satisfactory performance is no longer possible" (Erwin, 1976, p. i).

It is worth noting previous research (Davis, Davis, Loomis, Harvey, and Hobart, 1937; Ogilivie and Harsh, 1994; Ogilivie and Wilkinson, 1988) indicates there exists no precise point, physiological or behavioral, associated with sleep onset. As previously explained, sleep onset corresponds with the occurrence of the difficult to detect Stage 1 sleep. Successful detection of sleep onset is an important aspect of assessing a driver's ability to safely operate a vehicle. Consequently, since successful operation of a motor vehicle is heavily reliant on a driver being able to detect and respond to visual cues in the driving environment, intrusive sleep onset is presented by Erwin (1976, p. ii) as being "that moment when persistent eyelid closure occurs".

FATIGUE

While the concept of fatigue is fairly easily understood, the scientific community has yet to reach a universally agreed upon definition. Many definitions have been offered: "…fatigue is a general term to describe manifestations of extended time on task and insufficient rest…" (Wierwille and Muto, 1981); "…fatigue is a term used to cover all those discernable changes in the expression of an activity which can be traced to the continuing exercise of that activity under its normal operation conditions, and which can be shown to lead, either immediately or after delay, to deterioration in the expression of that activity, or, more simply stated, to the results of the activity that are not wanted…" (Bartlett, 1977, p.1); "…the subjective experienced disinclination to continue the task at hand…" (Brown. 1994, p. 302); "…there are, therefore, two interrelated aspects of the practical problem of driving and fatigue, namely the fatigue arising from driving – operational fatigue – and the effect of whatever source, on driving…" (Crawford, 1961, p. 143). Bartley and Chute (1947) reserve the definition of fatigue to the purely subjective interpretation of the individual. Olsen and Post (1979) recognized the notable weaknesses in the definitions of fatigue and identified nine distinct conditions warranting individual attention: acute, chronic, accumulated, exhaustive, boredom, loss of alertness, uncontrollable sleepiness, hypnotic-like states, and subjective fatigue.

In light of this lack of a universally agreed upon definition of fatigue, it may be more useful to define fatigue operationally, or in terms of its relevant symptoms. In the language of experimental modeling, fatigue is a latent or theoretical variable that cannot be measured directly. To observe such a variable, a model must be developed which expresses the latent variable in terms of observable or manifest variables (Bacon, 1998). Fatigue can be defined in terms of three categories of observable variables: performance, physiological, and opinion (subjective) measures (Wierwille and Muto, 1981). An additional category, behavioral or cognitive measures, supplements those mentioned by Wierwille and Muto (1981).

Performance Measures

Performance measures, or measures of direct vehicle control, offer the most intuitive and least intrusive methods for detecting a loss of alertness or the onset of fatigue. A major limiting factor of performance based measures, however, is a decline in performance capacity may in fact occur prior to changes in driver performance (Dinges and Graeber, 1989, as cited in Williamson *et al.*, 1994). This phenomenon can be attributed to driver skill and the ability of more experienced drivers to compensate during a relatively routine driving task, despite their diminished capacity. Despite this shortcoming, performance measures representing physical manifestations of driver performance provide insight into the operational effects of fatigue. Common performance measures include velocity maintenance, steering measures, and unplanned lane deviations.

Velocity maintenance. Previous research such as the studies conducted by Hulbert (1972), Platt (1963), and Safford and Rockwell (1967) indicate as a driver becomes increasingly fatigued, speed control or velocity maintenance deteriorate. That is, as fatigue increases so does the velocity variance; therefore drivers tolerate increased speed control variability. This increase in variability and reduction in vigilance also suggests that the number of abrupt braking maneuvers will also increase.

It is worth noting that Brown, Tickner, and Simmonds (1970) found drivers affected by fatigue might attempt to adapt by reducing their overall velocity. Williamson *et al*. (1994) compared the mean velocity after two hours of driving (towards the beginning of a trip) with the mean velocity after 11 hours of driving (towards the end of the trip) and found no significant differences. It is possible this conclusion may have been erroneously reached; especially considering arousal factors were not considered (*e.g.*, arousal may occur as expectation of trip completion increases) by Williamson *et al*. (1994). It may be valuable, in subsequent applications of this measure, to correlate reduced velocity with other measures of fatigue (*e.g.*, observer rating of drowsiness) in order to determine the sensitivity and applicability of this measure.

Steering measures. Platt (1963) was among the first researchers to employ steering wheel reversals as a measure of driver performance. Steering reversals are comprised of two measures 1) the time between a steering wheel turn in one direction and a corresponding correction in the normal maintenance of vehicle control, and 2) the magnitude of the reversal. Employing this measure, Safford and Rockwell (1967) studied drivers in a 24-hour driving task and reported that steering reversals generally increased over time, thus suggesting fatigue induced reduction in vigilance and decreased driver performance. Wierwille and Muto (1981) offered more detailed results. They found during a long-duration simulator-based driving task, the number of steering reversals greater than two degrees increased while the number of small steering reversals (one-half to two degrees) were found to decrease. Mean steering reversal amplitude and standard deviation also increased over time. The implication of this trend is non-fatigued drivers detect and respond to environmental changes quickly with tight, precise corrections whereas fatigued drivers appear to have an increased detection threshold for what may constitute a necessary change and are not likely to respond as quickly as non-fatigued drivers. Fatigued drivers, therefore, are more likely to make fewer, more coarse corrections. Abrupt lateral maneuvers and the number of near misses are two additional measures related to steering and vehicle navigation, which tend to increase with increasing fatigue.

Unplanned lane deviation. Through simulator-based driving tasks, overall road position error has been found to increase with time (Sussman and Morris, 1970; Wierwille and Muto, 1981). This increase in road position error over time suggests measures of lane position error may indicate driver inattention, fatigue, or a reduced state of vigilance; however, such results may also be explained by the driver's reaction to traffic position (Bishop, Madnick, Walter, and Sussman, 1985). Bishop *et al*. (1985) elaborates by reporting on Trigg's (1980, no citation provided in Bishop *et al*., 1985) demonstration that vehicles travelling in opposite directions on a two-lane roadway will cause drivers to steer away from the dividing centerline.

Given that overall road position error is easily influenced by environmental criteria, it may be more useful to redefine the criteria as unplanned lane deviations. Unplanned lane deviations may be defined as crossing a lane divider (either into another lane, or onto the shoulder of the road) not as a result of an intentional maneuver of the driver. Less likely to be influenced by traffic conditions (other than roadway obstacles), several researchers have found unplanned lane deviations/departures to be effective measures of driver performance (Harris *et al*., 1972).

Physiological Measures

Dinges and Graeber (1989, as cited in Williamson *et al*., 1994) indicated a serious loss of physiological arousal and slowed sensorimotor function may exist despite a driver's ability to compensate while suffering from a diminished capacity due to fatigue. While driving performance measures may be relatively insensitive to a moderate diminished mental capacity, diminished capacity occurring as a result of fatigue is likely to be detectable by a set of fundamental physiological measures. Physiological measures, since they provide a direct objective measurement of the fatiguing system, are the measures most likely to provide a direct measure of fatigue. This is especially true of a measure such as electroencephalography (EEG) which provides insight into cerebral arousal. One notable shortcoming of physiological measures is they are not easily measured in an unobtrusive manner. Common physiological measures sensitive to the onset and detection of fatigue include: adrenaline/noradrenaline production, cortocosteroid production, brain electrical activity, eyelid closure, eye position/eye movement, heart rate, and gross body movement.

Adrenaline/noradrenaline production. Adrenaline and noradrenaline are general, non-specific, indicators of arousal. Adrenaline is generally more sensitive to mental arousal while noradrenaline is a more sensitive indicator of physical exertion (Hartley, Arnold, Smythe, Hansen, 1994). Levels of both chemicals have been shown to correlate well with an individual's state of arousal and with the efficiency with which boring monotonous tasks are performed (O'Hanlon, 1970, cited in Mackie *et al*., 1974). Mackie *et al*. (1974) demonstrated, over time, levels of adrenaline and noradrenaline decrease while driving. Results reported by Hartley *et al*. (1994) contradicted those reported by Mackie *et al*. (1974) as production of adrenaline and noradrenaline were found to increase over time while driving. A complete discussion of the possible explanations for this difference is beyond the scope of this discussion; however, two possibilities are presented: 1) differences in the scheduled collection times (all samples from a single day being combined vs. analyzing individual samples separately), and 2) a very small sample size of three drivers for the work reported by Hartley *et al*. (1994).

Corticosteroid production. Similar to adrenaline, production of cortisol is thought to increase during periods of stress (Collins and Weiner, 1968, cited in Mackie *et al*., 1974). Mackie *et al*. (1974) demonstrated that, over time, levels of cortisol decreased in individuals performing a driving task. No other references pertaining to cortisol were found in the literature.

Brain electrical activity. Electroencephalograms (EEG) record brain-wave activity and have been found to be valuable indicators of fatigue. The presence of Alpha waves (8-13 Hz) represents a state of relaxation and impending drowsiness; Theta (5-7 Hz) and Delta (0.5-5 Hz) wave replace the Beta waves as sleep onset occurs (Bishop *et al*., 1985). A decline in performance due to sleep onset is accompanied by the slowing cerebral activity, an increase in the occurrence of Theta waves and a corresponding decrease in Beta wave percentages. Several researchers, Kuroki, Kitakawa, and Oe (1974), Lemke, (1982), Mackie *et al*. (1974), Planque, Chaput, Petit, Tarriere, Chabanon, (1991), Seko, (1984), Sussman and Morris (1970), and Yajima, Ikeda, Oshima, and Sugi (1976), among others, have demonstrated the utility of EEG in determining states of reduced arousal and the onset of fatigue. One notable shortcoming of EEG is it cannot be easily collected in an unobtrusive manner.

Eyelid closure. Erwin (1976, p. xii) found eyelid closure to be "the cleanest and most stable signal" of the onset of sleep. Specifically, the eye aperture in the open position measures approximately 13mm +/- 1.5mm and remains stable across multiple subjects with relatively little between-subject variation. Additionally, there is almost no within-subject variation over time. Similarly, Dingus, Hardee, and Wierwille (1985), Skipper, Wierwille, and Hardee (1984), and Skipper and Wierwille (1986) identified eyelid closure as a valid measure of degraded task performance due to the onset of fatigue. Indeed, Erwin (1976) is reported (Skipper and Wierwille, 1986) as defining drowsiness, an aspect related to fatigue, as the point where persistent eyelid closure occurs. Further research conducted by Skipper and Wierwille (1986) and Wierwille and Ellsworth (1994) provide empirical evidence supporting eyelid closure as a valid measure of driver fatigue.

Eye position/eye movement. Bishop, *et al.* (1985) suggest eye movements are the most sensitive indicators of driver attentional status. A principle indicator of REM sleep is a burst of rapid eye movements. While this is unlikely to occur while an individual is driving, REM may occur briefly if the driver is experiencing a high level of fatigue. Drivers experiencing fatigue are more likely to exhibit slow eye movements (SEM).

SEMs are characteristic indicators of transition between wakefulness and sleep (Kryger, Roth, and Dement, 1994) and are easily distinguished from those exhibited by a person who is fully awake. A well-rested individual who is completely awake exhibits quick eye movements. During sleep onset, the number of quick, seemingly random eye movements begin to decrease and an individual's eyes will begin to move in a lateral pendulum-like motion (Hiroshige and Niyata, 1990). Both alertness and attentiveness have been found to decrease; Endo, Inomata, and Sugiyama (1978) found that attentiveness dissipates with sleep onset due to the decrease in the number of lateral voluntary eye movements that are commonly used to monitor the surrounding driving environment (*e.g.*, monitoring rear-view mirrors and side windows). Similarly, Bishop *et al*. (1985) reported that while the number of pursuit movements have been found to increase with increasing fatigue, the velocity of the eye is reduced.

Heart rate. During extended periods of low workload under monotonous conditions, heart rate has been shown to decrease while heart rate variability has been shown to increase (Bishop *et al.*, 1985; Wierwille and Muto, 1981). These effects and their relationship to fatigue have been demonstrated in an ‘on-the-road’ driving task (Lauer and Lisper, 1976; O’Hanlon and Kelley, 1977; Yajima *et al*., 1976) and simulator-based environment (Durman and Boden, 1972; Wierwille and Muto, 1981). Volow and Erwin (1973), however, found no correlation between heart rate variability and sleep onset.

Gross body movement. Wierwille and Muto (1981) noted gross body movement, defined as str*etc*hing or straightening motions, increased with time spent performing a simulator-based driving task. In related research, Watanabe, Kogi, Onishi, Shindo, and Sakai (1982) observed an increase in gross bodily movements by locomotive engineers after approximately 200 minutes of locomotive operation. Skipper *et al*. (1984) defined 17 different ‘mannerisms’ or incidental behaviors (16 defined behaviors and an “other” category to account for mannerisms which did not clearly fit into any of the defined categories) to describe these movements. In a study evaluating various measures of drowsy driver detection, Skipper *et al*. (1984) reported all of the mannerisms categories demonstrated a statistically significant main effect for time-on-task. These mannerisms are shown by category in Table 5.

Pupil aperture size variability. Lowenstein, Feinberg and Loewenfeld (1963) describe spontaneous pupillary movement as reflecting ‘tiredness’, ‘fatigue’, or ‘sleepiness’. Normal individuals experiencing fatigue or tiredness have been shown to exhibit changes in the size of the pupil (pupillary stability) and speed at which pupil size changed (pupillary oscillations). These changes were reported by Lowenstein *et al*. (1963) to be accurate and visible, albeit indirect, manifestations of changes occurring within the autonomic or central nervous system.

Skin potential level. Skin potential level (SPL) measures the difference in electrical potential between the outermost layer of skin (stratum corneum) and the layer immediately below it (stratum lucidum). Erwin, Hartwell, Volow, and Alberti (1976) reported that changes in SPL are correlated with stages of arousal. Specifically, EEG-defined sleep occurred only after an SPL shift (Erwin, *et al*., 1976). Erwin *et al*. (1976) also found that significant shifts in SPL preceded Stage 1 sleep but also the transition to Stage 1 sleep. In the several minutes following an SPL shift, subjects exhibited signs of drowsiness as demonstrated by decreased performance, persistent eyelid closure longer than one second, and EEG indicators of sleep (Erwin, *et al*., 1976). Despite that

TABLE 5

Categories of Mannerisms or Incidental Driving Behaviors (adapted from Skipper *et al*., 1984).

CATEGORY	MANNERISM DESCRIPTION
Hair	Scratching / Straightening
Eyebrow	Raise – Eyes Open Wide Lower - Scowl
Eyes	Peripheral Looks Rubbing / Scratching Excessive Blinking Slow Closure Slow Closure with Unfocussed Rolling Closure Greater Than 2 Seconds
Face	Rubbing / Scratching / Holding
Mouth	Yawning Lips Licking, Biting Tongue Motion Other:
Neck	Rubbing / Scratching / Holding Head Position Change / Nod
Body	Position Change / Shrug
Other	Specify:

decreased skin potential was shown to be a prerequisite of sleep onset, these periods were unpredictable in their time-duration, thus limiting their predictive utility. Similarly, there is considerable variation in the baseline values of SPL which exist both within and between subjects. Specifically, within-subject variation in SPL shifts may occur without being accompanied by drowsy behavior or sleep onset and sans any performance decrement as SPL is subject to changes in subjects' mood, activity level, and temperature.

Subjective Measures

Despite the variety of objective measures available by which fatigue may be assessed, it still remains essentially a subjective experience. Several different methods of self-report have been developed to collect information based upon the subjective experience of fatigue (Hoddes *et al*., 1973, Mackie and Miller, 1978, and Williamson *et al*., 1994). Kashiwagi (1971) and Wierwille and Ellsworth (1994) adopted a somewhat different technique recognizing observers could be trained to detect changes in a driver's fatigue level based upon a variety of criteria. While demonstrated to be sensitive to detecting fatigue, the ever-persistent concern regarding subjective measures - they are in fact subjective and are more susceptible than objective measures to the influence of corruption - persists.

Given the need to present the subjective instrument while the subject is driving, in a very short time period, and with eliciting the minimum amount of arousal, single-item scales - as opposed to a battery of multi-item scales - are of particular interest in assessing driver fatigue in the motor vehicle environment. Consequently, the current review of tools for subjective fatigue assessment will be limited to single-item instruments. These instruments are summarized in Table 6.

Stanford sleepiness scale (SSS). The Stanford Sleepiness Scale (Figure 2) is specifically focused on detecting increasing feelings of sleepiness (Hoddes *et al*., 1973). Studies conducted by Williamson *et al*. (1994) and Wylie *et al*. (1996) demonstrated the sensitivity and applicability of the SSS to the driving environment.

At least two studies (Glenville and Broughton, 1979; Hoddes *et al*., 1973) have related the SSS to task performance, which, while not a direct measure, is an objective measure of alertness or sleepiness. Glenville and Broughton (1979) reported correlations for the SSS with vigilance (r = -0.69; $p < 0.001$) and reaction time (r = 0.69; $p < 0.001$)

TABLE 6

Summary of Subjective Fatigue Assessment Single-Item Instruments.

SINGLE-ITEM INSTRUMENT	**SUMMARY**
Stanford Sleepiness Scale	Developed in 1973 by Hoddes *et al.* Seven point ordinal scale focuses on detecting increasing feelings of sleepiness Demonstrated to be sensitive and applicable to driving by Williamson *et al.* (1994) and Wylie *et al.* (1996)
Self-Ratings of Fatigue and Alertness 1	Developed in 1972 by Harris *et al.* Two eleven-point ordinal scale instruments (one for alertness and another for fatigue) Not demonstrated to be sensitive to driving; not validated.
Self-Ratings of Fatigue and Alertness 2	Developed in 1974 by Mackie *et al.* Two six-point instruments resembling a Likert-type scale (one for alertness and another for fatigue) Not demonstrated to be sensitive to driving; not validated.
Visual Analog Scales	Developed in 1994 by Williamson *et al.* Comprised of three analog scales (100mm in length and anchored at each end with a bipolar opposite) designed to supplement the Stanford Sleepiness Scale Found to be sensitive to progressive effects of fatigue (Williamson *et al.*, 1994)
Karolinska Sleep Scale	Developed in 1990 by Akerstadt and Gilberg Nine point ordinal scale focusses on detecting absolute levels of fatigue Frequently accompanied by the Karolinska Sleep Diary Demonstrated to be sensitive to EEG and EOG indicators of sleepiness (Akerstadt and Gilberg, 1990; Gilberg *et al.*, 1994)

STANFORD 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	Feeling active and vital. Alert and wide awake.
2	Functioning at a high level, but not at peak. Able to concentrate.
3	Relaxed and awake, but not at full alertness. Responsive.
4	A little foggy, not at peak. Let down.
5	More foggy. Beginning to lose interest in staying awake. Slowed down.
6	Very sleepy, fighting sleep, woozy. Prefer to be lying down.
7	Almost asleep. Lost struggle to remain awake

Figure 2. Stanford Sleepiness Scale (adapted from Hoddes *et al.*, 1973).

performance using the Wilkinson Auditory Vigilance task. Hoddes *et al*. (1973) reported the mean SSS ratings corresponded highly (though non-significantly) with performance on both the Wilkinson Addition Test ($r = 0.67$; $p < 0.05$) and the Wilkinson Vigilance Test ($r = 0.70$; $p < 0.05$). Johnson, Freeman, Spinwebber, and Gomez (1988) conducted a study relating physiological and performance measures with two subjective sleepiness scales; the SSS and Visual Analog Scales (discussed below). Using the Multiple Sleep Latency Test (MSLT) (a battery of physiological tests incorporating electrooculogram (EOG), electrocardiogram (EKG), and EEG measures) and lapses during a tapping task, Johnson, Freeman, Spinwebber, and Gomez (1988) demonstrated significant correlation between both the SSS and the MSLT ($r = 0.31$; $p < 0.01$) and the SSS and tapping lapses ($r = 0.25$; $p < 0.05$) early in the day (0600); however, these correlations became nonsignificant as the day progressed.

Self-ratings of alertness and fatigue. Harris *et al*. (1972) developed one of the earliest instruments to assess the subjective measures of alertness and fatigue. Separate, but similar, instruments based on alertness and fatigue employed an 11-point scale describing various levels of alertness. No evidence was provided the current self-reports of fatigue and alertness had been tested or validated; consequently, the effectiveness of these scales and the value of the results derived from them are suspect. Both instruments were found to be less sensitive than the authors would have desired, prompting reflection perhaps magnitude estimation would have yielded better performance (Harris *et al*., 1972). The fatigue and alertness scales used by Harris *et al*. (1972) are shown in Figure 3.

Another set of instruments designed to assess subjective measures of alertness and fatigue were developed by Mackie *et al*. (1974). Shown in Figure 4, these fatigue and alertness instruments resemble a Likert-type scale. Like the subjective measures of alertness and fatigue presented by Harris *et al*. (1972), these instruments are included in their respective works void of a discussion describing their testing and validation. One flaw of this incarnation of sleep and fatigue scales is their reliance on lengthy descriptors at the scale extremes while providing little or no information at the other, clearly labeled divisions.

Visual analog scales (VAS). Williamson *et al*. (1994) developed a series of three analog scales to complement the SSS. The SSS is focused on detecting increasing feelings of sleepiness while the VAS focused on various aspects pertaining to the relative experience of fatigue. The VAS was also found to be sensitive to the progressive effects

FATIGUE SCALE	
SCALE VALUE	DESCRIPTION
11	I have never been more rested; I feel no fatigue whatsoever.
10	
9	
8	I feel some fatigue.
7	
6	
5	
4	I feel considerable fatigue; I'm tired.
3	
2	
1	I have never felt more tired.

ALERTNESS SCALE	
SCALE VALUE	DESCRIPTION
11	I have never been more alert; my level of alertness is well above average
10	
9	
8	My level of alertness is about average for me.
7	
6	
5	
4	My level of alertness is considerably below my average.
3	
2	
1	My level of alertness requires that I stop to rest very soon.

*Figure 3***.** Subjective scales of fatigue and alertness (adapted from Harris *et al*., 1972).

FATIGUE SCALE

6	I am not at all fatigued. I feel maximally capable of performing physical work
5	
4	
3	Normal
2	
1	
0	My fatigue is extreme. I am incapable of performing physical work.

ALERTNESS SCALE

6	My alertness is as high as it ever is. I have never been as ready to perform any task
5	
4	
3	Normal
2	
1	
0	My alertness is as low as it ever is while I am awake. I feel on the verge of falling asleep and I am almost incapable of performing any task.

Figure 4. Subjective scales of fatigue and alertness (adapted from Mackie *et al.*, 1974).

of fatigue (Williamson *et al*., 1994). The VAS is shown in Figure 5. Visual analog scales are generally 100 mm in length and anchored at either end with bipolar opposites (*e.g.*, very alert and very sleepy). Participants respond by placing a mark at the point along the analog scale that relates to their associated level of sensation; the intensity of the participant's response is measured to the nearest millimeter. Scales may be oriented either vertically or horizontally, although vertically oriented scales have been shown to be easier to use (Gift, Plaut, and Jacox, 1986).

Gilberg, Kecklund, and Akerstedt (1994), using a straightforward implementation of a simple vigilance task and a second, unrelated visual signal detection task to elicit reaction times reported that the VAS was significantly correlated with vigilance tasks ($r = -0.49$; $p < 0.05$) and reaction times ($r = 0.56$; $p < 0.05$). Johnson *et al*. (1988) demonstrated significant correlation between both the VAS and the MSLT ($r = 0.34$; $p < 0.01$) and the VAS and tapping lapses ($r = 0.34$; $p < 0.01$) early in the day (0600); however, like the SSS results, these correlations became non-significant as the day progressed. After evaluating the relationships between the MSLT, tapping lapses, the SSS, and the VAS, Johnson *et al*. (1988) concluded these results suggested subjective and objective measures cannot be used interchangeably and may measure different aspects of sleepiness.

Karolinska sleepiness scale (KSS). Whereas the visual analogue scales were developed to measure relative levels of fatigue, the Karolinska Sleepiness Scale (KSS) was developed to measure absolute levels of fatigue (Gilberg *et al*., 1994). Although the KSS may be used by itself, it is frequently associated with the Karolinska Sleep Diary. Briefly, the Karolinska Sleep Diary is comprised of 12 items; 10 of which are asked directly of the participant and two of which are derived from their responses and additional objective measures such as time in bed and sleep length (Akerstedt, Hume, Minors and Waterhouse, 1994). The KSS is a single instrument and is administered while the individual is awake and just prior to falling asleep, whereas, the sleep diary is administered upon waking. The Karolinska Sleepiness Scale is shown in Figure 6.

The Karolinska Sleepiness Scale is strongly related to EEG and EOG indicators of sleepiness (Akerstadt and Gilberg, 1990; Gilberg *et al*., 1994). In separate experiments Gilberg *et al*. (1994), using straightforward implementations of a vigilance task and an unrelated visual signal detection task to elicit reaction times, reported the KSS was significantly correlated with vigilance tasks ($r = -0.62$; $p < 0.05$) and reaction times ($r =$

VISUAL ANALOG SCALES

On each of the following scales, please draw a cross (X) at the point that most closely describes how you are feeling now.

For Example: The following response would indicate that you are feeling more happy than sad

Happy ______X____ Sad

Fresh ____ **Tired**

Clear Headed ____ **Muzzy Headed**

Very Alert ____ **Very Drowsy**

Figure 5. Visual Analog Scales (VAS) for subjective assessment of fatigue and alertness (adapted from Williamson *et al*., 1994).

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	
7	Extremely sleepy, fighting sleep

Figure 6. Karolinska Sleepiness Scale (Gilberg *et al*., 1994).

0.71; $p < 0.05$). Another study (Akerstadt and Gilberg, 1990), found increasing levels of subjective sleepiness (based on the KSS) is related to EEG measures; specifically, that subjective responses of ‘sleepy’ or ‘fighting sleep’ were associated with increased levels of Alpha and Theta band energy.

Observer ratings of drowsiness. Kashiwagi (1971) first suggested the development of a generalized fatigue rating scale by which human fatigue could be assessed through a person’s appearance. Skipper *et al.* (1984) found it possible to detect the onset of drowsiness by gauging driver response to steering wheel torque and front wheel disturbances generated by a driving simulator; they also determined tat drowsiness and sleep onset could be predicted by evaluating a person’s appearance. Wierwille and Ellsworth (1994) elaborate upon this technique in which experimenters are able to estimate drowsiness based on characteristics such as facial tone, slow eyelid closure, and driver mannerisms (*e.g.*, rubbing, yawning, nodding). The observer rating process makes use of a five-point Likert-type scale anchored with ‘Not Drowsy’ and ‘Extremely Drowsy’ to measure the evaluator’s subjective perception of driver fatigue. Wierwille and Ellsworth (1994) conducted a validation study to evaluate intrarater reliability, test-retest reliability, and interrater reliability. During this study six individuals trained in the observer ratings of drowsiness method evaluated 24 videotaped segments containing images of drivers faces at a variety of apparent drowsiness levels. Raters consistently rated the level of drowsiness when asked to rate the same segment twice ($r = 0.88$; $p < 0.001$). Test-retest correlation ($r = 0.81$; $p < 0.001$) was found to be significant when the two rating episodes were separated by approximately one week. Finally, interrater reliability correlations, or ratings between two raters, were also found to be significant ($r = 0.81$; $p < 0.001$).

Cognitive/Behavioral Measures

An increased occurrence of errors and slowed cognitive processing times are two indicators fatigue has adversely affected cognitive processes. Based upon the same assumptions and principles used to measure the differential effects of operator workload, that the measurement of two tasks simultaneously enables an assessment of how much cognitive processing is required by a single task, dual-tasks are employed to detect cognitive decrement due to fatigue. As fatigue increases, it is supposed the primary task will require increased levels of cognitive processing such that performance on the secondary task deteriorates. This allows inferential determination of the cognitive requirements of the primary task. Using sleep-deprived participants, Hardee, Dingus, and

Wierwille (1985) employed secondary tasks in a simulator study. Results indicate auditory or visual secondary tasks were found to be reasonable predictors of whether a participant was experiencing performance impairment due to fatigue.

An alternative to the dual-task approach is to measure underlying information processing capabilities off-line, or while the driver is not driving. Given the possibility the presence of a secondary task may adversely affect performance of the primary task, this was the predominant approach adopted in the most recent, 'on-the-road' evaluations of driver fatigue (Wylie *et al*., 1996; Williamson *et al*., 1994). Tasks were generally performed immediately after the cessation of the driving task. One unfortunate shortcoming of this technique is the effects of fatigue can be reduced momentarily by slight changes in driver motivation and environmental stimulation (Williamson *et al*., 1994).

There are two theoretical requirements for a subsidiary task: it should not interfere with the primary task and the operator must be devoting sufficient attention to the primary task for the remaining processing capacity to be a test of the cognitive processing limit (Kantowitz, 1992). One concern not found to be formally stated in the existing literature is the introduction of a secondary task within the driving environment arouse the driver, thereby momentarily reducing his/her level of fatigue. If the secondary task was particularly demanding, accelerated fatigue could also result. In either case, if an experimenter is attempting to quantify the differences that may exist between two levels of an independent variable, inclusion of a subsidiary task is likely to confound the results.

Code substitution (CS). Wylie *et al*. (1996) used a CS test as an off-line measure of cognitive performance (information processing, perceptual speed, rapid visual search, and response selection speed). A letter was displayed on a monitor and based upon an arbitrary set of rules, the driver was required to depress the appropriate response key corresponding to the displayed letter. The CS Test was found to be sensitive to behavioral changes commonly associated with acute (within trip) fatigue and loss of alertness.

Simple response vigilance test (SRVT). Wylie *et al*. (1996) also used an on-line simple response vigilance test (SRVT) that required the driver to press a response button as quickly as possible after the appearance of a visual stimulus (three digits) on a computer screen. This test measured reaction time, a measure correlated to sustained attention or vigilance. Results indicated that the SRVT was sensitive to both acute and cumulative (across trip) fatigue.

Cognitive functioning. Williamson *et al*. (1997) developed an on-line test of cognitive functioning consisting of an auditory stimulus and an oral response. Upon hearing a signal, drivers responded as quickly as possible by saying 'yep'. The interval between the stimulus onset and the driver's response comprised the measure. A single block consisted of 30 trials unevenly spaced over a 15-minute period; blocks were presented throughout the duration of the driving task. Work practice and duration did not affect the drivers' reaction times on this test. Reaction times tended to be longer and more variable from late afternoon through midnight than at other times of the day ($p < 0.04$); however, the results may have been confounded by arousal due to the testing.

Critical tracking task (CTT). Originally developed by Jex, McDonnel, and Phatak (1966), O'Hanlon (1980) and Wylie *et al*. (1996) used an off-line first-order (velocity or rate-control), compensatory tracking device to evaluate driver fatigue. The CTT relies on a pointer moving in an unpredictable fashion along a horizontal axis on a computer display. The driver's task was to move the steering wheel to keep the pointer at center of the display; task difficulty increased during each 30-second presentation. The dependent measure, eye-hand perceptual-motor response time, was recorded at the point where the subject failed to be able to keep the pointer in the center of the display. CTT performance has been shown to decrease after extended periods of driving, suggesting it is sensitive to fatigue, or reduced states of attention.

Operational Definition of Fatigue

Statistically, a latent variable such as fatigue is operationally defined in terms of observable variables. Consequently, the previous section reviewing the pertinent measures of fatigue is itself a definition of fatigue. Unfortunately, this definition lacks desirable clarity and brevity. In light of these limitations, the following operational definition of fatigue is offered for the commercial motor vehicle environment in general and this research effort in particular:

> *the deprivation of rest or derivative of mental or physical effort, which may result in a reduced ability to perform the cognitive or physical requirements as measured by performance, subjective, and physiological measures (discussed, in detail in the next section) associated with the tasks of commercial motor vehicle operation*

Contributing to this definition of fatigue are three underlying factors:

- Fatigue can be derived from a variety of causal factors, the vast majority of which are likely to influence the mental or physical capacities of the operators.
- Humans are capable of compensating for some of the effects of fatigue. Consequently, not all fatigue necessarily results in reduced performance.
- While perhaps the most important task, driving is not the only task commercial motor vehicle operators are required to perform; therefore, a definition defined only in terms of driving performance would be found lacking.

METRICS SELECTED FOR FATIGUE ASSESSMENT

Fatigue itself cannot be uniquely identified and measured. Instead, a measure of fatigue is determined by evaluating those factors known to be affected by fatigue. Thus, nuances in the definitions of fatigue exist within the literature and are largely dependent on which manifest variables were included as estimators. Therefore, in order to accurately measure fatigue, it was important to choose a balanced set of estimators that were both sensitive and robust. Many of the benefits of each of the categories of fatigue measures have already been addressed; however, they are reviewed here within the context of selecting a set of factors that may be used to provide valid empirical measurements.

Several criteria influenced the decision of which variables should be included in the selected subset. Variables were chosen relevant to the following criteria:

- Must have been demonstrated to provide valid empirical measurements of fatigue or reduced states of alertness in previous research efforts.
- Must have been able to be implemented within the driving environment in a manner that was likely to minimize disruption to the truck driver and the driving task. (*e.g.*, related data equipment should be hidden from the driver so as to reduce its conspicuity).
- Must have not required the presence of an experimental assistant. Many previous research efforts (Harris *et al.*, 1972; Mackie *et al*. 1974; Williamson *et al*., 1994) have relied upon the presence of an experimenter, which may have influenced driver behavior, during all experimental sessions.
- Must have been capable of supporting naturalistic observation. That is, disruption of the driver's normal activities should have been minimized (for example, the location of an additional data collection device within view of the driver may be tolerable, whereas requiring the driver to unplug a data lead in order to exit the vehicle would be considerably less desirable)
- Should have been balanced. Each of the four categories of fatigue-related measures (*i.e.* performance, physiological, subjective, behavioral/cognitive) contribute to an overall understanding of fatigue; ideally, a balanced approach incorporating each of the aforementioned areas was employed.
- Must have been simple. Since an experimenter was not be present, operation of the equipment needed to be automated to the highest degree possible; that which could not have been automated was made intuitive. EEG, while it has been demonstrated to be an excellent indicator of cerebral arousal, would have required a level of effort from the drivers beyond what would have normally been expected of experimental participants.

In addition to the aforementioned criteria, it was necessary to consider the impacts of current and future research efforts. With this in mind, a logical progression from the status quo has the development of a system capable of detecting changes in the driver and driver performance consistent with the onset of fatigue. To realize this notion, it was necessary to limit the variables being considered to those that could reasonably be collected in a continuous and non-invasive manner. Consequently, variables relying on specimens of bodily fluids such as urine and blood were not considered (*e.g.*, determination of corticosteroids, adrenaline, and noradrenaline levels).

Based upon these criteria, The dependent measures meeting these criteria and chosen for inclusion in the current study were decided upon and are presented in a subsequent description of the experimental design.

This methodology and the design of the data collection system were designed to allow a large, comprehensive set of critical incident data to be acquired. The driving performance portion of this data set included the following measures.

- Eye position/eyes-off-road time. Research has indicated that the more time the driver spends looking away from the forward road scene, the higher the likelihood of being involved in an accident (Wierwille and Ellsworth, 1994).
- Presence/duration of an unplanned lane deviation. An unplanned lane deviation is a content-valid indicator of driver inattention and collision potential.
- Steering measures. Steering position and steering velocity measures have been shown to correlate to driver attention and fatigue. They are also useful as "trigger" measures to indicate a potential critical incident.
- Average vehicle velocity/velocity variance. Research indicates that velocity maintenance is a sensitive measure of changes in the amount of attention demanded by secondary driving tasks (Monty, 1984).
- Presence of abrupt lateral maneuvers. High lateral accelerations are indicative of a vehicle that is off-track due to inattention. This measure can also serve as a useful trigger criterion for further analysis.
- Presence of abrupt braking maneuvers. If drivers are looking away from the driving scene and glance back only to realize that an unanticipated event is occurring, the brake pedal must be depressed harder and the resulting deceleration is greater than in a normal attention situation.
- Time-to-collision with a forward vehicle. This measure serves to provide an objective assessment of the presence of a critical incident forward of the subject vehicle.

Eyelid closure and observer rating of drowsiness. Erwin (1976), as reported in Skipper and Wierwille (1986), identified eyelid closure as a valid measure of determining fatigue. Erwin defined drowsiness, an aspect related to fatigue, as the point where persistent eyelid closure occurs. Further research conducted by Skipper and Wierwille (1986) and Wierwille and Ellsworth (1994) provided empirical results suggesting that eyelid closure is indeed a valid measure of driver fatigue.

Based on previous studies conducted by Wierwille and Ellsworth (1994), various observers analyzed recorded images of subjects to determine whether drivers “appeared drowsy.” In addition to determining drowsiness, the observers were required to complete a questionnaire that focused on the driver’s behavior, such as whether he/she was chewing, singing, whistling, using the CB, or had droopy eyelids. The results indicated a direct correlation between the face-video and the lane-tracking and steering wheel movement data. Judgments of face video were found to be more sensitive in detecting drowsiness during driving than methods based on PSG (polysomnographic) measures.

While the observers did not rate the drowsiness of each driver, the questionnaire was used to determine the level of drowsiness based upon criteria used in a study by Wierwille and Ellsworth (1994). In that study, observers rated the drowsiness of the driver on a continuous scale that contained the following descriptors: Not Drowsy, Slightly Drowsy, Moderately Drowsy, Very Drowsy, and Extremely Drowsy. The results indicated subjective judgment of driver drowsiness from driver video is valid and reliable.

INSTRUMENTATION AND DATA COLLECTION SYSTEMS

Drivers employed by private trucking firms operated two university-owned Class 8 commercial tractors on their regularly scheduled revenue-producing runs to perform data collection. The vehicles, a 1997 Volvo VN Series L4 Integrated Sleeper and a Peterbilt Model 379, are shown in Figure 7.

Data Collection

Instrumentation systems implemented in other CTR research vehicles (Collins, Neale, and Dingus, 1999, Hanowski, Dingus, Gallagher, Kieliszewski, and Neale, 1999, Robinson, Neale, Petersen, Belz, Cooper, Casali, and Dingus, 1999, Wierwille and Hanowski, 1998) and in the Volvo tractor (Winters, 1998) for other research projects have recorded data continuously throughout the experimental trials. Such trials have typically been 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 deemed to be 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. Three methods, critical incident, random interval, and driver identified were used in concert to activate the intermittent collection of the dependent measures.

Critical incident. Critical incidents, sometimes referred to as 'near misses' or 'near accidents', may be defined as situations and circumstances, which if left unchecked, may result in the occurrence of an error (Champanis, 1959). Fitts and Jones (1961a, 1961b) were among the first researchers to employ this technique in order to describe problems that lead to aircraft accidents. Operationally, a critical incident may be defined as a measured variable that exhibits a pre-determined "signature" or exceeds a "trigger criterion" may be indicative of fatigue, lapses in performance, a safety-related external event, or potentially hazardous driving behavior. The critical incident method is based on the use of measured trigger criteria; the occurrence of which may be indicative of a reduced state of alertness.

Within ground transportation, the earliest use of a technique similar to that described by Fitts and Jones (1961a, 1961b) was employed by Older and Spicer (1976). Older and Spicer (1976) developed the traffic conflict study technique to evaluate situations where road users are in conflict with one another or some aspect of the travel path where evasive actions become necessary to avoid the occurrence of an accident. Based upon this technique, recurring situations leading to conflicts are able to be detailed through information describing vehicle involvement, queue position, vehicle paths, blocking maneuvers, and roadway geometry. Unfortunately, an automated method for recording only the data of interest to researchers was unavailable circa 1976; therefore, analyses relied on real-time observation of traffic or review of videotaped footage of real-time traffic patterns. Both of these methods were extensively time consuming since the evaluator was never certain when a conflict may occur and therefore had to review each tape in real-time to watch for such occurrences.

Dingus, McGehee, Hulse, Jahns, Manakki, Mollenhauer, and Fleischman (1994), Fleischman (1991), Fleischman and Dingus (1994) employed an in-vehicle data collection system in order to provide a detailed evaluation of driver performance and behavior while operating the TravTek system. This effort represented the first occasion that an in-vehicle data collection system had been deployed to evaluate driver behavior in a study of this magnitude. In addition, this system allowed researchers access to information heretofore unavailable including precise/detailed measurement and analysis of driving performance and behavioral measures (*e.g.*, velocity/displacement, steering, roadway scanning behavior, and workload).

Gellatly, Petersen, Ahmadian, and Dingus (1997) and Robinson *et al.* (1999) describe in detail the data collection technology deployed in this study and report on further advances to in-vehicle data collection technology. Substantial improvements have been achieved in the area of 'smart data collection' resulting in more efficient and focussed data sets. Specifically, the data collection system records a predetermined quantity of data continuously whenever the vehicle is in motion; however, only writes data when data exceed a set of a priori criteria (the values for which are based on previous research and extensive testing) indicative of 'non-normal' driving behavior. Once an *a priori* condition is detected, the predetermined quantity of data that exists for the time period prior to the condition plus a specified time period after the condition is then written to the data set. As a result, data is only recorded when a critical incident is present, thus increasing the analysis efficiency.

Specifically, a list of specific critical events for which the data acquisition system was programmed are presented in Table 7. Whenever one of these "triggers" was detected, the video and dependent measures data for a period of 1.5 minutes before and 0.5 minutes after the trigger event were automatically recorded. The cause, contributing

Figure 7. Instrumented class-8 tractors; 1997 Volvo VN series (Top Left) and Peterbilt Model 379 (Bottom Right) tractors.

TABLE 7

Critical Events and Associated Trigger Levels

CRITICAL EVENT	TRIGGER LEVEL
Steering Wheel Angular Velocity	3.64 radians / second
Lateral Acceleration (w/ Vehicle Velocity > 20 mph)	0.30 g
Zero-Velocity Limited Lateral Acceleration	2.2 g
Longitudinal Acceleration (w/ Vehicle Velocity > 20 mph)	0.25 g
Zero-Velocity Limited Longitudinal Acceleration	2.5 g
Time to Collision	4.0 seconds
PERCLOS Rating	8.0 %
Sleepiness Rating (Driver's response on Karolinska scale on dashboard)	7
No Response from the Driver when Queried for Sleepiness Rating	Boolean Occurrence
Lane Departure without Complete Lane Change	Boolean Occurrence
Lane Departure with Side Sensor Active	Boolean Occurrence

factors, and circumstances surrounding the incident were then determined via post-hoc analyses.

Random interval. The random interval method, based on a uniform probability distribution, triggered two minutes of data collection every forty-five to seventy-five minutes. The random interval method supplemented the critical incident method by enabling data collection of the progression of driver fatigue even when the outward manifestations were absent, or of such a magnitude as so not to activate the trigger criteria.

Driver identified. In addition to the critical incident and random interval methods, the driver also was able to activate the data collection system. A push-button incident detection box was mounted on the dash and convenient to the driver's workspace; this device was activated if the driver experienced a critical incident. This system acted as a redundant cue to trigger the data collection system in the event the driver detected some kind of critical or unusual incident that may not have had a "signature" detectable by the system. The incident detection box included an audio channel that became active upon depression of the incident button to allow the driver to verbally describe the event.

Instrumentation

The core of the data acquisition system was a Pentium-based microcomputer. The computer operated custom data acquisition software and was connected to 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 currently configured with 10 nodes. A schematic representation of the system appears in Figure 8.

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 programmed for data collection rates from 1 Hz to 30 Hz via a crystal oscillator.

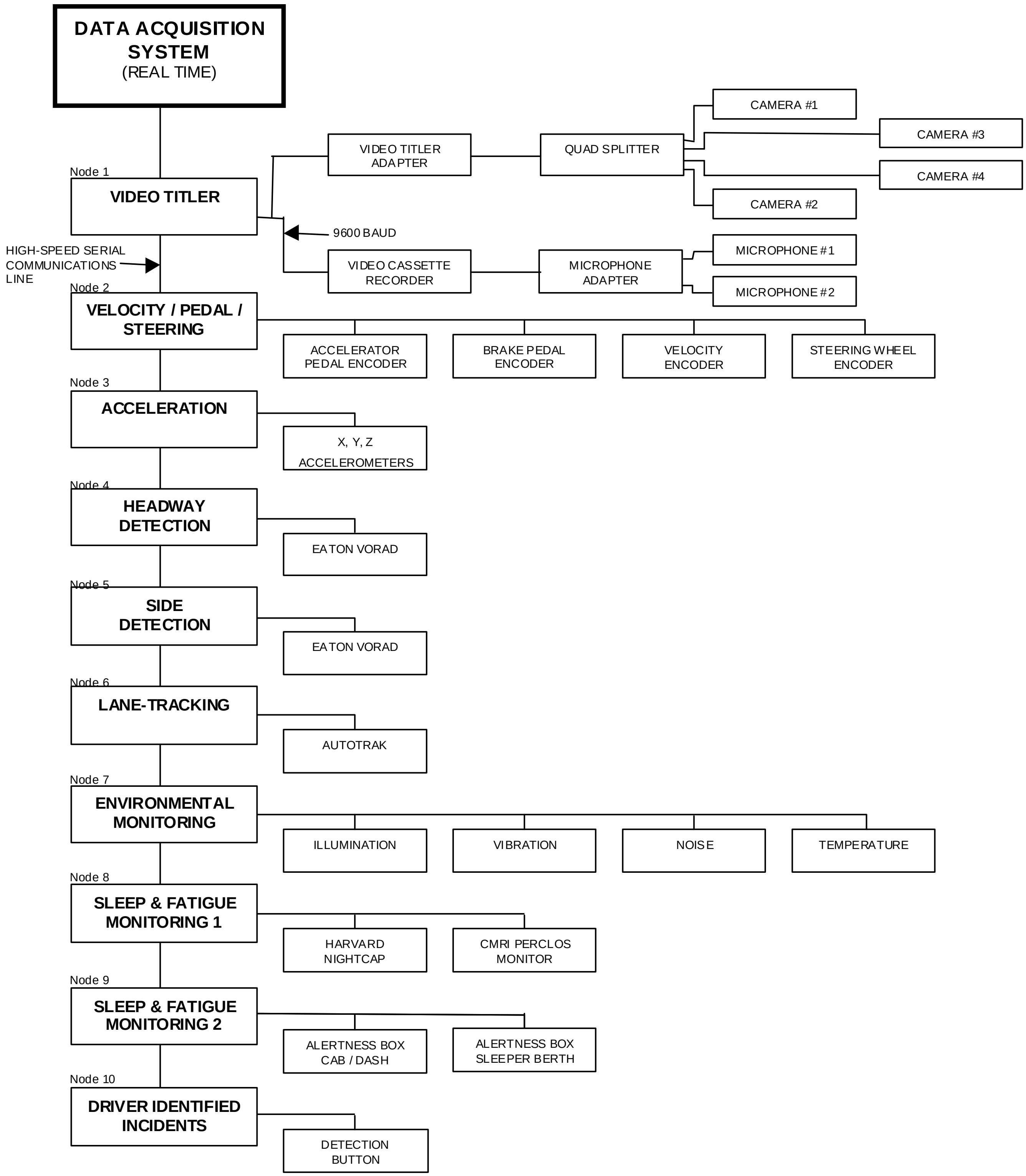


Figure 8. Schematic representation of the instrumentation package installed in the class 8 experimental vehicles.

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 enough 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 and 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, resulting in the observation of more natural behavior than would otherwise be possible if the driver were constantly reminded he/she were 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 located under the bunks in the sleeper berths of both trucks, Figures 9 and 10. The only devices visible to the driver were the PERCLOS monitor, sleep scale, and the critical-incident pushbutton installed on the trucks' instrument panel as shown in Figure 11.

Driver interaction with the data collection system was minimal. In addition to their normal activities, the drivers' only required activities were to: 1) indicate when an unusual critical event occurs by pressing a button located on the dashboard, 2) respond to random inquiries as to their subjective feelings of sleepiness by pressing one of nine buttons on a panel mounted on the dashboard, and 3) don the sleep monitoring device before going to sleep, 4) rate their subjective feelings of sleepiness when they woke up after sleeping by pressing one of nine buttons on a panel mounted in the sleeper berth, and 5) fill out two paper-based surveys each day. No other operation of data collection hardware was required of the drivers.

Node 1 – Audio and video subsystem. 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 and a bank of computer-controlled VCRs at a communications rate of 9600 baud. The tractors were wired to nine cameras (although only four were used in the present study) and two

Figure 9. Instrumentation concealed in locked compartment (Middle Left) under the bunk in the Volvo (Bottom Right). Access is gained from inside the sleeper berth by lifting the mattress platform (Top Right).

Figure 10. Instrumentation concealed under the bunk in the Peterbilt (Top Right). Access is gained from outside the cab through a pre-existing access panel (Bottom Left).

Figure 11. A view of the Volvo dashboard showing the showing the only instrumentation visible to the driver while driving.

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 12) 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 7), 1.5 minutes of video preceding the event and 0.5 minutes 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 lit 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. For example, in both trucks the camera observing the driver's face was concealed behind the A-pillar molding. 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. These positions are shown in Figure 13**.**

Node 2 – Velocity, pedal, and steering measures. The second node was a general input node. It measured the positions of the accelerator and brake pedals and steering position (using string potentiometers), and the vehicle velocity (via a Hall Effect sensor operating in conjunction with a magnetic element attached to the driveshaft). Steering velocity wheel velocity was computed based on the steering wheel position data.

Node 3 – Acceleration. The third node on the system was the acceleration measurement node. The accelerometers, combined with the electronics interface, provided three linear axes of acceleration measurement and a node interface in a box that measures just 2.54 cm. (1 in.) x 5.08 cm. (2 in.) x 10.16 cm. (4 in.). These three accelerometers measured the lateral, longitudinal, and vertical accelerations experienced by the tractor, and reported this information to the data acquisition computer when requested.

Figure 12. 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.

Figure 13. Some concealed camera locations on the Volvo and the Peterbilt (circles denote camera locations). (Left) Side mirror/Volvo. (Center) A-pillar/Volvo. (Right) Breather Can/Pete

Nodes 4 & 5 – Headway and side obstacle detection. To monitor following distance, a radar-based front-to-rear crash avoidance sensor was installed on the trucks 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 two tractors. Using time-to-forward-collision as a trigger criterion provided a second longitudinal measure in addition to longitudinal deceleration. Similar sensors, Figure 14, were also used as side clearance detectors, node 5.

Node 6 – Lane tracking. A lane-tracking device (SafeTRAC) based on forward-looking machine vision technology, provided accurate recording of lane. 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 used the same technology 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% of the time. (It should be noted Carnegie Mellon used this system for vehicle control whereas in this study, it would only be used for position measurement/tracking.) The SafeTRAC system consisted of two hardware components: the Sensor and User Interface Unit, and the Processing Unit. The interface unit is shown in Figure 15. Both components were small and mounted so they were invisible to the driver.

The SafeTRAC allowed measurement 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 some preset 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, as well as the transducers used in nodes 2 through 5, are presented in Table 8.

Node 7 – Environmental monitoring subsystem. The seventh node was dedicated to sampling environmental variables: temperature, illumination, vibration, and noise. Unlike the measures discussed previously, the environmental variables were not used to trigger critical events. Instead, the data are 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.

Figure 14. Eaton Vorad side clearance sensor (Top Left – passenger side shown) and headway sensor (Lower Left) mounted on the Peterbilt.

Figure 15. The SafeTRAC system by AssistWare Technology.

TABLE 8

Transducer Resolution for Driver/Vehicle Performance Measures

CRITICAL EVENT	RESOLUTION
Steering Wheel Position	± 1 degree (0.0175 RAD)
Cab Acceleration (in horizontal plane)	± 0.01 g
Lane Position (SafeTRAC)	± 5 cm
Normalized Accelerator Position	± 1 % of Normalized Range (0 to 1)
Normalized Brake Position	± 1 % of Normalized Range (0 to 1)
Velocity	± 1 mph

A Larson-Davis 824 real-time spectrum analyzer was installed in each truck. This portable instrument was 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), Figure 16. The 824 was unique because it allowed the spectral data (octave band levels) to be downloaded by a computer while it simultaneously performed a measurement. The instrument was configured to continuously record the Leq sound pressure level. Each 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 L_{EQ} and L_{MAX} levels (in dB) for the octave bands centered from 63 to 8,000 Hz. Broadband levels (both linear, dB, and A-weighted, dBA) were easily calculated from the octave band data. Subsequent statistical analyses (regression, correlation, ANOVA, *etc*.), was performed using both broadband and band-limited data. For example, it may be discovered that sleep disturbances are highly correlated with the SPL level in only one band, yet have 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.

For the intended purposes of this study, what was important was the degree to which the vibration that drivers experience while in the sleeper berth affected their quality and quantity of sleep. As such, the goal was to collect vibration measurements in a manner obtrusive to the driver while he or she was sleeping, yet provided 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 was "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 was dependent on body position and muscle contractions. In other words, the transmission of a vibration of a particular frequency and amplitude to the body was different in someone lying on his/her back as opposed to someone lying on his/her side.

Figure 16. Acoustically transparent microphone enclosure located above the bed in the Volvo sleeper berth.

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 be a particular frequency does not meet a resonating frequency of the body, but is 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 is to measure the range of frequencies that disrupt sleep. Based upon our calculations of the vibrations produced inside a tractor cab, believe 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.

Triaxial piezoelectric accelerometers were installed in each truck's mattress. 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 then to have been correlated with sleep quality measures to determine the effect of vibration on sleep quality.

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 and the degree to which it affected sleep quality and quantity will be determined in a future study/analysis. 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. Each minute, the average temperature for the preceding 1-minute interval was calculated and saved. Subsequent analysis was intended to determine the degree to which temperature and temperature fluctuation correlated with driving performance as well as objective and subjective measures of sleep quality.

It was also learned during the focus groups 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 with the intention of correlating the data with sleep quality and quantity.

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 CTR personnel, Figure 17. This device, a

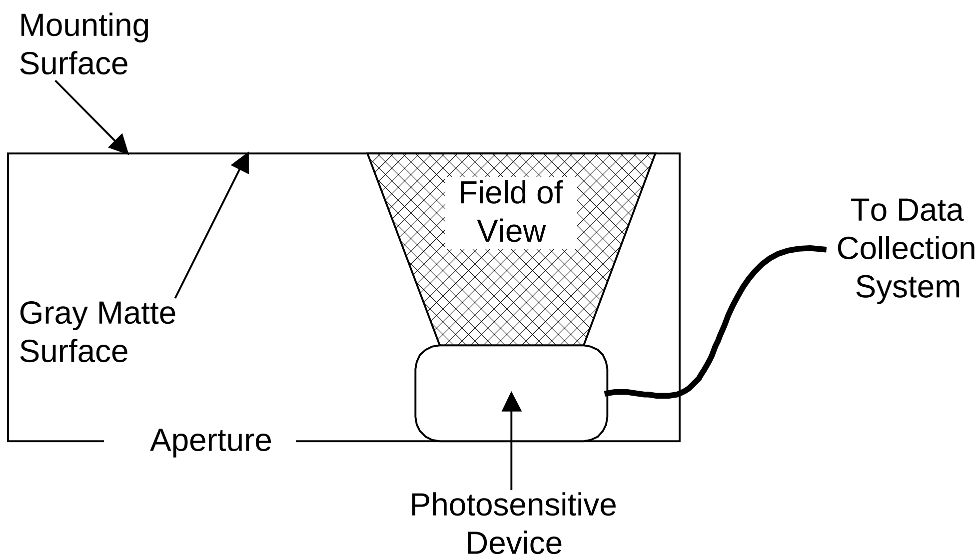


Figure 17. Sketch of Ambient Illumination Sensor.

photosensitive transducer, was 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, from 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 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 as well as the temperature sensor, as they were installed in the Volvo sleeper berth, are shown in Figure 18.

Nodes 8 & 9 – Measures of sleep and fatigue. The eighth node was dedicated to collection of sleep and fatigue measures using the Nightcap and an infrared eye closure (PERCLOS – Skipper and Wierwille, 1986) monitoring system 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 dashboard and in the sleeper berth.

The Nightcap was a two-channel recording device capable of distinguishing 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 consisted of an adhesive-backed piezoelectric film stuck to the upper eyelid and detected movements of the eye and lid without restricting eye movement. The other sensor was a cylindrical, multipolar mercury switch capable of detecting head movements. These sensors were connected by 1-meter cables directly to the trucks' data acquisition system via a small interface unit, Figure 19. (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 were produced by deformation of the eyelid sensor's flexible piezoelectric film, Figure 20, 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

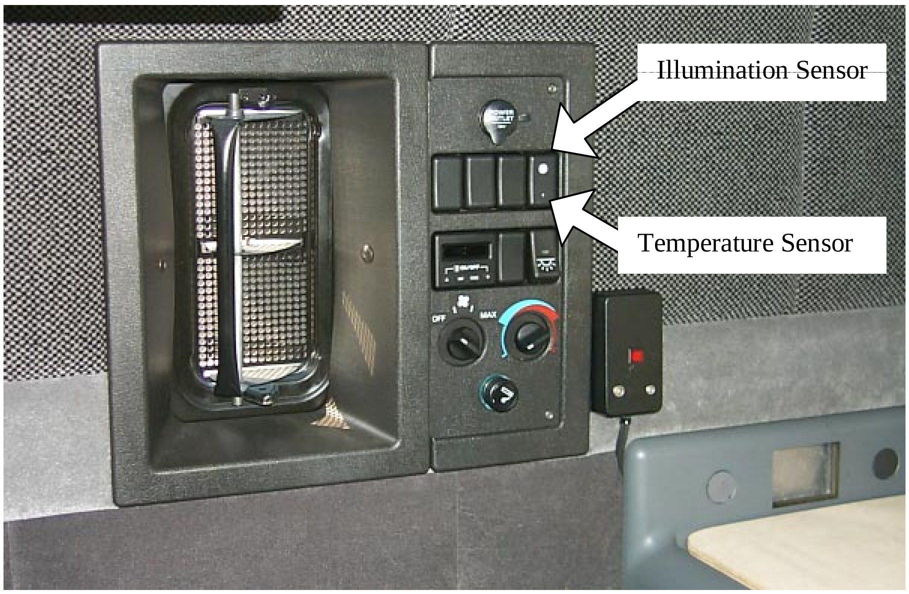


Figure 18. Location of the illumination and temperature sensors in the Volvo sleeper berth.

Figure 19. Nightcap interface unit located in the Volvo sleeper berth.

Figure 20. Nightcap eyelid movement sensor. (Left) Close-up. (Right) In conjunction with Nightcap sleep monitoring device.

a variety of sleep quality parameters, such as time of day slept, sleep duration, sleep latency, and sleep efficiency (Stickgold, Pace-Schott, Hobson, Neale, and Dingus, 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 being collected from truckers in their normal sleeping environment. Where possible, these data were collected immediately preceding or immediately following the experimental session.

To fulfill the intended 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. This system monitored 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. Of considerable advantage to this approach was 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 the driver is 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.

A bank of nine switches, Figure 21, wherein each switch corresponds to one of the nine ratings used in the Karolinska Sleepiness Scale (KSS – Gilberg *et al.* 1994), was placed within easy reach of the driver. A second set of identical switches was placed in the sleeper berth, Figure 22. Based upon a uniform distribution with endpoints at 45 and 75 minutes, the driver was randomly prompted to rate his subjective feelings of sleepiness by pressing the appropriate switch. A critical incident was triggered if the driver pressed a switch 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.

Figure 21. The Karolinska Sleepiness Scale as implemented in the sleeper berths. (Top Left) Karolinska Sleepiness Scale mounted over the head of the bed. (Bottom Right) Close Up of Karolinska Sleepiness Scale.

The Karolinska Sleepiness Scale 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. Furthermore, 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, Freeman, Spinwebber, and Gomez, 1991; Herscovitch and Broughton, 1981). The use of a knob or slider for implementation of the VAS was also considered, but this would allow the driver to track their previous responses, which could affect 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.* VAS-F, 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.

The Karolinska Scale has been used successfully to measure absolute levels of sleepiness and been found to be strongly related to EEG and electrooculogram signs of sleepiness and highly correlated with reaction times in vigilance tasks (Gilberg *et al.*, 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 *et al.*, 1994, Akerstedt and Gilberg, 1990).

Node 10 - Driver identified critical incidents. A pushbutton (node 10) was mounted within easy reach of the driver so that it could be activated it if he experienced a critical incident. This system acted as a redundant cue to trigger the data collection system in the event the driver detected some kind of critical or unusual incident that may not have a “signature” detected 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 22. (Also note the location of the PERCLOS camera and the Karolinska response box.)

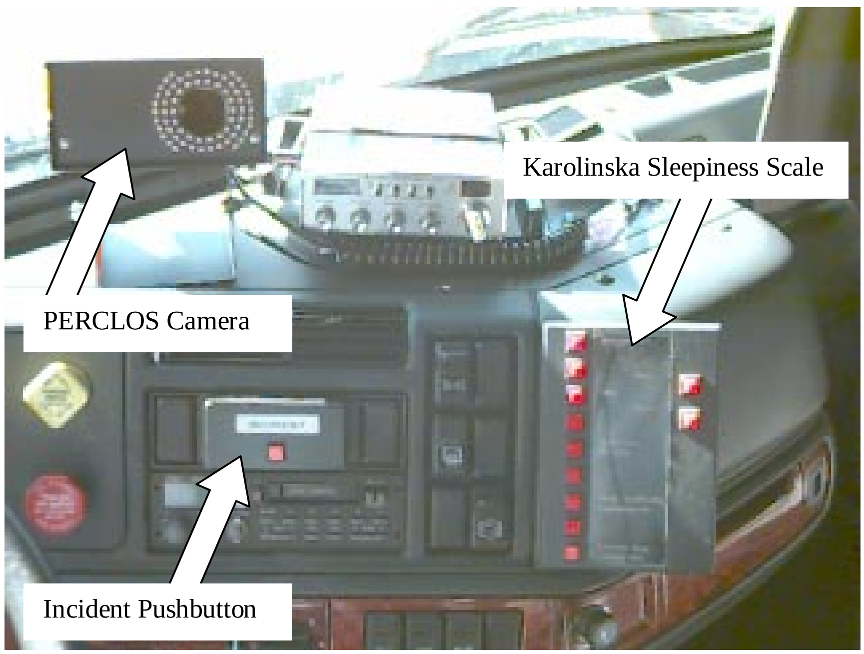


Figure 22. A view of the Volvo dashboard showing the showing the locations of the pushbutton used to trigger driver-initiated critical events, the Karolinska sleepiness scale, and the PERCLOS camera.

Surveys. Each driver was asked to respond to two survey instruments, shown in Appendix A, querying his/her activities and subjective self-assessment of well being each day they were on the road. The first of these survey instruments, the 'once a day' survey focuses on the events of the proceeding 24-hours may have contributed to the operator's level of fatigue. A substantial portion of this survey was modeled after the NASA-TLX workload assessment instrument (Byers, Bittner, Hill, Zaklad, and Christ, 1988, Hart and Staveland, 1988); however, modifications were made to increase usability, understandability, and applicability to the current research effort. Many of the questions represented in this survey are identical to those used by Wierwille *et al.* (1998) for their work in the local short-haul trucking industry.

The second survey, or 'wake-up' survey, was derived from the St. Mary's Hospital (SMH) Scale (Ellis, Johns, Lancaster, Raptopoulos, Angelopoulos, and Priest, 1981) and was designed to query individuals about quality aspects of their previous night's sleep. Each of the items on the SMH has demonstrated test- (administered 1-2 hours after waking) retest (administered approximately four hours later) reliability among healthy, normal volunteers with correlations ranging from 0.67 to 1.00. If two of the most subjective questions were removed, the lowest correlation for the remaining questions rose to 0.89 (Ellis *et al*. 1981).

CHRONOLOGY OF RESEARCH

Due to a variety of unforeseen complexities with this research project, implementation of the experimental methodology originally proposed was infeasible and ineffective. Presented herein is a brief chronological presentation of the original research proposal and the modified original research proposal, an overview of some of the problems encountered, their corresponding impact on the project, and a presentation of the revised dissertation focus.

Original and Modified Original Research Proposals

The proposed experiment was originally directed at: 1) establishing the relationship between objective and subjective measures of sleep quality, and 2) determining how sleeper berth usage affects operator fatigue. Two iterations of this experiment existed. The most notable difference between these versions was sample size; slight modifications to the experimental design were made in order to accommodate this difference. A brief description of the originally proposed experimental focus follows. Full descriptions of these research proposals, and a detailed proposal for data analysis of the modified iteration are presented in Appendix C. Indeed, the questions raised by the original study have yet to be addressed; therefore, this experimental design stands ready to address these issues, once the data become available.

Research Claims

The following research claims formed the cornerstone of these proposals and sought to explain 1) the relationship between the objective and subjective measures of fatigue and sleep quality, and 2) the effect of sleeper berth usage on operator fatigue. Ten research claims were to have been explored in the original proposal; a number reduced to six in the modified original proposal. The areas addressed by the research claims in each of the proposals were essentially the same; however, differences in the analysis methods between the modified original proposal and the original proposal enabled the restructuring and combination of several research claims. A complete listing of the research claims for the respective proposals is included in Appendix C.

Experimental Design

Originally, 48 drivers were to have been recruited. Of this number, one-half of the drivers recruited were to have been solo drivers while the other half were to have been team drivers. Due to a protracted data collection time period, this number was reduced to nine drivers, all solo, for the subsequent iteration of the original proposal. It was envisioned this subset would be used as a test bed for the development of a methodology that could then be applied to the entire sample size when the data collection had been completed.

Independent Variables

The experimental design was originally proposed as a three-way, mixed factor design examining the following independent, fixed-effects variables: Staffing (2 levels, between subjects), Wake/Sleep Schedule (2 levels, between subjects), and Trip Length (11 levels, within subjects). All main effects and interactions were to have been resolved in an Analysis of Variance (ANOVA). Selected covariates were to have been considered in separate post-hoc analyses. Regression was to have been to describe the continuous change in sleep quality over the entire trip.

Given the high level of importance on maintaining the observational nature of this study and the difficulty in identifying drivers who consistently adhered to a rigorous wake/sleep schedule, this factor was discarded in the second version of the original study. Similarly, since all of the participants in this study were solo drivers, comparisons between staffing arrangements could no longer be considered. Trip length was retained as the primary independent variable. Other independent variables, such as sleep location and trip length were also included. It is worth noting all of the independent variables were to have been dictated by real world needs rather than *a priori* experimental conditions. Specifically, the independent variables were also to have been measured rather than manipulated.

Data collection was originally proposed to occur over eight to ten 24-hour periods, yielding data for approximately 480 person days of driving (48 drivers x 10 person days each). This was subsequently reduced to reflect shorter trips ranging from four to eight days in length due to experimental difficulties. In addition, the data recorded by the data collection system did not exist for the entire trip. Up to three nights of home sleep data for each driver were also to have been collected subsequent to the termination of the on-road portion of the study.

Dependent Variables

The dependent measures included in this research effort were comprised of each of the four major categories of fatigue-related measures: performance, physiological, subjective, and behavioral/cognitive measures and are listed in Table 9. These measures were unchanged between the first and second versions of the original proposal. Each of these measures had been identified through previous research as being sensitive to the measurement of fatigue while enabling current researchers to conduct naturalistic, unobtrusive, and non-invasive data collection. Additional measures, while they may have been demonstrated to be sensitive to fatigue, would not have met the previously described requirements of being unobtrusive (especially true of additional behavioral/cognitive measures), noninvasive, and able to be implemented in an integrated data collection system requiring minimal driver effort. A more complete discussion of these variables is presented in Appendix C.

Data Reduction and Analyses

A complete discussion of the proposed data reduction methodology and analyses for each of the aforementioned research claims is presented in Appendix C.

Tribulations Requiring Experimental Adaptation

The following aspects comprised the majority of the unforeseen complexities encountered while performing this research. Consequently, the focus and thus the methodology of this research effort was altered from the original and modified original methodologies to accommodate these issues. Specific alterations are discussed in the following sections. Most notably, however, the focus and therefore the type of data analyses have been modified to accommodate the large quantity of incomplete data.

Licensing and state-to-state permitting logistics. Originally, it was intended that a variety of different driving experiences be represented in this research (*e.g.*, owner-operator, private carriers, contract/common carriers, union, non-union); however, the implemented methodology was subject to the constraint of legal requirements often at odds with preferred or ideal research practices. Specifically, it was envisioned (in the FHWA contract proposal) one or two large long-haul commercial transport companies would be identified as partnering agencies and data collection systems could then be installed in their vehicles (*e.g.*, Wierwille *et al.*, 1998). Then, a university-owned tractor (Volvo) would be outfitted in order to capture the owner-operator experience. Unfortunately, a long-haul commercial transport company of

TABLE 9

Dependent Measures Grouped by the Four Major Categories of Fatigue-Related Measures: Performance, Physiological, Subjective, and Behavioral / Cognitive Measures

CATEGORY	DEPENDENT MEASURES
Performance	Unplanned Lane Deviation Steering Position Steering Velocity Abrupt Lateral Maneuvers Average Vehicle Velocity Velocity Variance Abrupt Braking Maneuvers Time to Collision Number of Near Misses
Physiological	Eyelid Closure Eye Movement
Subjective	Observer Ratings of Drowsiness Karolinska Sleep Scale 'Wake-Up' Survey 'Once a Day' Survey
Behavioral / Cognitive	Evaluation of Driver Mannerisms Simple Response Vigilance Task

suitable size was not identified for the current research project; therefore, a second class-8 commercial sleeper tractor was acquired (Peterbilt) and both tractors were outfitted with data collection systems. Thus, the data collection strategy shifted from one of working with commercial transport companies and utilizing their equipment to one requiring the procurement and instrumentation of university-owned vehicles, which could then be loaned to participants as needed.

Since the study was being funded by the Federal Highway Administration, a government agency, options were explored to acquire an exemption from paying federal and state commercial motor vehicle operating taxes. After much research, however, it was determined such a mechanism could not be employed since the vehicles would be used by companies in order to generate revenue. Consequently, the use of these vehicles necessitated the procurement of appropriate use and tax permits.

In order to ensure compliance with all of the relevant authorities, Nationwide Truckers Permitting Service (NTPS), located in Harrisonburg, Virginia, was retained to procure the appropriate use and tax permits. This process included establishing power of attorney with NTPS so they were able to solicit permits and licensing on behalf of the university. Virginia State vehicle license plates were exchanged for apportioned tags commonly known as base plates. In addition, International Fuel Tax Agreement (IFTA) tags were acquired. IFTA is a mechanism intended to streamline the remittance of fuel taxes. The taxes are paid to the company's own state along with a record of miles traveled in other states. The state disperses the funds accordingly. Several states, Idaho, Kentucky, New Mexico, New York, and Oregon levy fees beyond those collected by IFTA; NTPS was responsible for arranging permitting in these states as well.

Permitting requirements and restrictions dictated these vehicles only be used to transfer 'for-hire' loads; therefore, a private carrier or company owning its own fleet of vehicles exclusively for transferring its goods could not participate. Despite this limitation, it was intended both of the Virginia Tech tractors be made available to smaller companies and owner operators, for whom instrumentation of their vehicles was not economically feasible.

In addition to permitting, legal and insurance requirements further influenced the methodology implemented. Companies are required by the Department of Transportation to insure all vehicles operating under their authority. In order for a company to insure a vehicle, however, they must be either owned or leased by that company. To fulfill this requirement, a lease arrangement was drafted where the vehicle would be leased to the company at no cost; however, the company was responsible for providing worker's compensation (as required by law), employee liability, general liability, and automobile liability insurance premiums. Originally, Virginia Tech's attorneys requested the companies accept liability for the data collection systems in the vehicles; however, after several companies indicated their disinclination to do so, the university insured all of the data collection equipment.

Unfortunately, complexities with the lease agreement further affected the experimental methodology by preventing owner-operators from participating in this study. Unless an owner operator has his or her own authority, they are unable to engage in the transfer of goods. Consequently, the majority of owner-operators interested in participating in this study did not possess their own authority, but rather, through an exclusive lease agreement, worked for a company that possessed its own authority. The experimental vehicle, therefore, would have to be leased to the driver who in turn would have to lease it to their company. Most companies were reluctant to enter into this type of relationship due to the increased paperwork and lack of direct benefit to them. As a result, owner-operators were prevented from participating in this study.

The many legal issues associated with permitting and insurance heavily influenced the implemented methodology. The complexities associated with operation of a commercial motor vehicle in the relatively unique circumstances posed by this study were not well understood at the beginning of this project. In addition, more than 100 union and non-union commercial transportation companies were contacted. Of this group, one medium-sized and several smaller companies indicated an interest in participating. Currently, only individuals from the medium-sized company have participated; therefore, the participants in this study are all non-union employees of the same company.

PERCLOS system. Another unforeseen issue delaying data collection pertained to the Carnegie Mellon Research Institute (CMRI) PERCLOS device used for measuring eyelid closure. This device was designed as an alertness monitoring system that 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. The PERCLOS device was to be employed to evaluate, but not alert, a driver based on their measured fatigue levels. The attorneys for CMRI were reluctant to have their device employed in an environment where the alerting device was disabled. That is, they were concerned there may be legal issues in providing a device capable of alerting the driver of possibly excessive fatigue but not doing so. In order to mitigate these concerns, Virginia Tech obtained a supplemental insurance policy on CMRI's behalf. Due to state law limiting a state institution from providing indemnification to another organization, a signature from the Governor of Virginia was required in order to obtain the insurance policy. This entire process delayed the delivery of the PERCLOS device approximately eight weeks.

In addition to the legal issues, performance issues associated with the device also necessitated a change in the experimental methodology. As previously mentioned, PERCLOS monitors eyelid position through the use of infrared light. Infrared light is a major component of sunlight, which inhibits the PERCLOS monitor from accurately measuring the driver's corneal reflection. Efforts were undertaken to identify manufacturers of thin films impervious to infrared light; however, none of the five manufacturers contacted were able to provide a product that could be applied to a motor vehicle windshield. Rather than abandon use of the PERCLOS system altogether, it was activated during evening and night driving only when the infrared corneal reflection could be more reliably measured.

The final challenge associated with the PERCLOS monitor related to the reduction in corneal reflection that occurs not as a result of the driver exhibiting the signs and symptoms of fatigue, but rather due to the driver turning his head away from the PERCLOS monitor. The trigger criterion was modified such that PERCLOS readings were averaged over a slightly longer time period in order to minimize the false positive rate. However, not all false positives were eliminated; therefore, epochs identified as containing a PERCLOS trigger were evaluated in order to determine if the driver's head position was such that a valid PERCLOS measurement was acquired. For those situations where such a measure was not acquired (*e.g.*, driver was looking at the driver's side rear view mirror or is continually glancing at the seat next to him/her as if looking for something) the PERCLOS measure was invalidated and the epoch was used to describe 'normal' or baseline driving behavior.

Triggered event technology. Previous commercial motor vehicle studies (*e.g.*, Wierwille, Hanowski, and Dingus, 1998; Wylie *et al*., 1996) incorporated continuous-recording on-board data collection systems. Unfortunately, the sheer volume of data collected continuously over an 8-10 day time period greatly inhibits successful reduction and analysis (Wylie *et al*., 1996). As a result, critical incident detection was implemented as a new paradigm for collecting data in the current research effort. Operationally, a critical incident may be 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. Whenever one of these "triggers" was detected, the video and dependent measures data for a period of 1.5 minutes before and 0.5 minutes after the trigger event were automatically recorded. Critical incident recording would enable data indicative of abnormal or sub-optimal driving conditions to be collected without generating the excessive quantity of data that would be generated if continuous recording were employed.

One unanticipated aspect of replacing the continuous recording system with a system based on the occurrence of critical incidents was the complexity of such a system. With a continuous recording system, data are collected and can be analyzed in great detail subsequent to the experimental session. During this analysis, the analyst made subtle changes in filtering criteria to obtain the highest quality data. A critical incident detection system; however, must filter data as they were being collected in order to determine if the data are representative of a trigger or a byproduct of the environment in which the data collection system resides. Real-time data filtering is inherently more difficult than filtering the data after they have been collected since the latter situation is greatly benefited by hindsight. (For this same reason, it is much easier to detect drift and sensor malfunction in a continuous data collection environment.) Consequently, a large quantity of 'false positives,' or situations where a trigger activated, but did not actually occur were recorded.

In addition to a generating a large number of 'false positives,' the critical incident data collection system was susceptible to failure as a result of the environmental conditions within the commercial motor vehicle environment. As these environmental conditions (*e.g.*, vibration, temperature, power spikes) were identified, the data collection system was appropriately fortified. When the data collection system failed during the middle of an experimental session, these data were not discarded due to the high cost associated with each experimental session. These data were treated as shorter, truncated trips.

System complexity also contributed substantial data loss. The complex nature of the system contributed to the presence of a substantial number of hardware and software errors embedded within the system. That the development and integration of the hardware and software took longer than projected, insufficient time remained to debug of the hardware and software configuration prior to being deployed. Consequently, conflicts between the software and hardware resulted in system malfunction on several occasions. The hardware and software controlling the bank of VCRs were frequently affected, resulting in only a portion of the total video data being recorded for several experimental sessions. Additionally, the Karolinska alertness rating box and driver activated critical incident pushbutton were inoperable during several trips due to errors within the system.

Much more could be written detailing these complexities and their resolution; however, a complete discussion of these issues is beyond the focus of this dissertation effort and is not fruitful to the resolution of how the existing data should be treated. It is important to recognize these complexities contributed to longer development cycle for this type of data collection environment than would have been expected for a continuous data collection environment. Despite this delay, the time and resources invested in development of such a system on this project are likely to be recouped in the savings garnered in efficient data analysis resulting from a more manageable set of data for future research efforts. However, the system requires additional testing and evaluation before being deployed in another extended on-the-road study.

Mechanical difficulties. In addition to the aforementioned delays due to the implementation and development of the triggered incident data collection technology, vehicle breakdown and repairs had a substantial impact on the resulting experimental methodology. Specifically, both vehicles experienced mechanical difficulties necessitating the premature termination of six experimental sessions. As with failures of the data collection system, these data were treated as shorter, truncated trips rather than being discarded. Mechanical failures associated with the Volvo requiring multiple trips to a service center included replacement of an oil temperature sensor, oil temperature thermostat, shift lever, and fan clutch. A short in the electrical system, cab air conditioning failure, sleeper air conditioning failure, and a repair to the shift lever comprised the mechanical failures associated with the Peterbilt. The lesson learned was simple: over-the-road trucks can and will break down, and this is a random variable that must be accounted for in the data collection process.

Resulting Impact

The end product of these tribulations is a small sample size (~9) and a severely disjointed data set are the results emanating as a result of the aforementioned problems.

The former is attributed to issues affecting project schedule with the ultimate result being there was not enough time to complete all 48 participants. The latter manifested itself in terms of data quality and completeness and had considerable effect on the types of analyses that could be conducted. Specifically, it was not possible to evaluate changes in driving performance over the course of a ten-day period if data exist only for the first two and a half days. Neither can comparisons between different fatigue and alertness measures be made when only one of the measures was recorded.

Experimental Adaptation

While the data set is disjointed when taken as a whole, a substantial portion of the data has been collected as a result of the time-to-collision criterion being triggered. To capitalize on this opportunity, an in-depth field-study evaluation of the time-to-collision driving behavior metric was conducted. Of primary interest is determining whether time to collision is a valid indicator of driver fatigue. Such a validation involved describing driver characteristics and mannerisms associated with a spectrum of time-to-collision values. Similarly, it is of interest to determine whether self-assessment of fatigue is a valid indicator of driver fatigue. The knowledge gained from both of these evaluations will provide researchers with a better understanding of the methods and design criteria associated with employing a driver-monitoring device and warning system based on time-to-collision criteria.

RESEARCH NEEDS AND OBJECTIVES

This research comprises one portion of a multi-year project designed to assess the impact of sleeper berth usage on driver fatigue and alertness. Driver fatigue is recognized as a major causal factor in accidents involving long-haul commercial drivers. To provide an efficient means for drivers to sleep, sleeper berths are often provided on tractors to allow drivers to obtain some rest when not driving. However, the sleeper berth environment and/or manner in which the truck drivers actually use the sleeper berth many not contribute to quality rest. For example, noise and vibration in the sleeper berth may interfere with the sleep of one member of a team as the other member drives or the movement of the tractor may prevent the driver from sleeping if he/she attempts to do so while the trailer is being loaded or unloaded.

The original objective of this research was to identify the impact of sleeper berth usage on driver performance. The proposed focus is outlined in a subsequent section and presented in full in Appendix C and was designed to monitor existing commercial motor vehicle practices in order to assess the impact of sleeper berth usage on commercial motor vehicle operator alertness, fatigue, and driving performance. These findings were then to be applied towards evaluating the current hours-of-service regulations and making recommendations for possible changes designed to improve the quality of sleep experienced by drivers. Additionally, improvements to the design of the sleeping facilities within commercial motor vehicles may also have emanated from the findings of this research. Benefits of improved quality of sleep include increased operator alertness, decreased fatigue and improved driving performance.

The revised objective of this research was to focus on determining whether time-to-collision and self-assessment of fatigue are reliable and valid indicators of driver fatigue. Such a determination will aid future researchers in determining which attributes accurately reflect the onset of driver fatigue and thus are most appropriate for inclusion in an in-vehicle fatigue monitoring system. Additionally, further refinements in the selection of time-to-collision trigger criterion levels may also emanate from this research. These findings can then be applied towards developing guidelines for a driver monitoring device and warning system based on time-to-collision criteria or self-assessment of fatigue.

While much of the time-to-collision research conducted has yielded important insight into braking and the ability of a driver to accurately estimate impending time-to-collision, it does not provide insight into some of the key issues surrounding its incorporation in an on-board collision monitoring system. Little attention has been directed towards describing driver behaviors or characteristics that may contribute to a driver allowing an excessively short time-to-collision to exist. Similarly, from a fatigue-modeling perspective, no research offering an in-depth evaluation of time-to-collision as a predictor of driver performance or fatigue has been found. The reliability of such a measure depends largely on its ability to adequately indicate changes in the state of driver alertness; information not currently supported by the existing body of scientific literature. A more accurate profiling of driver characteristics related to time-to-collision is needed; such profiling may assist in the development and selection of different collision avoidance technologies, the incorporation of which is based on specific time-to-collision values.

EXPERIMENTAL METHODOLOGY

The data collection procedures employed in this research project are identical to those that would have been employed in the Original and Modified Original Proposals. Similarly, the instrumentation employed remains unchanged. The focus of the analyses has shifted, however, as the available data were not able to support the previously proposed analyses.

Hypotheses

The following hypotheses were tested to support the goals and objectives of this dissertation.

H_1 Self-assessment of fatigue will vary as a function of driver fatigue.

H_2 Temporal separation, as measured by time-to-collision or headway will vary as a function of driver fatigue.

Due to the exploratory nature of this research, the hypotheses were no directional (*i.e.*, some differences were expected, but the nature of the expected differences was unpredictable).

Participants

A total of 9 licensed, Class A, commercial motor vehicle operators used two Virginia Tech Transportation Institute (VTTI) owned tractors in hauling their normal cargo to perform the data collection runs. Participants were required to possess a valid Class A commercial motor vehicle operator's license, have vision and hearing in the normal range, and agree to adhere to all laws regarding operation of a Class 8 tractor including those pertaining to alcohol and drug use. Normal hearing is defined by the Federal Highway Administration (1994) as having a pure-tone hearing threshold in the better ear of not more than 40 dB at 500, 1000, and 2000 Hz. Similarly, normal vision is defined as having a minimum visual acuity of 20/40 in each eye and a distant binocular acuity corrected to at least 20/40 (Federal Highway Administration, 1994). Since drivers are required to have a current medical physical in order to possess a commercial driver's license, these items were not included in the screening process. There were no *a priori* gender restrictions imposed; however, all of the participants were male.

Experimental Design

The research described herein is framed as a field experiment, which differs from a typical laboratory experiment where: 1) independent variables are manipulated, 2) dependent variables are measured, 3) extraneous variables are controlled for, and 4) participants are randomly assigned to conditions. Typically, independent variables are not manipulated nor is randomization required in field studies, as they are "…scientific inquiries aimed at discovering the relations and interactions among…variables in real social structures" (Kerlinger, 1986, p. 372). Kerlinger continues in describing that field studies may be used for exploratory or hypothesis testing but in either case, their greatest strength may be their link to realism (external validity) as participants are observed and measured in their natural environment. Recall that the emphasis of this revised research proposal is to focus on the characterization of events and driver behaviors as they relate to time-to-collision and related safety issues in a real-world driving environment.

Independent variables. The predominant independent measure was driver drowsiness as measured by observer ratings of drowsiness. Additional measures of driver drowsiness included driver mannerisms. While a more sensitive measure of sleep detection, such as EEG, would have been preferred, implementation of such a measure was not practical, as it would have required the presence of an experimenter. As discussed by Kerlinger (1986) in his discussion of field experiments, independent variables are not controlled for *a priori*; therefore, collection of video data (from which observer ratings of drowsiness and driver mannerisms were derived) coincided with dependent measure collection. Subsequent to the data collection session, the video data were analyzed in order to determine the observer ratings of drowsiness and related mannerisms for each subject.

Dependent variables. Evaluating the effectiveness of self-assessment of fatigue as a predictor of driver fatigue employed both the driver's response and time-to-response (reaction time) to the Karolinska Sleepiness Scale. The effectiveness of temporal separation as a predictor of driver fatigue employed three related measures: 1) minimum time-to-collision, 2) minimum headway, and 3) mean headway. Each of these measures is closely related to time-to-collision while being easily incorporated as a trigger into a separation detection device. Due to the computation difficulties in establishing a continuous stream of data (*e.g.,* discontinuous characteristic exhibited by the function when relative velocity between the vehicles approaches zero) for the TTC value, mean TTC was not included as a dependent variable.

EXPERIMENTAL PROCEDURES

Prior to the participant's arrival, a background check was performed to ensure that, 1) the individual is licensed to operate a Class 8 commercial motor vehicle, 2) no outstanding deficiencies exist on their driving record, and 3) the individual, or his/her employer, has insurance to cover the goods being transported.

Instructions and Informed Consent

Experimenters met participants at their place of employment. After introductions had been made, the participant read all the necessary information concerning the study, including the certificate of confidentiality (Appendix B), and reviewed and signed the informed consent form (Appendix B). At this time, the participant was encouraged to ask any questions he/she may have had. The participant was then given a brief health survey to screen for medical conditions that may suggest the participant was at greater than normal risk. All of the participants passed the health-screening test. Participants were then given a comprehensive introduction to the test vehicle, including approximate camera locations and all data collection devices. Any questions the participants had were then answered.

Training

The experimenter conducted a brief inspection of the vehicle with each participant and pointed out important details unique to each of the vehicles (*e.g.,* location and operation of various controls). When the participant indicated that they felt comfortable with the controls and other aspects of the vehicle, the experimenter did the same for the data collection devices.

After these displays and controls were introduced, the experimenter demonstrated the data collection systems (*e.g.,* Nightcap) and showed the driver the approximate location of each camera. The cameras' fields of view were limited to the scene outside the vehicle and to that within the truck cab; no camera viewed the sleeper berth. The cameras were directed so as to capture images of the road ahead of the truck, the views behind the truck, the driver, and the sleeper berth. In addition to the video data, a variety of driver performance and sleep quality measures were collected. Measurements of steering wheel movement, brake application, speed, lateral and longitudinal acceleration, lane position, and infrared retinal reflection (to determine operator alertness while driving; this device does not affect a driver's ability to see in any way) were recorded in real time by computer. Measurements of noise, vibration, temperature, and light level were also obtained. By quantifying the driving and non-driving vehicle cab environment, the potential for adverse effects on driving performance, sleep, and the general health and well being of the driver can be determined. Additionally, drivers were asked to respond subjectively to feelings of alertness and fatigue when prompted by an integrated data collection device based upon the Karolinska Sleep Scale. This integrated display was mounted in such a manner as not to interfere with the driver's field of vision; similarly the driver was instructed not to respond to the device if it is not safe to do so.

In addition to training the operator on equipment within the tractor and the tractor itself, the operators were instructed on appropriate procedures in case of an accident or other emergency. The use and operation of the cellular phone was demonstrated. The placement of all emergency equipment (*e.g.*, flares, fire extinguisher, tow-hooks) was also conveyed.

The complete training manual is presented in Appendix D.

Prior and Subsequent to On-Road Data Run

The average trip length in this study lasted 8 days. This allowed effective analysis of day of week and circadian effects as well as the study of additive sleep loss and lower sleep quality effects for longer trips. In order to have an effective baseline of sleep quality data for comparison to the sleeper berth data, participants were also asked to wear the nightcap for several nights while sleeping at home subsequent to returning from a data collection trip.

On-the-road data run. Drivers were provided with an emergency phone number at which a member of the experimental team could be reached should they have any problems. Drivers were asked to drive and conduct themselves as they normally would while transporting their load; however, special emphasis was placed on:

- Adhering to all laws regarding operation of a Class 8 tractor especially those pertaining to alcohol and drug use,
- Conforming to the laws and regulations of driving on public roadways,
- Following the experimental procedures as well as they can, and
- Informing the experimenters if they (the drivers) incur difficulties of any type.

Terminology

As previously mentioned, three methods were in concert to activate the intermittent collection of the dependent measures in establishing the current data set (*critical event*, *random interval*, and *driver identified*). For the analyses that follow, unless otherwise specified, only critical events are considered. It is prudent, therefore, to review some relevant terminology and their nuances prior to continuing.

Epochs are blocks of recorded data stored in *.dat files. An epoch contains at least one event; however, multiple events may be present in a single epoch if they occur simultaneously or overlap.

Events are three-minute blocks of recorded data and exist within an epoch. Multiple events may exist within a single epoch as one event may overlap another event. An event is recorded when a trigger exceeds a predetermined value. Data are recorded for two minutes prior and one minute following the occurrence of a trigger.

A **trigger** occurs when a trigger variable exceeds a predetermined value. When this occurs, event data are recorded for two minutes prior and one minute following the occurrence of a trigger. If a subsequent trigger occurs in the minute of data collection following the occurrence of the first trigger, data collection continues for one minute beyond the subsequent trigger (data already exists for the two preceding minutes).

When multiple events occur within a single epoch, the most salient of these triggers will be identified as the **primary trigger**. For example: a driver drifting out of his / her lane may cause the first trigger while a second trigger is activated as the driver makes a quick steering correction. In this situation, the unintended lane deviation would be identified as the primary trigger.

Critical events are those that are: 1) directly related to degraded driving performance or 2) are directly related to fatigue. The data analyst will classify an event as being critical or non-critical upon review.

Data Reduction

The organization of the data, as they exist at the end of the experimental session, is characterized in Table 10. Data collected instruments employed during the homesleep portion of the study were comprised of two paper-based Karolinska Sleep Scale Instruments (one administered prior to falling asleep and the other upon waking), a

TABLE 10

Summary of Experimental Data as They Exist at the End of the Experimental Session.

INSTRUMENT DESCRIPTION		SUMMARY
GENERAL	General Survey	Paper-based instrument recording demographic information on driver's professional experience and medical / medication background.
HOMESLEEP	Karolinska Scale – Before Sleep Karolinska Scale – Wake Up	Paper-based instrument recording subjective self-assessment of driver alertness prior and subsequent to sleep period.
	'Wake Up' Survey	Paper-based instrument recording subjective self-assessment of preceding sleep period.
	Nightcap Data File (0.6 V) Nightcap Data File (2.5 V)	Digital files (0.6 and 2.5 V thresholds, respectively) containing objective measures of sleep quality and quantity.
ON THE ROAD	Driver Logs	Paper-based instrument recording driver's official work / rest schedule.
	Vehicle Mileage Records	Paper-based instrument recording mileage accrued by driver in respective states.
	'Once A Day' Survey	Paper-based instrument recording self-assessment of the preceding day's activities.
	'Wake Up' Survey	See Above.
	Critical Incident Data (*.DAT) Files	Digital file containing measures of driving performance.
	Sleep Data (*.SLP) Files	Digital file containing measures of environmental data for each sleep period. Karolinska before and after sleep period self-assessment measures of driver alertness are included herein for On the Road conditions.
	Nightcap Data (*.REM) Files	See Above; threshold in vehicle set at 2.5V.
	Video Data	Video of driver and area surrounding vehicle corresponding to critical incidence occurrence.

paper-based ‘wake-up’ subjective survey instrument, and the computer-based data files for both 0.6 and 2.5 V thresholds of the Nightcap sleep monitoring device. Data generated from the on-the-road portion of the study were composed of both subjective and objective measures. A general survey instrument recorded personal information from each driver related to his or her background, work experience and health. A ‘once a day’ survey focussing on the events of the preceding 24-hours that may have contributed to the operator’s level of fatigue was completed for each day the driver participated in the study. The ‘wake up’ survey, completed after each rest period, was derived from the St. Mary's Hospital (SMH) Scale (Ellis *et al.*, 1981) and was designed to query individuals about quality aspects of their previous night’s sleep. In lieu of the paper-based Karolinska Sleep Scale Instrument employed in the homesleep portion of the study, an electronic version was implemented in the on-the-road portion of the study. These results, along with measurements of the sleeper cab environmental data during sleep episodes are stored in a data file (*.slp) where each data file corresponds to a separate sleep episode. Driving performance, PERCLOS, and other measures of driver alertness were stored in critical incident driving performance data (*.dat) files. Much of the data represented herein were originally designed to support the original proposal and therefore, was not used in the current analysis. The analyses contained herein were limited to evaluating the video and driving data.

The data reduction process is shown in Figure 23. Prior to conducting the video analysis, the raw driving performance data files (*.dat) were concatenated into a single driving performance data file. From the concatenated data file, a project data file (*.prj) was generated for use by the video analysis system. The video data were then analyzed and the independent measures of driver fatigue (observer rating of drowsiness and driver mannerisms) were added to the project data file. Subsequent to this analysis, the project data file was reformatted; in addition a formatted report detailing the incidents contained within each epoch was generated. A change in the frequency during which driver mannerisms were recorded (from once per epoch to once per minute in order to coincide with the observer rating of drowsiness measurements), necessitated the development of an intermediate mannerisms data file. Once the mannerisms had been reanalyzed, the resulting file was added to the relational database. The formatted project data file was then purged of all epochs containing only invalid incidents and a formatted data report was generated. The formatted project data file (with invalid epochs removed) was then used to purge the concatenated data file of all data corresponding to epochs

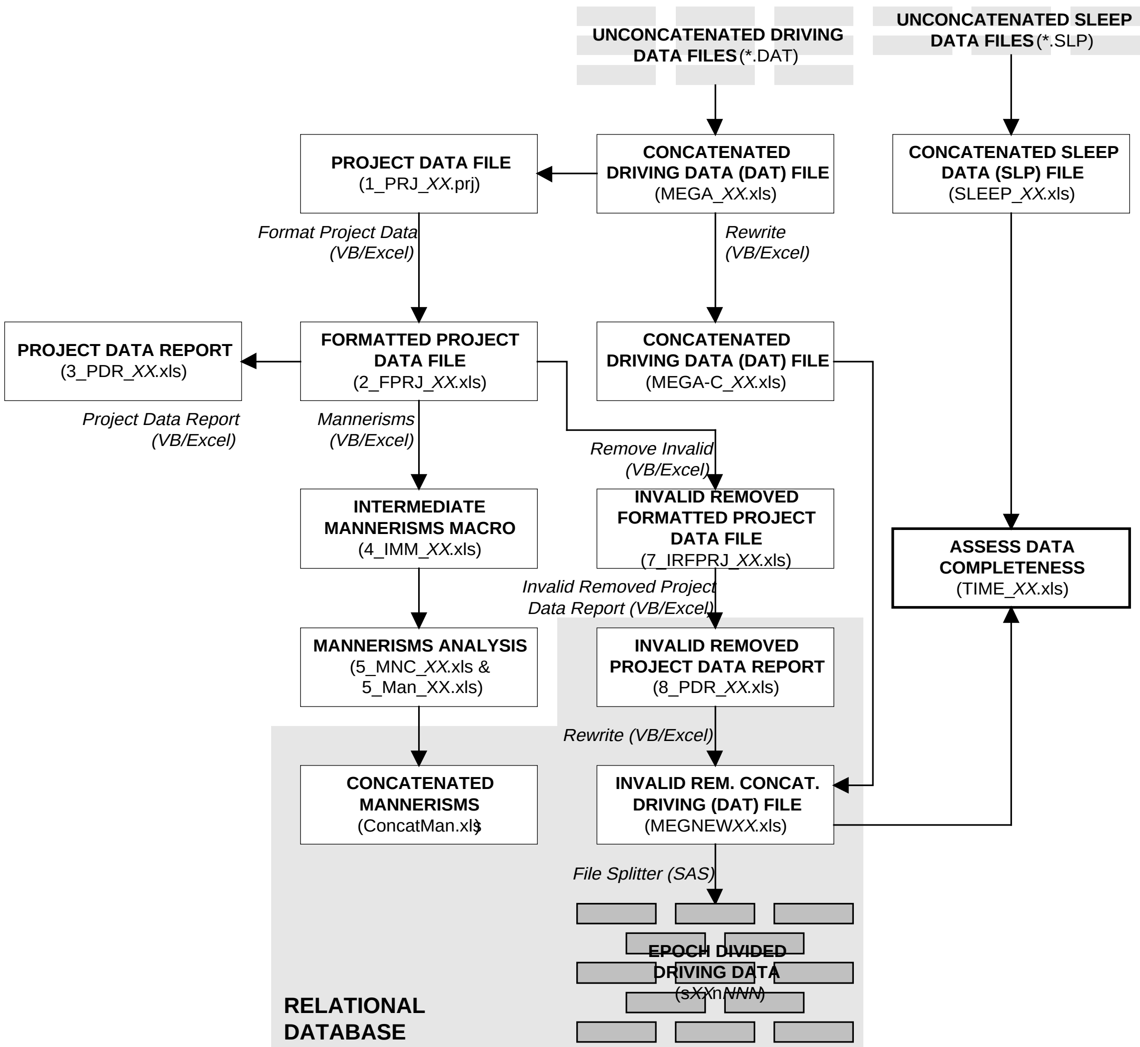


Figure 23. Graphical depiction of data reduction and recombination to establish the relational database structure.

containing only invalid data. The formatted project data report, concatenated driving performance file (with invalid data removed), and mannerisms file comprised the relational database structure. Within each file, the subject number epoch sync numbers comprised the index value, or method by which the files were linked. Additionally, the concatenated data file was split into epoch-level driving performance files to allow the researchers maximum data analysis flexibility.

Data Analysis

A systematic observation was conducted of the videotapes, wherein each epoch and incident recorded were evaluated, that recorded the events as the driver performed his daily responsibilities. During this time, all of the video segments were viewed. Those time-to-collision incidents where a target (*e.g.*, individual, vehicle) in the current lane of travel could not be identified were removed from the data set. Recall that the trigger criterion level for time-to-collision was set at four seconds; therefore, each of the time-to-collision incidents had a time-to-collision of four seconds or less. For each of these incidents, the minimum associated separation (in terms of headway and time-to-collision) in addition to mean headway experienced by the driver was extracted from the data files. The headway and time-to-collision values were then compared with driver attributes and behaviors.

In addition, those events where the proximate cause was not based on driver behavior, but rather on a timed trigger, were also be identified and examined. Representative of normal driving, the behaviors demonstrated in these incidents was compared with the behaviors demonstrated in the incidents where the time-to-collision criterion had been exceeded. Specifically, these incidents were analyzed on the basis of driver behaviors. It was suspected that drivers experiencing relatively long separation values would demonstrate behaviors similar to those represented in normal driving situations; whereas, drivers experiencing extremely short separation values were more likely to demonstrate behaviors indicative of increased fatigue and decreased attention. Behaviors analyzed consisted of driver mannerisms (Skipper *et al.*, 1984), subjective evaluation of driver fatigue (Wierwille and Ellsworth, 1994; Skipper *et al.*, 1984), and a narrative describing the driver’s actions prepared by the data reductionist.

A multivariate discriminant analysis was then conducted on the aforementioned incidents. Discriminant analysis is a statistical technique similar to regression analysis. Unlike regression, however, the dependent variable in a discriminant analysis is categorical rather than continuous. The purpose of this discriminant analysis was to develop a mathematical rule or classification scheme to predict whether the driver, based upon his behaviors, was fatigued as indicated by the recorded separation values. Such a rule could potentially serve as a basis for the development of a rule-based time-to-collision assessment of a driver's fatigue and alertness level.

In addition to the discriminant analysis, the time-to-collision incidents were subject to a multiple regression analysis. The multiple regression analysis focussed on evaluating the behavior as predictors of time-to-collision values. This analysis will seek to characterize the change in driver behaviors over the time-to-collision spectrum.

It was suspected that drivers experiencing relatively long time-to-collision values demonstrated behaviors similar to those represented in normal driving situations; whereas, drivers experiencing extremely short time-to-collision values are more likely to demonstrate behaviors indicative of increased fatigue and decreased attention. To test this hypothesis, a multivariate cluster analysis was performed. If the above presumption were found to be correct, the clusters would have been arranged according to different levels of time-to-collision. If this were not the case, the time-to-collision critical incidents would have been arbitrarily grouped according to their values (specific groupings will be determined based on the distribution of time-to-collision values). Subsequently, a multivariate analysis of variance and appropriate post hoc tests were conducted to determine if a difference in driver behavior is detected across the spectrum of time-to-collision values.

EMPIRICAL RESULTS

Data Reduction

The raw data, as previously described, were used to construct a relational database from which data could be queried to answer specific research questions. These data were, as much as possible, left in their native format. While some incidents, due to missing video or computer data, had already been declared invalid and thus excluded from this database, additional filtering and recombination of data were necessary in order to exclude data where the individual measure to have been evaluated in the current analysis was adversely affected. Eliminating all observations containing any invalid data in the first step would have unnecessarily reduced the overall data set; whereas allowing the analyst to exclude queried files for which the measure of interest was invalid provided maximum database flexibility.

Self-assessment of fatigue. The database was queried in order to identify a subset of the data containing all incidents meeting a timed trigger criterion. Table 11 contains a list of the data within this data subset. Once identified, these data were filtered to remove all observations where the maximum allowable response time (30 seconds) was violated since no associated Karolinska responses existed for these observations. Subsequently, the mannerisms data were reformulated according to Table 12.

Temporal separation. The database was queried in order to identify a subset of the data containing all incidents having a time-to-collision criterion. Epoch level driving performance data files were queried and a variety of summary statistics calculated for each time-to-collision incident. Table 13 contains a list of the data within this data subset. Once identified, these data were filtered to remove all observations not indicative of interstate travel (*i.e.*, the maximum velocity did not reach 55 miles per hour). In addition, data were filtered to remove all observations indicative of a velocity sensor failure. This failure mode was easily detected as the velocity data stream demonstrated a large (~50 miles per hour) increase in the velocity (*i.e.*, the acceleration) of the vehicle over a very short time interval (< 1 second). Such an acceleration value would not have been consistent with the normal operation of the vehicles employed in this study. The driver mannerisms were reformulated according to Table 12.

TABLE 11

Data Contained within the Self-Assessment of Fatigue Data Subset

COLUMN	VARIABLE NAME	TYPE	DESCRIPTION
1	Participant ID	Integer	Participant ID
2	Karolinska Response	Integer	Karolinska Scale Response
3	Karolinska Reaction Time	Single	Reaction Time from Alert to Karolinska Response
4	B_Incident ID	Integer	Before Alert – Incident ID
5	B_Mannerism ID	Integer	Before Alert – Mannerism ID
6	B_Participant ID (repeated)	Integer	Before Alert – Participant ID
7	B_Epoch ID	Integer	Before Alert – Epoch ID
8	B_EpochBeg	Integer	Before Alert – Epoch Begin Sync
9	B_EpochEnd	Integer	Before Alert – Epoch End Sync
10	B_ORD Beg	Integer	Before Alert – Epoch ORD Begin Sync
11	B_ORD Mid	Integer	Before Alert – Epoch ORD Middle Sync
12	B_ORD End	Integer	Before Alert – Epoch ORD End Sync
13	B_ORD Value	Single	Before Alert – Epoch ORD Value
14 … 44	B_Driver Mannerisms		Before Alert – Driver Mannerisms
45			
46	A_Incident ID	Integer	After Alert – Incident ID
47	A_Mannerism ID	Integer	After Alert – Mannerism ID
48	A_Participant ID (repeated)	Integer	After Alert – Participant ID
49	A_Epoch ID	Integer	After Alert – Epoch ID
50	A_EpochBeg	Integer	After Alert – Epoch Begin Sync
51	A_EpochEnd	Integer	After Alert – Epoch End Sync
52	A_ORD Beg	Integer	After Alert – Epoch ORD Begin Sync
53	A_ORD Mid	Integer	After Alert – Epoch ORD Middle Sync
54	A_ORD End	Integer	After Alert – Epoch ORD End Sync
55	A_ORD Value	Single	After Alert – Epoch ORD Value
56 … 86	A_Driver Mannerisms		After Alert – Driver Mannerisms
86			

TABLE 12

Reformulation of Driver Mannerisms Data

REFORMULATED VARIABLES	ORIGINAL VARIABLES	DESCRIPTION
Hair	Hair	Scratching / Straightening
Brow	Brow_raise	Brow Raise – Eyes Open Wide
	Brow_lower	Brow Lower – Scowl
Eye1	Eye_peripheral	Peripheral Looks
	Eye_rub	Rubbing / Scratching
	Eye_blink	Excessive Blinking
	Eye_stare	Staring
	Eye_glass	Glassy Appearance
Eye2	Eye_slwcls	Slow Closure
	Eye_unfrol	Slow Closure with Unfocussed Rolling
	Eye_proclos	Prolonged Closure (> 2 seconds)
Face	Face_t-1	Slightly Slack Facial Tension
	Face_t-2	Considerably Slack Facial Tension
	Face_cont	Facial Contortions
	Face_rub	Rubbing / Scratching / Holding
Mouth	Mouth_ywn	Yawning
	Mouth_lips	Lips Licking, Biting
	Mouth_tng	Tongue Motion
	Mouth_oth	Other
Neck	Neck_rub	Rubbing / Scratching / Holding
	Neck_HPC	Head Position Change
Body	Body_	Position Change / Shrug
Other1	Oth_drink	Drinking
	Oth_tobac	Using Tobacco
	Oth_chew	Chewing (*e.g.*, gum)
	Oth_eat	Eating
Other2	Oth_radio	Radio On
	Oth_cb	Using CB

TABLE 13

Data Contained Within the Time-to-Collision of Fatigue Data Subset.

COLUMN	VARIABLE NAME	TYPE	DESCRIPTION
1	Participant	Integer	Participant ID
2	Epoch Begin	Integer	Sync Number Corresponding to Epoch Begin
3	Epoch End	Integer	Sync Number Corresponding to Epoch End
4	Incident Begin	Integer	Sync Number Corresponding to Incident Begin
5	Incident End	Integer	Sync Number Corresponding to Incident End
6			
7	Vel-Mean	Single	Velocity Mean
8	Vel-SD	Single	Velocity Standard Deviation
9	Vel-n	Integer	Velocity Observations in Incident
10	Vel-Min	Single	Velocity Minimum
11	Vel-Max	Single	Velocity Maximum
12	Vel-Med	Integer	Velocity Median
13			
14	TTC-Mean	Single	Time-to-Collision Mean
15	TTC-SD	Single	Time-to-Collision Standard Deviation
16	TTC-n	Integer	Time-to-Collision Observations in Incident
17	TTC-Min	Single	Time-to-Collision Minimum
18	TTC-Max	Single	Time-to-Collision Maximum
19	TTC-Med	Integer	Time-to-Collision Median
20			
21	Hd-Mean	Single	Headway Mean
22	Hd-SD	Single	Headway Standard Deviation
23	Hd-n	Integer	Headway Observations in Incident
24	Hd-Min	Single	Headway Minimum
25	Hd-Max	Single	Headway Maximum
26	Hd-Med	Integer	Headway Median
27			
28	ORD ID	Integer	Observer Rating of Drowsiness ID
29	ORD Beg	Integer	Observer Rating of Drowsiness Sync Begin
30	ORD Mid	Integer	Observer Rating of Drowsiness Sync Middle
31	ORD End	Integer	Observer Rating of Drowsiness Sync End
32	ORD Value	Integer	Observer Rating of Drowsiness Value
33	Hair_	Boolean	Mannerism – Scratch/Touch/Rub Hair
34	Brow_raise	Boolean	Mannerism – Raise Brow
35	Brow_lower	Boolean	Mannerism – Lower Brow
36	Eye_peripheral	Boolean	Mannerism – Peripheral Eye Motions
37	Eye_rub	Boolean	Mannerism – Rubbing Eyes
38	Eye_blink	Boolean	Mannerism – Excessive Eye Blinking
39	Eye_slwcls	Integer	Mannerism – Eye Slow Closure
40	Eye_unfrol	Integer	Mannerism – Eye Unfocussed Roll
41	Eye_proclos	Integer	Mannerism – Eye Prolonged Closure
42	Eye_stare	Boolean	Mannerism – Eye Staring
43	Eye_glass	Boolean	Mannerism – Glassy Eyes
44	Face_nrml	Boolean	Mannerism – Face Normal Tension
45	Face_t-1	Boolean	Mannerism – Face Slightly Slack Tension
46	Face_t-2	Boolean	Mannerism – Face Considerable Slack Tension
47	Face_cont	Boolean	Mannersim – Face Contortions
48	Face_rub	Boolean	Mannerism – Rubbing/Touching/Holding Face
49	Mouth_ywn	Boolean	Mannerism – Mouth Yawn
50	Mouth_lips	Boolean	Mannerism – Biting or Licking Lips
51	Mouth_tng	Boolean	Mannerism – Tongue Motion
52	Mouth_oth	Boolean	Mannerism – Other Mouth Motion
53	Neck_rub	Boolean	Mannerism – Rubbing/Touching/Holding Neck
54	Neck_HPC	Boolean	Mannerism – Head Position Change
55	Body_	Boolean	Mannerism – Body Position Change
56	Oth_drink	Boolean	Mannerism – Other - Drinking
57	Oth_tobac	Boolean	Mannerism – Other – Tobacco Usage
58	Oth_chew	Boolean	Mannerism – Other – Chewing (*e.g.*, gum)
59	Oth_radio	Boolean	Mannerism – Other – Radio On
60	Oth_cb	Boolean	Mannerism – Other – Using CB
61	Oth_fgtdrow	Boolean	Mannerism – Other – Fighting Drowsiness
62	Oth_other	Boolean	Mannerism – Other – Other
63	Oth_o_desc	String	Mannerism – Other - Description

Descriptive Analyses

Experimental session. State mileage totals were not available for one of the nine participants (he changed employers immediately following his participation in the study); therefore, the totals represented herein reflect the travel accumulated by the remaining eight participants. Despite these missing data, the remaining data were used to characterize the travel conducted. Nine drivers drove two instrumented vehicles a total of approximately 30,000 miles, resulting in 72 days of data collection.

Experimental sessions lasted between six and ten days (Mean: 8, SD: 1.4) during which drivers logged an average of 3,657 miles (Range: 1,588 to 4,639, SD: 1,076.3) across 11 states (Range: 6 to 16; SD: 4). In total, travel was conducted in 24 states; the greatest number of miles were logged in Virginia (6,840) and the fewest in New Hampshire (102). State-by-state mileage summaries are presented in Table 14, while Figure 24 portrays the same information graphically.

Participants. Nine licensed male commercial truck drivers participated in this study and all of the participants possessed Class A licenses. That only male drivers participated in this study is a factor of the industry's demographics rather than conscious effort; 86.6% of all commercial motor vehicle operators are male (Kinghorn and Bittner, 1993).

The mean age of the participants was 42.8 years (Range: 32 to 63, SD: 11.4). Participants' commercial truck driving experience ranged from two to forty-two years with a mean of 17.9 years (SD: 11.7). Driver demographics are presented in Table 15.

Drivers, at the time of their participation, possessed an average of two additional endorsements above the base operating license (Range: 0 to 4; SD: 1). An airbrake endorsement is required to obtain a Class A license, and therefore, for the purpose of this discussion, is not considered optional. Endorsements reflect further training by the driver and are required for operating with certain types of loads and may be used as metric to approximate a driver's experience level. Generally, drivers with less experience have fewer endorsements than those with more experience; however, this is somewhat of an oversimplification since drivers would occasionally allow an endorsement to expire if they did not feel they would have a need for it in the near future. The four most common endorsements (drivers possessing in parentheses) include hazardous materials ($n = 8$), tanker ($n = 3$), double/ triple trailers ($n = 2$), and passenger ($n = 2$).

TABLE 14

Study Mileage Totals by State (*n* = 8; Data Unavailable for One Participant)

STATE	ABBREVIATION	MILEAGE TOTALS
Alabama	AL	603
Arkansas	AK	281
Connecticut	CT	335
Delaware	DL	788
Georgia	GA	1225
Illinois	IL	773
Indiana	IN	1809
Kentucky	KY	747
Louisiana	LA	514
Massachusetts	MA	233
Maryland	MD	2529
Missouri	MS	638
North Carolina	NC	2753
New Hampshire	NH	102
New Jersey	NJ	1038
New York	NY	354
Ohio	OH	1885
Pennsylvania	PA	2491
Rhode Island	RI	114
South Carolina	SC	972
Tennessee	TN	760
Texas	TX	533
Virginia	VA	6840
West Virginia	WV	937
	TOTAL	29254

Figure 24. Study mileage totals by state (n = 8; Data unavailable for one participant).

TABLE 15

Participant Demographics - Summary Statistics

	PARTICIPANT										
	1	2	3	4	5	6	7	8	9	Mean	S.D.
Age (Years)	32	61	36	40	35	35	63	44	39	42.8	11.4
Class A Experience	2	23	13	19	5	17	42	25	15	17.9	11.7
Avg. Trip Length (Miles)	1600	2800	2875	2500	2750	2500	3000	2850	3000	2652.8	435.3
Avg. Trip Length (Days)	3-4	5	5	4-5	5	5	5	5-6	7	5.1	0.9
Avg. Break Length (Days)	2	2	2	2	2	2	2	1-2	2	1.9	0.2
Actual Trip Length (Miles)	3793	2952	N/A[1]	2967	1588	4639	4603	4353	4395	3656.7	1076.3
Actual Trip Length (Days)	8	7	9	6	6	10	9	9	8	8	1.4
										Total	%
Endorsements:											
Hazardous Materials	X	X	X	X		X	X	X	X	8	88.9
Tanker	X					X		X		3	33.3
Double / Triple Trailers	X			X		X				3	33.3
Passenger		X				X				2	22.2
Cargo Experience:											
Dry Goods / Box	X	X	X	X	X	X	X	X	X	9	100.0
Refrigerated		X	X	X			X	X		5	55.5
Tanker								X		1	11.1
Hazardous Materials	X	X	X	X		X	X	X	X	8	88.9
Flatbed	X		X	X		X	X		X	6	66.7
Flatbed – oversize							X			1	11.1

[1]Data not available for this participant.

Inferential Analyses

It is prudent to mention that MANNERISMS is comprised of 28 individual variables divided into ten meta variables (as presented previously, Table 12); however, to reduce confusion and improve efficiency, wherever possible they are referred to collectively. Where this is not possible (*e.g.*, results from a multivariate analysis where some meta variables were found to be significant while others were not), meta variables emanating from MANNERISMS are denoted in italicized capital letters (*e.g.*, *MOUTH*, *EYE1*).

Self-assessment of fatigue. In order to determine whether self-assessment of fatigue (KAROLINSKA) and the associated reaction time (RXNTIME) are valid indicators of driver fatigue, it was necessary to compare these measures against measures known to be reliable and valid indicator of fatigue, observer rating of drowsiness (ORD) and driver mannerisms (MANNERISMS). Data exist for only eight of the nine participants due to failure of the Karolinska device for one participant.

A scatterplot (n = 93) showing ORD plotted as a function of KAROLINSKA for the remaining participants is shown in Figure 25. (Note: Where higher order dimensions fail to greatly improve visualization of the data, the plots shown are limited to two dimensions). A multiple regression analysis was performed employing ORD and MANNERISMS as the independent variables and KAROLINSKA as the dependent variable. Table 16 shows a summary of the multiple regression analysis. ORD (p = 0.0019) was found to be a significant (a = 0.05) predictor of KAROLINSKA; however, overall model fit was low (*Adj.* R^2 = 0.0782).

Figure 26 shows a scatterplot (n = 93) of ORD plotted as a function of RXNTIME. A multiple regression analysis was performed employing ORD and MANNERISMS as the independent variables and RXNTIME as the dependent variable. A summary of the multiple regression analysis is presented in Table 17. *OTHER2* (p = 0.0010) was found to be the only significant (a = 0.05) predictor of RXNTIME; however, overall model fit was low (R^2 = 0.1121).

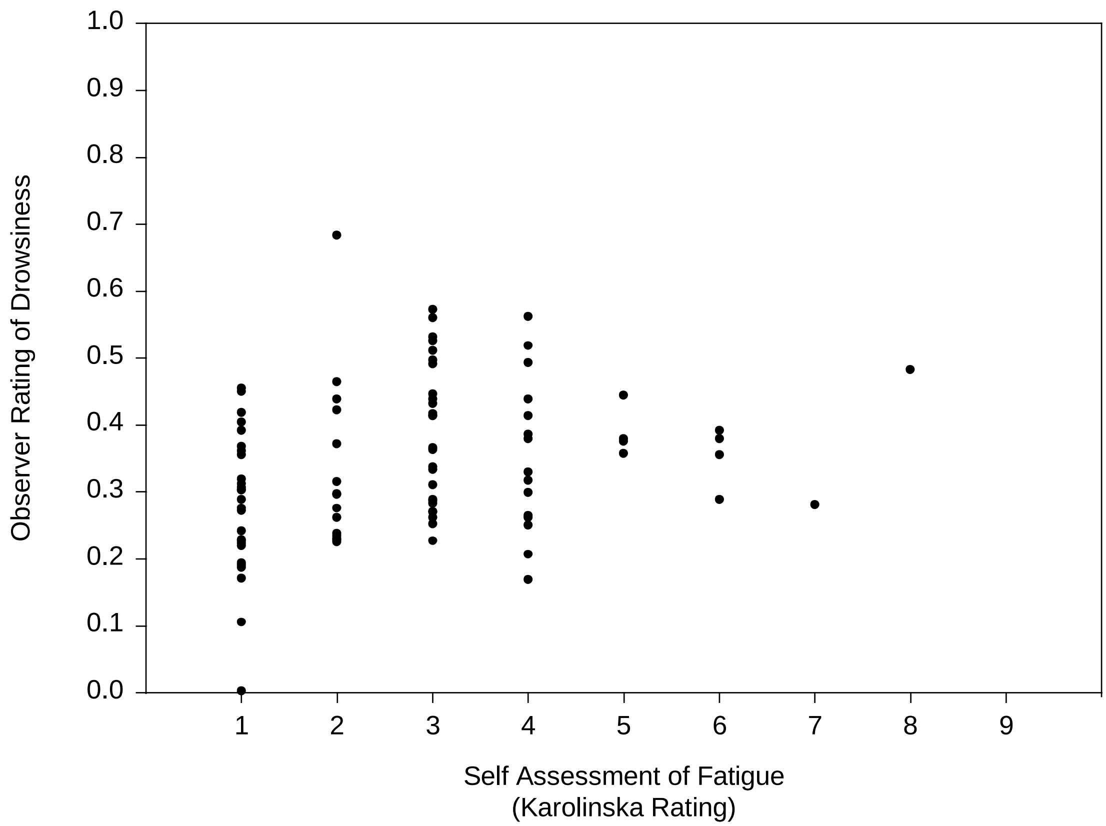


Figure 25. Observer rating of drowsiness (ORD) plotted as a function of self-assessment of fatigue (KAROLINSKA, n = 93). Table XXX shows the descriptions corresponding to the Karolinska Self Assessment of Fatigue levels.

TABLE 16

Multiple Regression Summary Table of KAROLINSKA Using ORD and MANNERISMS

GOODNESS OF FIT *(Regression)*

METRIC	**VALUE**
R^2	0.0782
C(p)	2.7813

ANALYSIS OF VARIANCE

SOURCE	**DF**	**SS**	**MS**	***F***	***p***
Model	1	17.5304	17.5304	7.72	0.0066*
Error	91	206.7491	2.2719		
Total	92	224.27957			

PARAMETER ESTIMATES

VARIABLE	**PARAMETER ESTIMATE**	**STANDARD ERROR**	**SS**	***F***	***p***
Intercept	1.4253	0.4954	18.8083	6.39	0.0132*
ORD	3.8378	1.3816	17.5304	10.25	0.0019*

* Statistically significant at $p \leq 0.05$

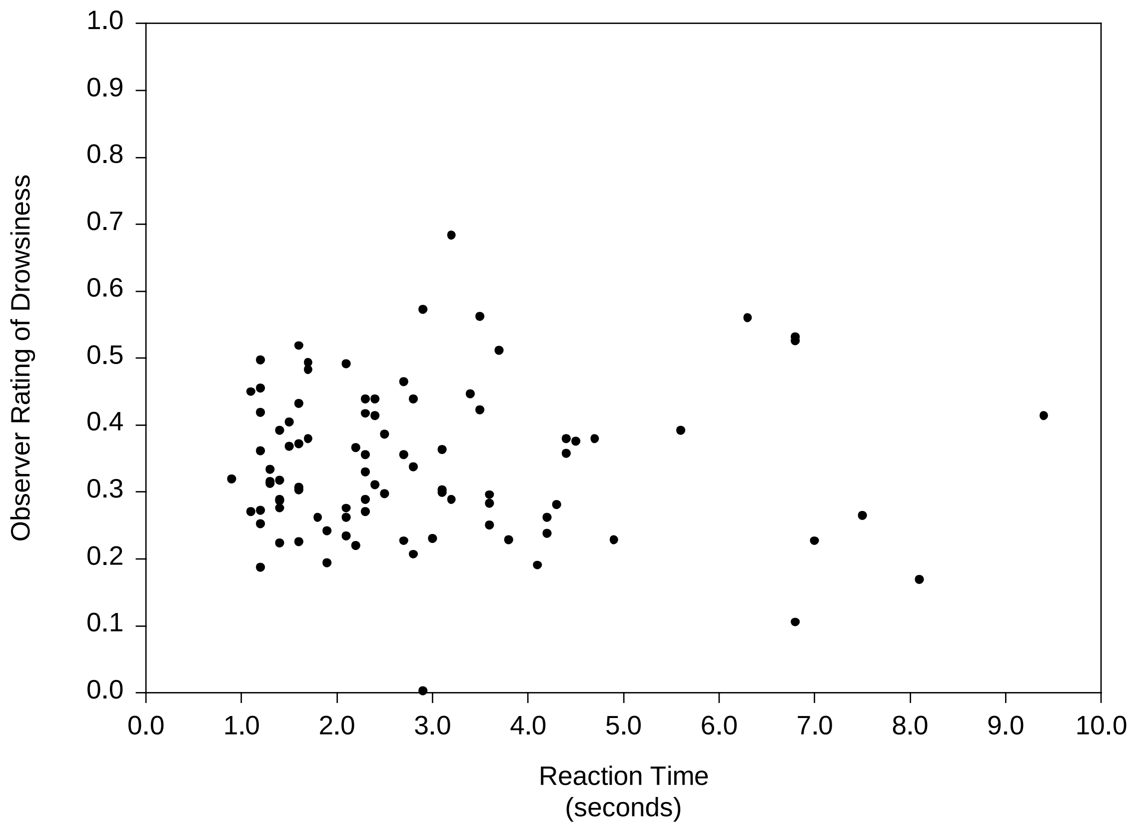


Figure 26. Observer rating of drowsiness (ORD) plotted as a function of RXNTIME response to self-assessment of fatigue (n = 93).

TABLE 17

Multiple Regression Summary Table of RXNTIME Using ORD and MANNERISMS

GOODNESS OF FIT *(Regression)*

METRIC	**VALUE**
R^2	0.1121
C(p)	3.0389

ANALYSIS OF VARIANCE

SOURCE	**DF**	**SS**	**MS**	***F***	***p***
Model	1	56.7686	56.7686	11.49	0.0010*
Error	91	449.6910	4.9417		
Total	92	506.4596			

PARAMETER ESTIMATES

VARIABLE	**PARAMETER ESTIMATE**	**STANDARD ERROR**	**SS**	***F***	***p***
Intercept	1.9404	0.4295	100.8412	20.41	<0.0001*
OTHER2	1.6321	0.4815	56.7686	11.49	0.0010*

* Statistically significant at $p \leq 0.05$

Anecdotal evidence from the video reduction process suggested the alerting tone which solicited the driver to report his level of fatigue according to the Karolinska scale had an alerting affect on the driver arose during the video reduction process. To evaluate this hypothesis a paired *t*-test was performed. A significant ($\alpha = 0.05$) increase (p = 0.0244) in the observer ratings of drowsiness was found to exist between the time period immediately preceding the onset of the Karolinska scale alert and the subsequent time period, Table 18.

Temporal separation. As with self-assessment of fatigue, it is necessary to compare time-to-collision with a measure known to be a reliable and valid indicator of fatigue, such as observer ratings of drowsiness, in order to determine whether time-to-collision is a valid indicator of driver fatigue. Three scatterplots (n = 145) and associated histograms showing observer ratings of drowsiness as a function of minimum time-to-collision (MINTTC), minimum headway (MINHEAD), and mean headway (MEANHEAD) are presented in Figures 27, 28, and 29, respectively. Due to equipment malfunction, data was only available for eight of the nine subjects (although the participant excluded for this analysis was not the same participant previously excluded).

Because data were collected only for time-to-collision values of four seconds or less, a complete range of time-to-collision values was unavailable. Presuming time-to-collision to be a valid measure of fatigue, it was first necessary to determine whether the transition in behaviors had occurred at a headway level greater than the four-second trigger, for which actual data were available. Specifically, it was necessary to determine whether a difference in driver fatigue exists between the time-triggered data and the time-to-collision triggered data.

Towards this end, a classification variable (GROUP) was created in order to distinguish between the timed-trigger and time-to-collision trigger conditions. A multivariate analysis of variance (MANOVA) was performed on the independent variable GROUP to determine if significant differences in fatigue level existed between the time-triggered data and time-to-collision triggered data. An overall MANOVA was chosen in lieu of multiple single analyses of variance in order to control the inflated

TABLE 18

Results of Paired *t*-Test for ORD Immediately Preceding and Following Karolinska Trigger

POPULATION STATISTICS

VARIABLE	**N**	**MEAN**	**STANDARD DEVAITION**	**MIN**	**MAX**
ORD_BEFORE	93	0.3404	0.1101	0.0000	0.6957
ORD_AFTER	93	0.3262	0.1137	0.0018	0.6829

ANALYSIS VARIABLE: DIFFERENCE[1]

N	**MEAN**	**STANDARD ERROR**	***t***	***p***
60	-0.0141	0.0061	-2.2891	0.0244*

[1] DIFFERENCE = ORD_AFTER – ORD_BEFORE

* Statistically significant at $p \leq 0.05$

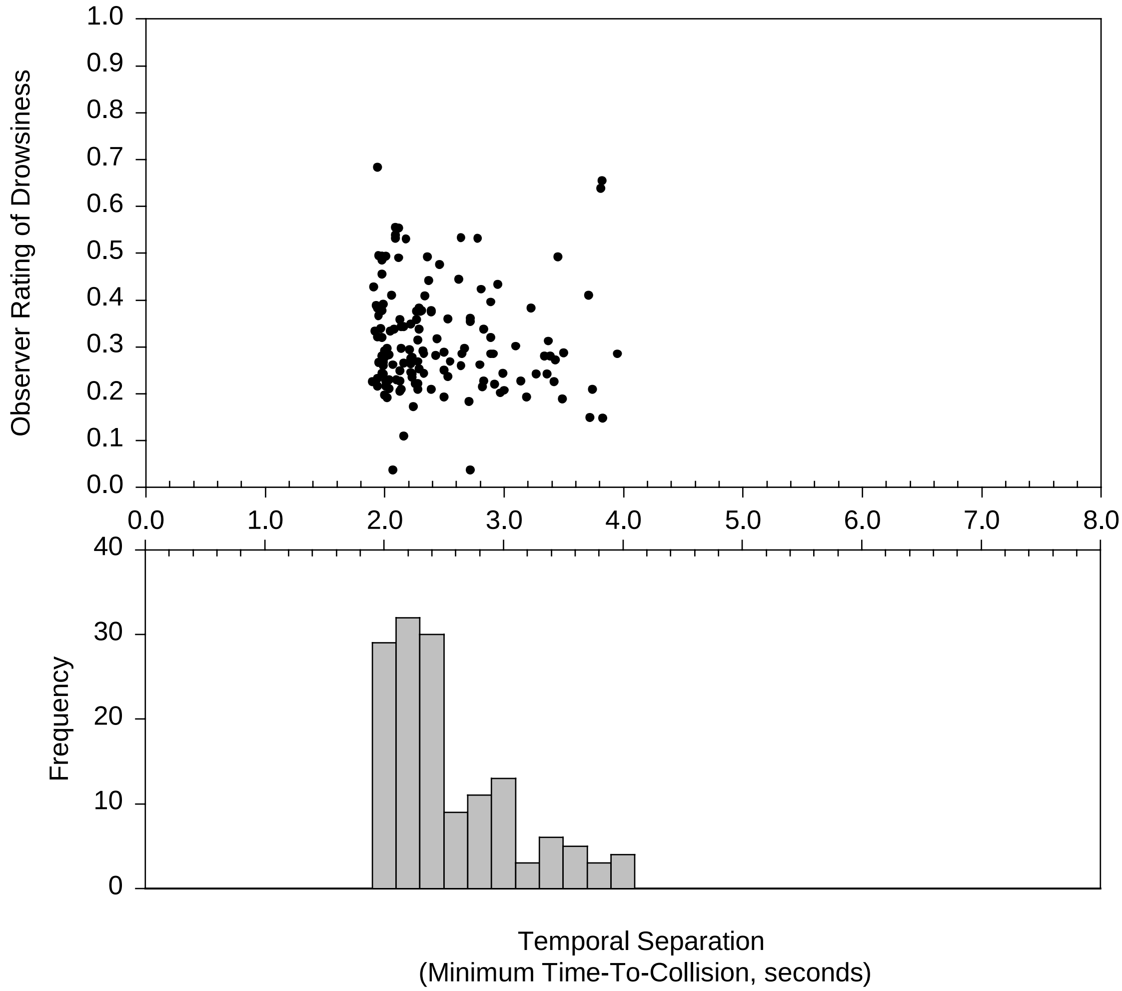


Table 27. Observer rating of drowsiness (ORD) plotted as a function of minimum time-to-collision (MINTTC, n = 145).

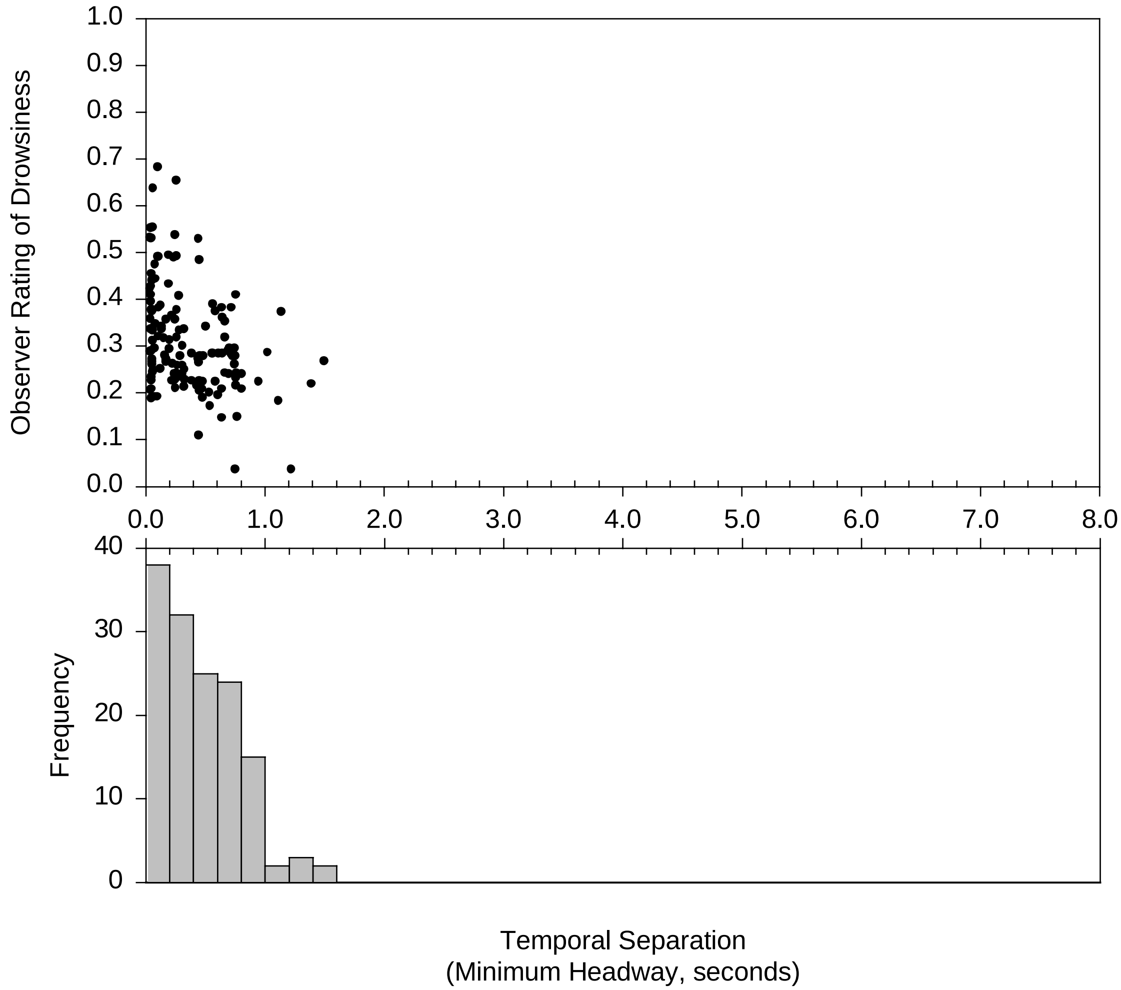


Table 28. Observer rating of drowsiness (ORD) plotted as a function of minimum headway (MINHEAD, n = 145).

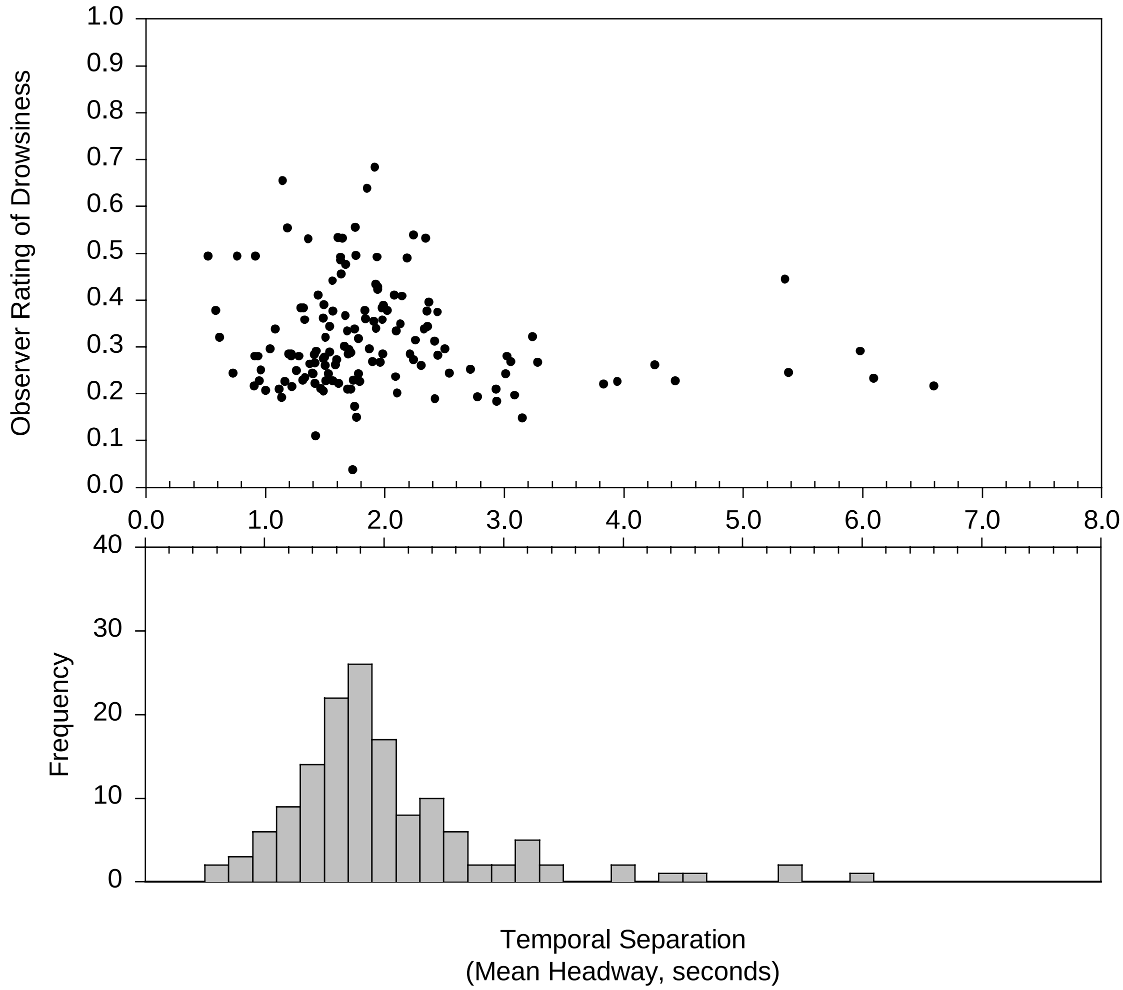


Table 29. Observer rating of drowsiness (ORD) plotted as a function of mean headway (MEANHEAD, n = 145).

experiment-wide error rate inevitably present with multiple dependent variables; Wilks Lambda was chosen *a priori* as the test-statistic upon which the decision criterion was based. If the null hypothesis were rejected by the multivariate test statistic, univariate *F*-tests were performed on each dependent measure. Dependent variables in the model included Observer Rating of Drowsiness (ORD) and driver mannerisms (MANNERISMS). The time-to-collision sample contained 142 observations from seven participants while the timed trigger sample contained 66 observations from seven participants (since the comparisons being made were within-subject, the participants for which there were missing data in the first analysis were also excluded).

Significant ($\alpha = 0.05$) effects of *FACE* {F (1,200) = 340.56, p < 0.0001}, *MOUTH* {F (1,200) = 37.82, p < 0.0001}, *NECK* {F (1,200) = 5.61, p = 0.0189}, *BODY* {F (1,200) = 4.96, p = 0.0271}, *OTHER1* {F (1,200) = 31.87, p < 0.0001}, and *OTHER2* {F (1,200) = 13.58, p = 0.0003} were observed for the classification variable GROUP. The MANOVA and associated ANOVA summary tables are provided in Table 19; group means are shown in Table 20. Post hoc tests were not performed since each variable was comprised of only two levels.

A significant increase (1.01) in the number of FACE mannerisms was found to occur for the time-to-collision trigger condition as compared to the timed-trigger condition. MOUTH mannerisms associated with the time-to-collision trigger condition were found to be significantly greater (0.52) than those associated with timed-trigger condition. Significantly fewer (0.15) NECK mannerisms were recorded for the timed-trigger condition than for the time-to-collision condition. A significant increase (0.10) in the number of BODY mannerisms was found to occur for the time-to-collision trigger condition as compared to the timed-trigger condition. Significantly fewer (0.39) OTHER1 mannerisms occurred during the timed-trigger than occurred during the time-to-collision condition. Finally, the OTHER2 mannerisms associated with the time-to-collision condition were found to be significantly greater (0.21) than for the timed trigger condition.

TABLE 19

Multivariate Analysis of Variance (MANOVA) on GROUP Using ORD and MANNERISMS

OVERALL TEST

METRIC	**VALUE**	***F***	**DF**	**DEN DF**	***p***
Wilks' Lambda	0.2747	45.5905	11	190	0.0001*
Pillai's Trace	0.7252	45.5905	11	190	0.0001*
Hotelling Lawley Trace	2.6394	45.5905	11	190	0.0001*
Roy's Greatest Root	2.6394	45.5905	11	190	0.0001*

ANALYSIS OF VARIANCE

VARIABLE	**DF**	**SS**	**MS**	***F***	***p***
ORD	1	0.0014	0.0014	0.13	0.7180
SUBJECTS	6	0.6387	0.1064		
HAIR	1	0.0150	0.0150	0.24	0.6229
SUBJECTS	6	0.6366	0.1061		
BROW	1	0.0155	0.0155	0.08	0.7713
SUBJECTS	6	5.6023	0.9337		
EYE1	1	2.5008	2.5008	3.51	0.0624
SUBJECTS	6	32.8912	5.4819		
EYE2	1	2.2418	2.2418	3.11	0.0794
SUBJECTS	6	26.5886	4.4314		
FACE	1	40.7927	40.7927	340.56	0.0001*
SUBJECTS	6	3.0367	0.5061		
MOUTH	1	12.3532	12.3532	37.82	0.0001*
SUBJECTS	6	4.9020	0.8170		
NECK	1	0.6493	0.6493	5.61	0.0189*
SUBJECTS	6	2.0109	0.3351		
BODY	1	0.5496	0.5496	4.96	0.0271*
SUBJECTS	6	0.8704	0.1451		
OTHER1	1	7.1595	7.1595	31.87	0.0001*
SUBJECTS	6	3.5879	0.5980		
OTHER2	1	1.8944	1.8944	13.58	0.0003*
SUBJECTS	6	3.6970	0.6162		

* Statistically significant at $p \leq 0.05$

TABLE 20

Dependent Measures Group Means from MANOVA

DEPENDENT MEASURE	GROUP			
	TIME-TO-COLLISION		TIMED TRIGGER	
	Mean	SD	Mean	SD
ORD	0.3168	0.1218	0.3398	0.1141
HAIR	0.0633	0.2666	0.0758	0.2445
BROW	0.1761	0.4223	0.2273	0.4658
EYE1	0.5000	1.4910	0.2254	0.4672
EYE2	0.0303	0.1727	0.2535	1.0943
*FACE**	0.0000	0.0000	1.0070	0.4375
*MOUTH**	0.0151	0.1231	0.5422	0.7001
*NECK**	0.0303	0.1727	0.1831	0.4059
*BODY**	0.0606	0.2404	0.1619	0.3697
*OTHER1**	0.4929	0.3288	0.8788	0.5424
*OTHER2**	0.0606	0.2404	0.2676	0.4442

* Statistically significant at $p \leq 0.05$

Subsequent to this analysis, it was necessary to further evaluate the time-to-collision subset in order to determine whether time-to-collision was a valid predictor of fatigue. Minimum time-to-collision (MINTTC), minimum headway (MINHEAD), and mean headway (MEANHEAD) were each regressed against observer rating of drowsiness (ORD) and driver mannerisms (MANNERISMS) in a multiple regression analysis. The stepwise method of admitting and removing variables from a multivariate regression analysis was employed. This method is similar to the forward; unlike the forward method, however, variables may be removed from the model if doing so improved model fit.

A stepwise multiple regression analysis was performed employing ORD and MANNERISMS as the independent variables and MINTTC as the dependent variable. Table 21 shows a summary of the multiple regression analysis. *NECK* (p = 0.0012), and *OTHER2* (p = 0.0241) were found to be significant (α = 0.05) predictors of MINTTC; however, overall model fit was low (R^2 = 0.1130).

A stepwise multiple regression analysis was performed employing ORD and MANNERISMS as the independent variables and MINHEAD as the dependent variable. Table 22 shows a summary of the multiple regression analysis. ORD (p < 0.0001), *BROW* (p = 0.0263) and *EYE1* (p = 0.0508) were found to be significant (α = 0.05) predictors of MINHEAD; however, overall model fit was low (R^2 = 0.2324).

A stepwise multiple regression analysis was performed employing ORD and MANNERISMS as the independent variables and MEANHEAD as the dependent variable. Table 23 shows a summary of the multiple regression analysis. ORD (p < 0.0001) and *BROW* (p = 0.0218) were found to be significant (α = 0.05) predictors of MEANHEAD; however, overall model fit was low (R^2 = 0.0942). Following the MANOVA and regression analyses, a discriminant analysis was conducted. Discriminant analysis (Rencher, 1995) is a statistical technique similar to regression analysis; however, unlike regression, the dependent variable is categorical rather than continuous. The purpose of this discriminant analysis was to develop a mathematical rule or classification scheme to predict whether the driver, based upon his behaviors, was fatigued as indicated by the recorded separation behaviors (MINTTC, MINHEAD, and MEANHEAD). Based upon the observer rating of drowsiness scale, two groups were defined in order to enable

TABLE 21

Multiple Regression Summary Table of MINTTC Using ORD and MANNERISMS

GOODNESS OF FIT *(Regression)*

METRIC	**VALUE**
R^2	0.1130
C(p)	4.4717

ANALYSIS OF VARIANCE

SOURCE	**DF**	**SS**	**MS**	***F***	***p***
Model	2	4.45246	2.2262	9.04	0.0002*
Error	142	34.9544	0.2462		
Total	144	39.4069			

PARAMETER ESTIMATES

VARIABLE	**PARAMETER ESTIMATE**	**STANDARD ERROR**	**SS**	***F***	***p***
Intercept	2.3323	0.0510	515.4162	2093.84	<0.0001*
NECK	0.3582	0.1016	3.0572	12.42	0.0006*
OTHER2	0.1800	0.0855	1.0898	4.43	0.0371*

* Statistically significant at $p \leq 0.05$

TABLE 22

Multiple Regression Summary Table of MINHEAD Using ORD and MANNERISMS

GOODNESS OF FIT *(Regression)*

METRIC	VALUE
R^2	0.2324
C(p)	5.0131

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	*F*	*p*
Model	3	3.1398	1.0466	14.23	<0.0001*
Error	141	10.3712	0.0736		
Total	144	13.5110			

PARAMETER ESTIMATES

VARIABLE	PARAMETER ESTIMATE	STANDARD ERROR	SS	*F*	*p*
Intercept	0.6810	0.0664	7.7344	105.15	<0.0001*
ORD	-0.8732	0.2046	1.3399	18.22	<0.0001*
BROW	-0.1218	0.0521	0.4020	5.47	0.0208*
EYE1	-0.1126	0.0532	0.3292	4.48	0.0361*

* Statistically significant at $p \leq 0.05$

TABLE 23

Multiple Regression Summary Table of MEANHEAD Using ORD and MANNERISMS

***GOODNESS OF FIT** (Regression)*

METRIC	VALUE
R^2	0.1130
C(p)	4.4717

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	*F*	*p*
Model	2	4.4525	2.2262	9.04	0.0002*
Error	142	34.9544	0.2462		
Total	144	39.4069			

PARAMETER ESTIMATES

VARIABLE	PARAMETER ESTIMATE	STANDARD ERROR	SS	*F*	*P*
Intercept	2.3323	0.0509	515.4162	2093.84	<0.0001*
NECK	0.3581	0.1016	3.0572	12.42	0.0006*
OTHER2	0.1800	0.0855	1.0898	4.43	0.0371*

* Statistically significant at $p \leq 0.05$

evaluation of discrimination between low and high levels of observer-rated fatigue (HI/LO). Observations with observer ratings of drowsiness equal to or less than 0.50 were included in the first (*i.e.*, low) group (n = 134); the second (*i.e.*, high) group (n = 10) was comprised of observations with an observer rating of drowsiness rating greater than 0.50. Table 24 shows the results from the discriminant analysis, including the linear discriminant function.

Despite failing to exhibit significance, the resulting discriminant analysis function correctly classified 72.1% of the incidents. Eighty-six of the 134 low fatigue and 8 of 10 of the high fatigue observations were correctly classified. Forty-eight of the low fatigue and 2 of the high fatigue incidents were incorrectly classified.

Finally, a multivariate cluster analysis was performed in order to assess whether observations clustered on the basis of time-to-collision or headway values would coincide with the onset of fatigue (ORD). Cluster analysis (Rencher, 1995) is an exploratory data analysis method by which the similarity or dissimilarity between individual observations and then later the similarity or dissimilarity between two clusters of observations is assessed. As applied herein, this analysis was concerned with assessing the similarity / dissimilarity of fatigue characteristics relative to temporal separation (time-to-collision and headway). Specifically, it was of interest to ascertain whether extremely short time-to-collision and headway values were differentiable from longer time-to-collision and headway values on the basis of fatigue.

Following the 'rule of thumb' presented by Johnson (1998) and Smith (1998), parameters are included in the cluster analysis model if their eigenvalue is greater than 1. However, since each of the three eigenvalues in the current analysis were each approximately one, and contributed approximately equally to explaining model variance, all three were retained. (Strict adherence to the 'rule of thumb' would have resulted in a model that could account for only 38% of the variability in the measured variables). Since all of the eigenvalues were retained, the model accounts for 100% of the variability in the measured variables; however, this does not offer any indication about the associated factors (*e.g.*, fatigue onset) that may accompany classification.

TABLE 24

Linear Discriminant Analysis of HI/LO Using MINTTC, MINHEAD, and MEANHEAD

OVERALL TEST

METRIC	**VALUE**	***F***	**DF**	**DEN DF**	***p***
Wilks' Lambda	0.9522	2.36	3	141	0.0742
Pillai's Trace	0.0477	2.36	3	141	0.0742
Hotelling Lawley Trace	0.0502	2.36	3	141	0.0742
Roy's Greatest Root	0.0502	2.36	3	141	0.0742

CLASSIFICATION MATRIX

		PREDICTED	
		LOW (p = 0.9305)	**HIGH** (p = 0.0694)
OBSERVED	**LOW**	86 (64.1%)	48 (35.8%)
	HIGH	2 (20.0%)	8 (80.0%)
	TOTAL	88 (61.4%)	56 (38.6%)

CLASSIFICATION FUNCTION

VARIABLE	**LOW** (<0.50 ORD)	**HIGH** (>=0.50 ORD)
CONSTANT	-11.9424	-12.2843
MINTTC	8.6448	9.1663
MINHEAD	0.8104	0.6625
MEANHEAD	2.7289	0.0684

* Statistically significant at $p \leq 0.05$

Observations were sorted and chronologically numbered (SEQUENCE) according to their ORD value (therefore, similar ORD values had SEQUENCE numbers of close proximity) and a preliminary, unbounded cluster analysis performed. Based upon this initial analysis, the cubic clustering criterion (CCC) was employed to determine the optimal number of clusters. Sarle (1983) introduced the CCC as a statistic that can used to assist the researcher in determining an appropriate number of clusters. CCC is plotted against the number of clusters obtained from an unbounded cluster analysis; peaks occurring when CCC is greater than three correspond to an appropriate number of clusters. Despite the use of CCC and other cluster identification methods, choosing the number of clusters remains a highly subjective process (Smith, 1998). Given the exploratory nature of the current analysis, however, the CCC was used to determine the number of clusters. Eleven was identified by as the most appropriate cluster quantity (CCC = 3.5) for this analysis. Subsequent to the determination of the most appropriate number of clusters, a bounded cluster analysis was performed, limiting the number of clusters to eleven.

Normally, a principle components analysis would be performed in order to (hopefully) provide insight into how the combination of the dependent variables were used to identify separation amongst the observations. Given that each of the dependent measures employed in this analysis were various measures of temporal separation, a principle components analysis holds little value.

Recalling, the original purpose for this analysis, to determine whether the measures of temporal headway indicated differing levels of fatigue, the clusters, their related SEQUENCE numbers, and summary statistics are presented in Table 25. This analysis does not appear to offer any evidence supporting time-to-collision as a valid indicator of driver fatigue levels for time-to-collision values less than four seconds (trigger level). If such a pattern had been evident, SEQUENCE numbers within a given cluster would have been tightly grouped; the hypothetical optimal mean difference and standard deviation between observations would be equal to 1.

TABLE 25

Resulting Clusters, Components (SEQUENCE Numbers), and Summary Statistics

CLUSTER ID	**N**	**SEQUENCE**		**COMPONENTS**
		AVERAGE DIFFERENCE $(X_2\text{-}X_1)$ / N	STANDARD DEVIATION	
1	34	4.03	3.40	3, 6, 9, 12, 14, **16, 17, 18**, 23, **25, 26, 27, 28**, 30, 31, 40, 44, 52, 55, **62, 63, 64**, 66, 70, 71, 78, 82, 97, 107, 113, 116, 119, 128, 136
2	59	2.12	2.08	20, 34, 35, **37, 38, 39**, 43, 47, **49, 50, 51**, 54, 56, 57, 59, 60, 65, 69, 77, 80, 81, **86, 87, 88**, **90, 91, 92, 93, 94**, 96, 98, 99, **101, 102, 103**, 105, 108, 109, **110, 111, 112**, 115, 118, 122, 124, 126, 127, 129, 130, **132, 133, 134, 135**, 137, **139, 140, 141**, **142,** 145
3	5	23.25	17.09	32, 46, 53, 79, 125
4	11	12.30	10.14	15, 21, 33, 41, 48, 84, 95, 117, 121, 123, 138
5	15	8.00	8.32	2, 5, 13, 42, 45, 68, **72, 73, 74**, 76, 83, 89, 100, 104, 114
6	10	15.11	14.00	8, 11, 19, 61, 75, 85, 120, 131, 143, 144
7	2	14.00	0.00	22, 36
8	4	33.00	15.52	7, 24, 58, 106
9	3	31.50	9.19	4, 29, 67
10	1	10.00	0.00	10
11	1	1.00	0.00	1

NOTE: Bold-Face Type Indicates a Series of Three or More Consecutive SEQUENCE Numbers

DISCUSSION

Detecting and quantifying driver fatigue has been, and will continue to be, a substantial challenge to the human-factors transportation researcher. On one hand, the measures exhibiting the greatest sensitivity (*e.g.*, EEG) are also the most intrusive and impractical to implement for large scale usage. By contrast, less intrusive measures are also less sensitive. The impetus of this research was to determine if two relatively unobtrusive measures, self-assessment and time-to-collision, were sensitive indicators of a fatigued state. Specifically, the stated objectives of this research project were to determine

1) whether self-assessment of fatigue is a valid indicator of driver fatigue, and

2) whether temporal separation, as measured by headway and time-to-collision, is a valid indicator of driver fatigue.

Overall, the results of this study agree with the aforementioned notion that relatively unobtrusive measures are not sensitive predictors of driver fatigue. Despite the lack of a breakthrough in fatigue monitoring, the results of the analyses did yield some insight relative to driver behavior and performance.

Predictive Ability of Regression Analyses

Without exception, the regression analyses for both the self-assessment of fatigue and temporal separation yielded models low in predictive ability, as evidenced by their extremely small R^2 values. Table 26 shows a summary of the analyses conducted, the variables found to be significant contributors to the model, and relative goodness of fit. The MINHEAD model demonstrated the largest R^2 value; however, it only explains approximately 23% of the total sum of squares, a quantity too small to be of practical use in predicting fatigue onset. Consequently, on the basis of these multivariate regression analyses, neither self-assessment of fatigue nor temporal separation have been shown to be reliable nor valid predictors of fatigue.

Self-assessment of fatigue. That self assessment of fatigue as measured by the Karolinska scale was not found to be a sensitive predictor of driver fatigue, despite having been previously proven valid and reliable (Akerstadt and Gilberg, 1990; Gilberg

TABLE 26

Summary of Multivariate Predictive Regression Analyses Conducted; ORD and MANNERISMS Comprised the Independent Variables for Each Analysis

DEPENDENT MEASURE	R^2	INCLUDED VARIABLES ($p \leq 0.05$)
Timed Trigger		
KAROLINSKA	0.0782	ORD ($p = 0.0019$)
RXNTIME	0.1121	OTHER2 ($p = 0.0010$)
Time-to-Collision		
MINTTC	0.1130	NECK ($p = 0.0006$) OTHER2 ($p = 0.0371$)
MINHEAD	0.2324	ORD ($p < 0.0001$) BROW ($p = 0.0208$) EYE1 ($p = 0.0361$)
MEANHEAD	0.1130	NECK ($p = 0.0006$) OTHER2 ($p = 0.0371$)

et al., 1994), is attributed to drivers operating for prolonged periods at a reduced cognitive state. Specifically, the task performed by long haul drivers is essentially a repetitive manual control tracking task performed over an extended period of time. Such a task is likely to promote inattention known as Driving Without Attention (DWA).

First coined “road hypnosis” by Danial O. Skinner in the June 4, 1921 edition of Literary Digest, driving without awareness refers to “a tendency to become drowsy and fall asleep when driving an automobile” (Williams and Shor, 1970, p. 223). Williams (1963) first coined the term “highway hypnosis” to describe the occasional attention lapses and development of drowsiness experienced by many drivers during prolonged, relatively uneventful driving experiences.

One suggestion proposed by Williams (1963) suggested that the monotony of the surroundings and the need to attend to a relatively small portion of the visual field while driving were two factors that make drivers susceptible to the hypnotic, trance-like phenomena. While somewhat intuitive, the definition lacks a desirable scientific rigor, as the concepts of monotony and hypnosis were not easily quantified in a manner conducive to measurement and thus further experimentation.

Wertheim extended the work performed by Williams (1963) and identified highway hypnosis as, “a lowered state of alertness leading to the development of drowsiness and failure to react adequately to changes in the road situation” (Wertheim, 1978, p. 111). In an attempt to move towards a more quantifiable expression of highway hypnosis, Wertheim (1978) replaced the notion of monotony with that of predictability. Monotony, at best, could be described as relating to scene complexity or information present in the surroundings. Predictability, by contrast, refers to the degree of to which the objects in the visual field move relative to the observer. He also proposed that a driver’s mental abilities are differently related to the complementary notions of attentive and intentive ocular motor control. The attentive ocular component refers to the feedback received from the retina while the intentive component refers to the intention of a driver to move their eyes.

Perceived motion, or changes in the visual field drive the attentive ocular motor control component. Driving in an urban environment where pedestrians and vehicles are constantly entering and exiting the roadway is an example of a scenario where the attentive ocular motor control component is likely to predominate. By contrast, driving on roadway with little moderate traffic is one example of a highly predictable visual scene. As the driving scene becomes more predictable, a more standardized scanning pattern, or automation of eye movements, is reflective of a decrease in attentive and an increase in intentive ocular motor control (Wertheim, 1991). This change is associated with a certain degree of mental relaxation, lowered alertness, and an impaired receptiveness to the use of warning signals or the detection of movement in the surrounding environment.

Wertheim (1978) argued that the ocular motor hypothesis for explaining 'highway hypnosis' does not depend on the general level of a driver's fatigue. A well-rested driver, for example, can succumb to the effects of highway hypnosis fairly quickly if environmental factors are conducive. However, he also noted that fatigue may make an individual more susceptible to the effects of highway hypnosis. There is some evidence to suggest that portions of the brain cannot be continuously activated over long periods of time (Wertheim, 1978), the attentive ocular motor control, he hypothesizes, is one such process. Consequently, in the absence of attentive control, intentive control ocular motor control is favored, thus facilitating highway hypnosis.

"Road hypnosis" or "highway hypnosis" has since been renamed "driving without awareness" or DWA to reduce any mystical connotations of a stage hypnotist using a swinging watch to induce a trance (Brown 1991, 1993). The current scientific view (Brown, 1991; Wertheim, 1991) coincides with Wertheim (1978) and asserts that DWA is descriptive of a state wherein drivers are not in a position to monitor their own behavior, are steering their vehicle subconsciously with their attention removed from roadway such that they are also unaware of any impending hazards.

This situation is exacerbated further when drivers were, as a result of their prolonged exposure, able to adapt their behaviors to adequately perform a relatively repetitive manual control tracking task at a reduced cognitive functioning level. An important factor which may contribute to this is that, since commercial truck drivers are typically paid by the number of miles they travel, there is a strong incentive to continuing driving despite a moderate or high level of fatigue.

Temporal separation. While self-assessment of fatigue was not found to be a valid predictor of driver fatigue was attributable to psychophysical phenomena, that time-to-collision was not found to be a valid predictor of driver fatigue was ascribed to a lack of metric sensitivity. That is, the measures of temporal separation are dispersed in such a manner that a trend cannot be ascertained and therefore cannot be characterized by a predictive fatigue function. Specifically, high and low time-to-collision values exist for high and low fatigue and alertness values.

Self-Assessment of Fatigue and Karolinska Arousal

Despite the lack of significance reported in the regression analyses, an arousal effect is associated with the Karolinska Scale. A short 'beep' solicited the drivers to report their level of fatigue according to the Karolinska scale. A paired *t*-test confirmed that a small but statistically significant difference in the observer ratings of drowsiness existed between the time period immediately preceding the onset of the Karolinska scale alert and the subsequent time period. The actual difference between the fatigue levels observed (0.014 on a 0 to 1 scale) is not likely to be of any practical importance. Additionally, because the data collected were trigger-based rather than continuous, the duration of the arousal period could not be ascertained.

Fatigue, Drowsiness, and Time-to-Collision Greater Than Four Seconds

As previously noted, none of the temporal separation measures were found to be significant predictors of fatigue for the incidents having a headway of four seconds or less (those triggered by the time-to-collision criterion). To determine whether fatigue may be present at time-to-collision values greater than four seconds, a multivariate analysis of variance (MANOVA) was performed to determine whether a significant difference in fatigue existed between the time-to-collision and timed-trigger incidents. The results of the MANOVA indicated that a difference in fatigue did exist between the two populations.

That many of the behaviors or driver mannerisms were found to be statistically significant, but that observer rating of drowsiness was not is indicative of drivers generally being more active (*e.g.*, eating, drinking, using tobacco products, radio, cb) during the timed trigger incidents. That observer rating of drowsiness was not found to be statistically significant may indicate that the difference in these behaviors is not due to a change in fatigue, per se, but rather a transition into DWA and overall reduction in cognitive functioning. Further evaluation of this phenomenon with increased time-to-collision levels and more sensitive (*i.e.*, physiological and psychological) fatigue metrics is recommended.

Minimum Separation

Despite the lack of a clearly defined trend by which fatigue could be predicted, the dispersion of the observations is such that additional consideration of the MINTTC and MINHEAD dependent measures is warranted. The dispersion patterns represented by each of these measures are very similar; therefore, in order to minimize redundancy only MINTTC will be discussed herein. Of particular interest from an alertness indication perspective is that relatively few time-to-collision incidents occur at very low observer ratings of drowsiness (ORD < 0.20), Figure 30. The second observation, of particular interest from a driver behavior perspective, is that regardless of ORD value, a minimum level of temporal separation (~1.9 seconds TTC and ~0.06 seconds Headway) was never violated, Figure 31.

That relatively few time-to-collision observations corresponding to low-levels of observer ratings of drowsiness existed is attributed to very alert drivers managing temporal separation better than moderately or extremely drowsy individuals. A subsequent review of the time-to-collision incidents indicated that the proximate cause of the majority of these incidents could not be attributed to driver inattention, but were more appropriately attributed to driver (participant) distraction or the actions (*e.g.,* cut-off) of another vehicle on the roadway. Given only the limited information from which these observations are drawn, further speculation is somewhat tenuous; therefore, these results should be considered anecdotal and fodder for future research.

Of considerable interest regarding driver behavior is that, regardless of ORD value, a minimum level for temporal separation was never violated, Figure 31. While it is possible that this phenomenon was the result of an anomaly caused by the data collection system itself, a review of the system found no evidence to support this conclusion. One possible explanation is that drivers have established a minimum separation or ‘comfort’ threshold. Repetitive training, both formal and informal, would reinforce this concept until it was strong enough that a driver experiencing fatigue or DWA would effectively integrate this threshold into their driving habits. Unfortunately, the current experiment lacks the robustness necessary to adequately resolve the issues

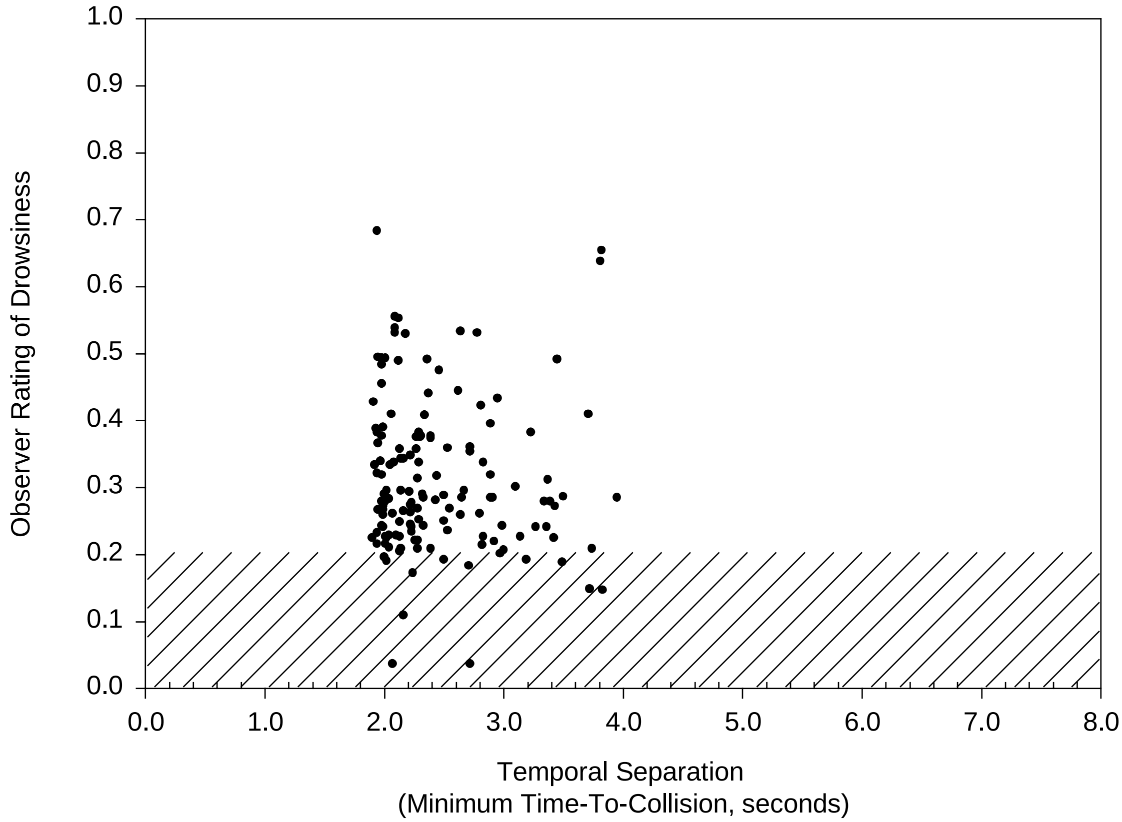


Figure 30. Observer rating of drowsiness (ORD) plotted as a function of minimum time-to-collision (MINTTC, n = 145). Note that relatively few observations exist in the diagonal crosshatched area that spans observer rating of drowsiness values from 0.0 to 0.2.

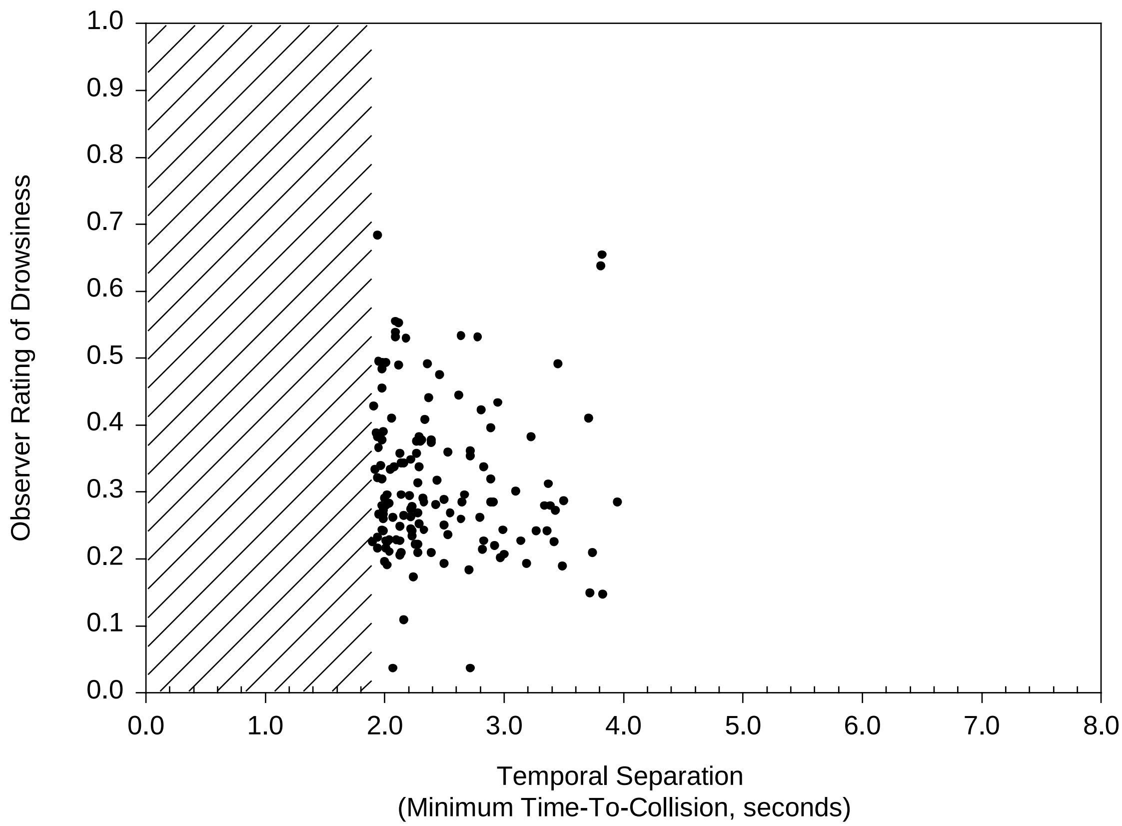


Figure 31. Observer rating of drowsiness (ORD) plotted as a function of minimum time-to-collision (MINTTC, n = 145). Note that no observations exist in the diagonal crosshatched area that spans temporal separation values from 0.0 to 1.9 seconds.

surrounding this unexpected finding; therefore, it is not possible to ascertain the cause of this phenomenon.

While the cause of the 'wall' phenomenon is unknown, that it exists has real implications for commercial vehicle operators. Of particular interest is whether the allotted temporal separation, a time-to-collision of 1.9 seconds, provides adequate time for the driver to respond and safely decelerate to avoid a collision. To determine whether adequate time is provided for, it is useful to consider a hypothetical interaction between a tractor-trailer and an automobile. For simplicity, the interaction is framed on a flat roadway sans any adverse road conditions (*e.g.*, rain, snow). The automobile is traveling at sixty miles per hour when a tractor-trailer approaches from behind; the tractor-trailer is traveling at approximately 67 miles per hour. The relative velocity between the vehicles is 10 ft/s; that is, the tractor trailer is traveling 10ft/s faster than the automobile. The tractor-trailer continues to approach the automobile until a time-to-collision value of 1.9 seconds is attained. The vehicles are approximately 20 feet apart feet apart (1.9s @ 10 ft/s) and an event occurs causing the driver of the automobile to bring the automobile quickly to a stop (without skidding) and the driver begins decelerating. The stopping distance for an average sedan (neither a high-performance sport car, nor a van or sport utility vehicle) is approximately 130 feet (Road and Track, 2000). With a uniform deceleration, the automobile decelerates at a rate of 29.8 ft/s^2 (approximately 0.80g) and will come to a complete stop in 2.95 seconds.

Once the automobile's brake lights have illuminated and presuming an alert driver, approximately one second passes before the driver of the tractor-trailer begins to decelerate (Johansson and Rumar, 1971; McKnight and Shinar, 1992). It is worth noting that a driver experiencing fatigue or distraction will exhibit longer brake-response reaction times, on the order of 1.5 seconds or greater (Lerner, *et al*, as cited in Badger, 2000). According to a report published by the Institute of Traffic Accident Investigators (Newby, 2000), a typical heavy (no skidding) deceleration rate for commercial vehicles ranges from 7.9 ft/s^2 to 12.8 ft/s^2 (converted from 2.4 and 3.9 m/s^2, respectively). With a uniform deceleration of 12.8 ft/s^2 (approximately 0.4g), the tractor-trailer will require 375 feet (7.6 seconds) to come to a complete stop. The total stopping time (assuming a brake reaction time of 1.0 second and deceleration) is approximately 8.6 seconds and would require approximately 473 feet. Note that, for this example employing a time-to-collision of 1.9 seconds only about 150 feet (20 feet of separation and 130 feet required to stop the automobile) are available for stopping the truck once automobile operator begins to decelerate. Figure 32 shows a graphical depiction of this example.

In the previous example, the tractor-trailer operator may not even have a chance to react to the automobile driver's deceleration before colliding with the rear of the automobile and resulting in a severe traffic accident. Clearly, the 1.9-second headway is inadequate for this type of vehicle interaction. In order to avoid a collision in the previous example, the operator of the tractor-trailer would have had to maintain a time-to-collision of not less than 5.5 seconds (approximately 540 feet at 67 miles/hour). Clearly, while the data reported herein indicate hat drivers have adopted a comfort zone time-to-collision of 1.9 seconds, likely based on experience, it is inadequate for safe driving at interstate velocities.

Anecdotal Report of Population Differences

In addition to the aforementioned discussion of results emanating from *a priori* analyses, there exist several unanticipated behavioral observations related to fatigue onset that appear to contradict established reports in the literature and therefore warrant mention. Wierwille and Ellsworth (1994), Skipper and Wierwille (1984), and Skipper *et al.* (1984) report that progression of extreme fatigue is accompanied by slow eye closure, unfocussed eye rolls, and prolonged eye closure. The chronology of the events reported by Wierwille and others is supported by research performed independently by Hiroshige and Niyata (1990), Bishop *et al*. (1985), and Endo *et al.* (1978).

Of particular interest in this research effort, therefore, is the notable lack of fatigue-onset behaviors demonstrated by several participants. While these individuals eventually demonstrated extreme fatigue levels, the onset period was sudden and preceded by time periods in which extremely low levels of fatigue were demonstrated.

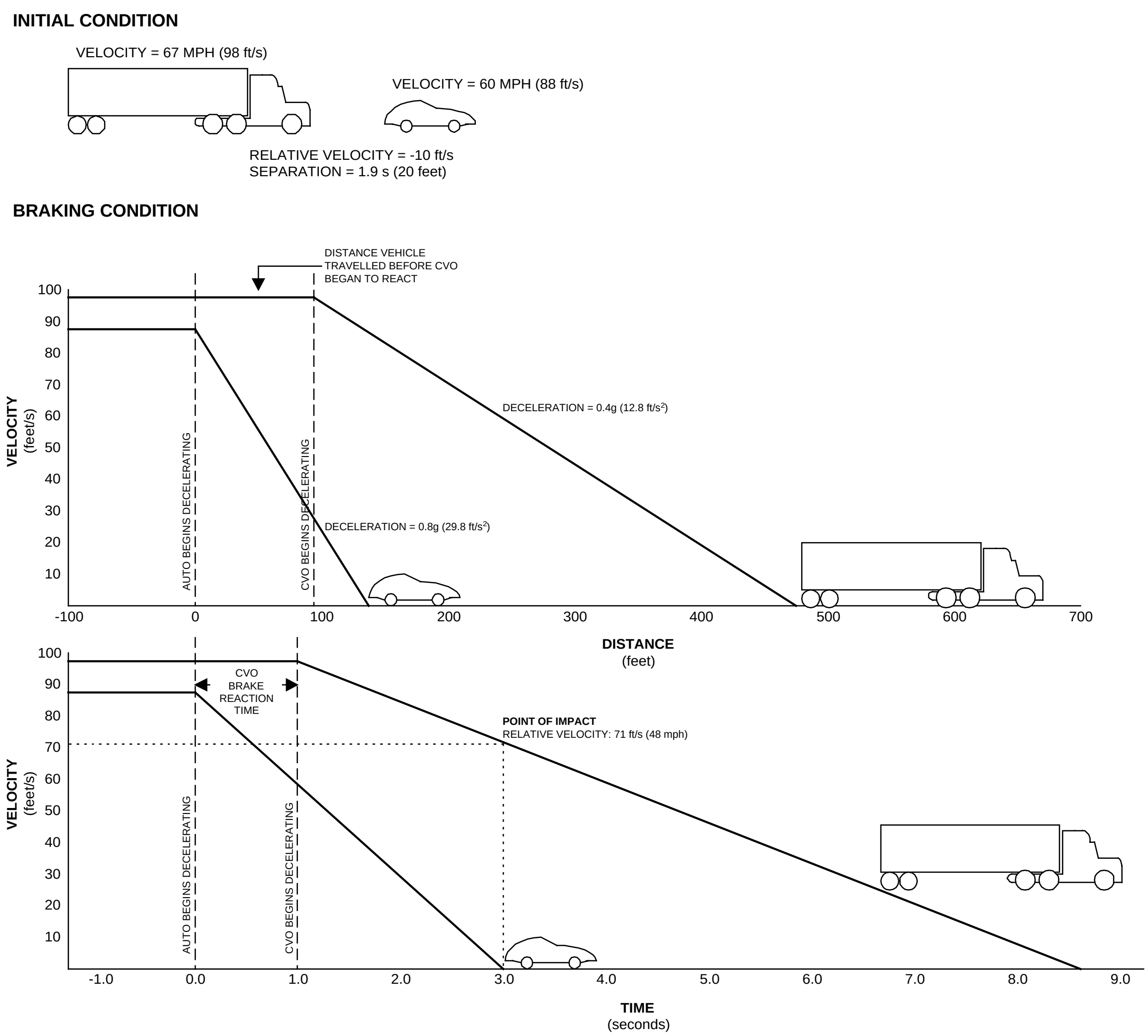


Figure 32. Graphical depiction of hypothetical braking scenario based on a 1.9s headway criterion.

The absence of the measures employed in this research to detect eye-related behaviors indicative of fatigue onset is of particular interest. Several drivers failed to exhibit the natural progression of these behaviors. Specifically, eye-related behaviors (*e.g.*, closure greater than two seconds) indicative of extreme levels of drowsiness were observed; however, those indicative of moderate fatigue were not. A typical violation of this progression involved a driver who appeared to be under the trance-like influence of DWA with extended glance durations (> 45 seconds) where very little, if any, eye movement was observed. Following such an episode, sans any intermediary behaviors (*e.g.*, slow closure), the individual would then demonstrate an eyelid closure greater than two seconds in duration. It is not possible, at this time with the currently available data, to determine if the observations made herein are representative of a true population difference (*e.g.*, the previously reported measures of fatigue onset are not as sensitive a measure for commercial drivers – perhaps due to training or sensitization – as they are for non-commercial drivers) or statistical anomaly.

Besides the aforementioned possibilities, another possible explanation exists for the inability of the measures employed in this research to detect eye-related behaviors indicative of fatigue onset. Specifically, the drivers may not have demonstrated the levels of fatigue experienced by those in previous simulator studies. Specifically, Wierwille and Ellsworth (1994), Skipper and Wierwille (1984), Skipper *et al.* (1984), and others, in order to maximize experimental efficiency, established an environment conducive to fatigue onset in order to maximize experimental efficiency.

The use of nicotine and caffeine were discouraged, individuals were encouraged to eat a large meal prior to the experimental session, and the experimental sessions were scheduled to begin late at night in the studies conducted by Wierwille and colleagues. Further, while the simulator employed a moving-base, the forward visual scene was low fidelity representation of a simple driving task (*e.g.*, no turns). Even a very simple real-world driving environment (*e.g.,* a dark unlit road) contains a variety of addition stimulants, both within the visual field and the vehicle itself, not present in the described simulated driving environment (*e.g.,* radios, food, drink, etc.). It is possible, therefore, that the onset of fatigue in within the simulated environment was accelerated such that the normal progression of fatigue was inadvertently affected. Evaluation of the video data from the current study indicates that it is likely that the drivers experience episodes of driving without awareness followed by a sudden onset of fatigue-related symptoms. Wierwille and Ellsworth (1994), Skipper and Wierwille (1984), or Skipper et al. (1984)

did not report behavior of this nature occurring in any of their research. Therefore, once conceivable explanation is that the individuals participating in these studies began to fall asleep prior the onset of DWA, thus accounting for some of the differences chronicled herein. Additionally, it is plausible that commercial motor vehicle operators operating within a real-world environment have a much lower threshold for fatigue than non-professional drivers operating within a low-risk simulated driving environment.

Presuming either of the aforementioned explanations are true, it would be necessary to modify the observer ratings of drowsiness to reflect the differences between real-world and simulator-based driving environments. Further, while there appear to be some physiological differences between DWA and fatigue onset, within a real-world environment, these issues may be inconsequential since the results (reduced awareness of the driving environment) are similar and eventuate degrading driving performance. Modifications to the observer ratings of drowsiness metric expanding its coverage to include DWA-like behaviors may include other ocular-motor behaviors as demonstrated by drivers participating within this research effort. Specific behaviors may include gaze duration, blink frequency, and saccade frequency. Additionally, large body and head movements were observed as indicators of fatigue; however, these movements were preceded by periods of very little movement. These periods of very little movement frequently coincided with the periods of DWA and increased gaze duration. Similarly, they appeared replace moderate and moderately severe fatigue behaviors as they occurred just prior to the onset of the most severe fatigue symptoms observed in this research effort (*e.g.*, eye closure > 2 seconds). Given that the sample size of this study is relatively small and that a substantial portion of the data are missing, it is not prudent, at this time, to offer an elaborate model replete with specific changes for the real-world environment to the observer rating of drowsiness developed by Wierwille and colleagues. Instead, key anecdotal evidence is presented in order to make others known of the differences encountered within this on-road experiment and as a springboard for future research.

Experimental Limitations

The results of this study fail to support the use of self-assessment of fatigue nor temporal separation as valid indicators of driver fatigue and drowsiness. Neither quantity demonstrated the necessary sensitivity and reliability required of a suitable fatigue alertness measure. That neither of the measures discussed herein produced significant results should not serve as an absolute deterrent to other researchers in the field; rather, the results and methodology presented herein is available to other for use in the formulation of their research plans.

As with any study employing human participants, it is of concern that the individuals participating in the study accurately represent the population to which the results will be generalized. While the population participating in this study was demographically diverse in terms of age and experience, all of the participants were males employed by the same company. Extreme caution should be taken, therefore, in generalizing these results to female commercial motor vehicle operators since no data exist to evaluate how gender may affect these findings. That the same company employing all of the participants would affect the generalizability of the results is another concern. The actual impact of this limitation is regarded to be minimal since the vast majority of the drivers had driven for other employers prior to being employed by their current employer.

Another potentially limiting factor involves the participants in the study. Every effort was made to recruit subjects from a cross-section of the trucking population; however, legal issues associated with permitting and insurance heavily influenced this process. Most notably, the participants in this study were all non-union employees of the same company. It is worth mentioning that drivers from other companies will be participating in this study; however, the subset analyzed thus far was comprised solely of individuals from the same company.

With regard to participants, the reasoning offered by several potential drivers for not participating is particularly notable. First, at least one potential participant declined to participate out of distrust for the agency funding the research. Secondly, at least two drivers declined to participate since they did not feel their driving was '*what we were looking for.*' With regard to this second point, one driver elaborated that regardless of the situation or time-sensitive nature of the load, he 'just took his time'. Another driver conveyed his reluctance to participate through a third party; therefore, it was not possible to query him further as to his specific reasons. It is not known to what extent these opinions pervaded the potential participant population; therefore, their precise effects, if any, on the study and the findings reported herein are not known.

Issues pertaining to the data collection system could also limit the applicability or validity of the findings reported herein. First, an element of uncertainty was introduced in the data in determining exactly when the vehicle started moving and stopped moving and the driver's activities when they were not driving, but were awake. While deemed to be more reliable than the driver logs, the Activity Information Survey (the mechanism used to record this information, Appendix A) still relies on drivers recording their activity and its respective start and stop times. An approach based on a more objective and reliable means for determining driver activity would have yielded less uncertainty.

Second, the complexity of the data collection system may serve as a limiting factor. While some indicators of equipment malfunction were obvious (*e.g.*, a 50-mph increase in velocity over 0.1 second) and therefore easily detectable, it is possible that other less obvious malfunction may exist.

Construct validity may have been compromised if the drivers changed their behavior based upon their perceptions regarding what they perceived the experiment was trying to prove or disprove (hypothesis guessing). Considerable efforts were taken to reduce this type of behavior, including reminding drivers that we were just looking at how they did their job. Additionally, none of the drivers were aware of the precise nature of the current research project. Despite these efforts and the efforts of the instrumentation team to minimize the visible indicators that they were participating in a research study, the drivers were constantly reminded of this since they were not driving their regularly assigned vehicle. In addition, they were required to modify their behaviors slightly (*e.g.*, vehicles were not equipped with Qualcomm units, Karolinska Scale, and responding to surveys) from their normal course of action.

Finally, when the data collection system failed, it generally did so early in the experimental session. Therefore, the data represented herein are skewed towards occurring earlier in a trip. Unfortunately, there are not enough data to determine if trip duration affects behavior, and if so, how; therefore, it is not known whether the findings reported herein can be extended to longer trip durations.

CONCLUSIONS

The most notable conclusion of the current study involves the use of self-assessment of fatigue and temporal separation as indicators of a driver fatigue. Within the scope of the project, neither metric was found to be a valid indicator of driver fatigue. Some evidence suggests that temporal separation may be able to distinguish between extremely low and moderate/high levels of fatigue; however, further research is needed to explore the nature of this relationship for time-to-collision values above the four second criterion level.

This study illuminated some possible findings that require further exploration. Of particular interest is the possibility that observer rating of drowsiness is not as effective a measure of driver fatigue in the real world as it is in a simulated environment. That this measure may not have been particularly effective in a real-world environment is attributed to the absence of extreme levels of fatigue. That is, it is reasoned that the extreme levels of fatigue demonstrated by participants in the driving simulator were not achieved by the individuals operating within a real-world driving environment.

Also of interest are the anecdotal reports that commercial motor vehicle operators do not appear to follow the standard progression of events associated with the onset of driver fatigue as reported by Wierwille and Ellsworth (1994), Skipper and Wierwille (1984), Skipper *et al.* (1984), and others. The mechanism driving these differences is unknown at this time; however, experience and experiential training are considered likely possibilities. It is possible that further exploration of this problem may give rise to the quantification of driver population differences, which in turn could be used to further drowsy driver detection.

In addition, a ‘wall’ effect was found to exist for minimum time-to-collision values. Specifically, none of the participants in this research effort exhibited following behaviors with less than a 1.9-second time-to-collision criterion. The exact nature of this relationship could not be determined based upon the available data; however, this headway was determined to be insufficient for interstate roadway travel.

SUGGESTIONS FOR FUTURE RESEARCH

Despite the tribulations that accompanied this research project, it is generally considered to have been successful. Most notably, this research incorporated for the first time a data collection technology based on the detection of critical incidents, rather than continuous recording, for collecting a high volume of driving data. In addition, the primary focus points of the revised methodology were recognized – evaluation of self-assessment of fatigue and temporal separation as driver drowsiness metrics. In addition, this research provided some insight into the analyses and data structure that will be necessary for the associated ongoing three-year contract with the Federal Highway Administration.

As previously mentioned, the focus of this research effort shifted from analyzing all of the data as proposed in Appendix C to developing and evaluating a set of analysis techniques more suitable to the data as they existed at the end of the study. Based upon this work, efforts should focus on completing the rest of the study by employing the analyses discussed herein. Additionally, future research is needed to determine the cause of the 'wall' effect associated with the minimum time-to-collision criterion. Increasing the understanding of the causal factors of this phenomenon may lead to developing the most appropriate interventions to lengthen temporal separation between vehicles. Further research is also needed to determine if temporal separation is in fact indicative of fatigue onset, but only for values greater than the four second time-to-collision trigger value.

Hours of Service

Since no effort was made to measure the effects of other work / rest cycles, a future study should concentrate on quantifying these effects. Specifically, the Federal Highway Administration has recently released for public review the proposed changes to the hours-of-service regulations. Research comparing the proposed changes and existing hours-of-service regulations in terms of driver performance and fatigue is currently underway; however, the results of which have not yet been released (T. Dingus, personal communications, September 6, 2000).

Re-evaluation of Fatigue Assessment Measures

In consideration of the issues presented surrounding the in-vehicle use of observer rating of drowsiness as the 'gold standard' by which other real-time, real-world fatigue measures are evaluated, further evaluation employing higher fidelity sleep/fatigue measurement is warranted. This document acknowledges that the any in-vehicle, real-time driver monitoring technology will have to make use of detection measures that are transparent to the driver. That being said, the issues raised pertaining to the suitability of observer rating of drowsiness in a real-world environment gives cause for more sensitive measures (e.g., EEG) to be used in determining which non-obtrusive measures are valid and appropriate.

Coupled with the aforementioned evaluation, determination of observer rating of drowsiness as an appropriate measure of fatigue within a real-world driving environment is a topic of considerable value. That this, based on the research conducted herein, this measure may not be particularly effective in a real-world environment due to the possible absence of extreme levels of fatigue capable of being produced within the simulator environment. That is, it is reasoned that the extreme levels of fatigue demonstrated by participants in the driving simulator are beyond those acceptable to individuals operating within an actual driving environment. Therefore, considerable benefit would result from an evaluation of the observer rating of drowsiness within an on-road environment that couples preexisting research conducted by Wierwille and colleages (Wierwille and Ellsworth, 1994; Skipper and Wierwille, 1984; and Skipper *et al.*,1984), existing knowledge of DWA, and the anecdotal evidence presented herein to extend the observer ratings of drowsiness to be capable of evaluating fatigue in an real-world, on-road environment.

Ocular Dynamics

Further research is necessary to develop an unobtrusive set of indicators capable of detecting driver inattention and fatigue. As presented herein, one shortcoming of the tradition methods for indicating driver fatigue is that they are easily masked by the condition known as driving without awareness (DWA). The characteristics associated with the ocular were observed herein as being a possible indicator of reduced awareness (DWA) and fatigue. On this basis, further research into the effectiveness of ocular dynamics is necessary. Specifically, this research should incorporate machine vision technology (for automatic detection) and a real-world driving environment in order to determine if eye blinks and eye closure coupled with PERCLOS can be used to determine driver inattention and fatigue. (*It is worth noting that the performance of the PERCLOS system deployed in this study was inadequate; however, the next generation promises considerable improvements in performance over the unit deployed herein.)*

Fatigue Modeling

The purpose of this study was to determine and characterize the effect of sleeper berth usage through monitoring the commercial long haul driving experience. An important next step is to determine if driver fatigue can be modeled and therefore, predicted. The development of a reliable model of driver fatigue represents a contribution as substantial to those performing fatigue-related transportation research as the grand unification theory is to physicists; despite their respective importance, neither has been realized. Nevertheless, the data emanating from this research effort, and others like it, may contribute to furthering the research in this area.

Two areas are of considerable importance when considering model development for relevant aspects of commercial motor vehicle fatigue. From a micro perspective, a fatigue model may take the perspective of a fatigue prediction system and employ a variety of behavioral and physiological inputs in determining whether the driver is indeed fatigued. A model of this nature would necessarily be required to distinguish between periods of reduced attention (i.e., DWA) and actual fatigue and respond accordingly. Despite considerable research in the area of fatigue and driver drowsiness, no reliable models of driver fatigue or alertness based upon driver behavior and physiological status are known to exist.

From a macro perspective, the situation appears to be somewhat more promising. Because of their highly variable schedule, commercial motor vehicle operators can be essentially thought of as workers who's shift changes on a daily basis. Fletcher and Dawson (1997) offer a predictive model of work-related fatigue based on hours of work. This model is based on the notion that fatigue increases as a function of prior wakefulness (though not monotonically) and is also affected by the duration and timing (circadian) of work periods. The model generates a relative work-related fatigue score based on the duration and timing of the previous seven-day work/non-work schedule with the most recent work and non-work periods weighted more heavily than those less recent. The R^2 values from correlations between the model's predicted scores and relative assessments of fatigue were; tiredness (0.838), vigilance (0.826), performance (0.797), and sleepiness (0.757).

The purpose of the model proposed by Fletcher and Dawson (1996) is not to predict sleep onset, but rather, on the basis of hours worked, to be able to determine if: 1) a particular work schedule is better or worse than another, or 2) to predict the occurrence of potentially dangerous levels of fatigue prior to specific schedules being worked. This model is ripe with opportunity for extension including adding attributes such as type of work and whether to determine if model accuracy could be improved.

Technological Opportunities

In as much as data collection capabilities are continuously evolving, it is worth mentioning several potential aspects that could add considerable value in the future. The first of these is the incorporation of broadband satellite communications capability with the data collection system. Such capability would enable real time troubleshooting and access to data as it was being generated. Further, addition of a Global Positioning System (GPS) to the data collection system would enable researchers to more accurately track the route taken in addition to the time of day and exact location of the critical incidents.

As data collection becomes more and more sophisticated, so too must our tools to analyze such data. Currently, each project requires the development of separate data analysis and reduction software to aid in reducing the data for analysis. A modular software system, incorporating reusable components would greatly reduce the development lifecycle of these products.

Similarly, data reduction software incorporating dynamic visual representation of key data streams would greatly enhance an analyst's ability to more clearly visualize the events as they occurred. For example, determining the exact sequence of events for a simple course of events such as determining whether a driver had their turn-signal activated for a lane change is a cumbersome process. The researcher must find the incident in question in the project analysis software, cue the tape, and then open the original data file and scan Column #12 for an intermittently occurring '1' (right) or '2' left. By contrast, when employing a graphical system such as LabVIEW, it is possible to build a graphical representation of the various columns of data and then review the driving data file by viewing the iconic representation. Figure 167 shows a hypothetical representation of a graphical interface. This interface could then be electronically synced with the main computer and the VCR; therefore, when the analyst advances the tape, the graphical user interface advances at the same rate. Such an advance in generating highly usable (and reusable) software products will likely result in greater accuracy (through improved data visualization) and a reduced need for constant retraining by increasing the skill transfer from one project to the next.

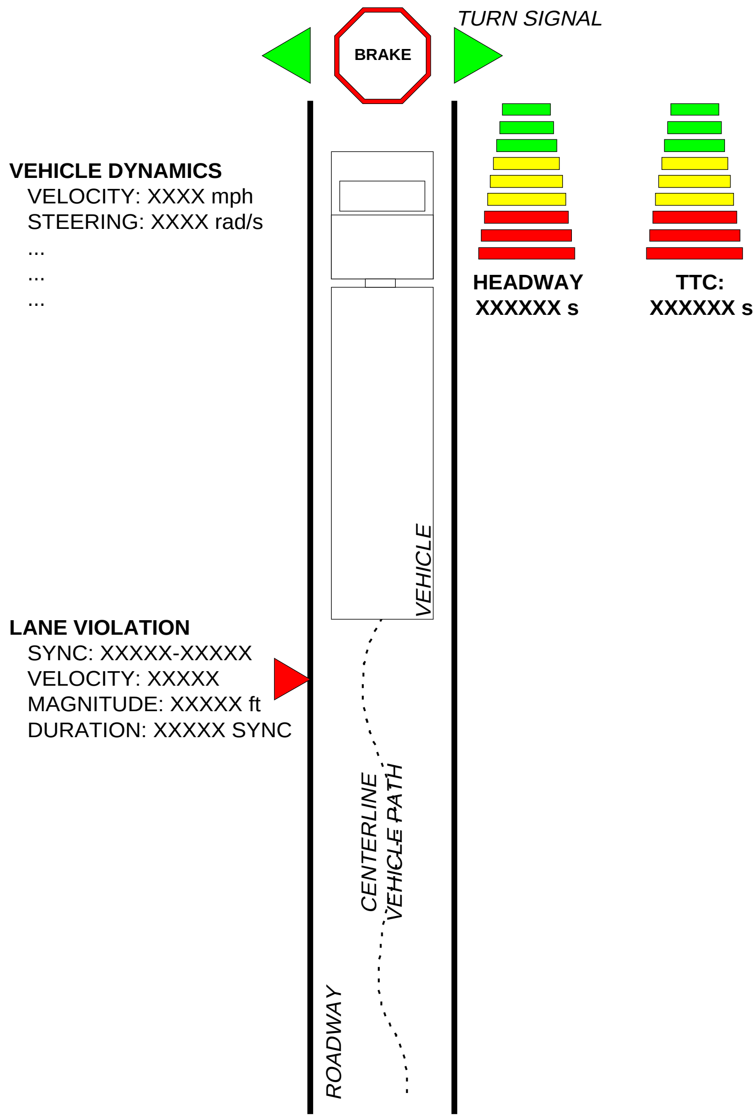


Figure 33. Hypothetical graphical representation of driving environment. Lower right area could be used to display information regarding weather, specific task, or active triggers. Lower left displays information about a recent lane violation, including information regarding severity. Upper left shows information regarding general vehicle dynamics. Upper right shows temporal separation between truck and another vehicle.

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APPENDIX A

Participant Surveys

GENERAL SURVEY

PERSONAL

OFFICE USE ONLY

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

GENERAL SURVEY

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?

A1. General Survey (pages 1 & 2).

GENERAL SURVEY

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)?

GENERAL SURVEY

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?

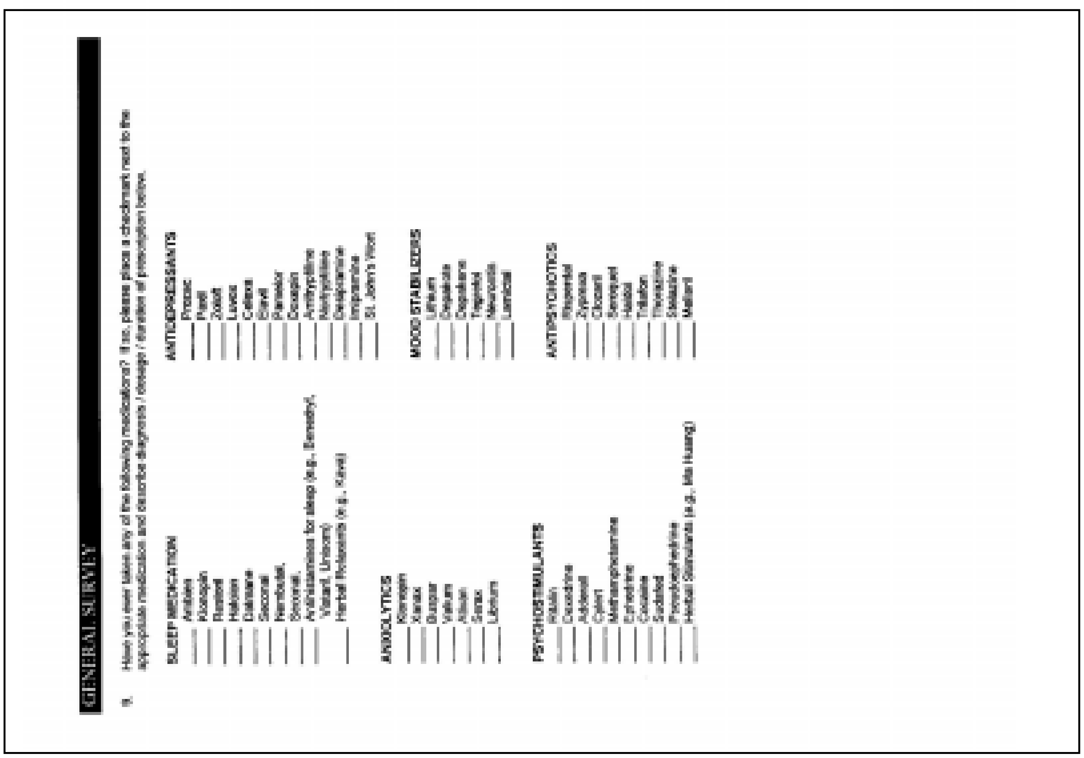
7. Please place a check mark next to any of the following that you have experienced, on a regular basis, related to your sleep? NOTE: We are asking if you have experienced these but also if anyone else (such as a spouse or partner) has reported them to you.

____ 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
____ Fibromyalgia
____ Any chronic pain that interferes with sleep
____ Heart Arrhythmia (slow or fast heart rate, atrial fibrillation?)

A1 (continued). General Survey (Pages 3 & 4).



GENERAL SURVEY

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
___ Sonata
___ Antihistamines for sleep (e.g., Benadryl, Vistaril, Unisom)
___ Herbal Relaxants (e.g., Kava)

ANTIDEPRESSANTS
___ Prozac
___ Paxil
___ Zoloft
___ Luvox
___ Celexa
___ Effexor
___ Serzone
___ Remeron
___ Doxepin
___ Amitriptyline
___ Nortriptyline
___ Desipramine
___ Imipramine
___ St. John's Wort

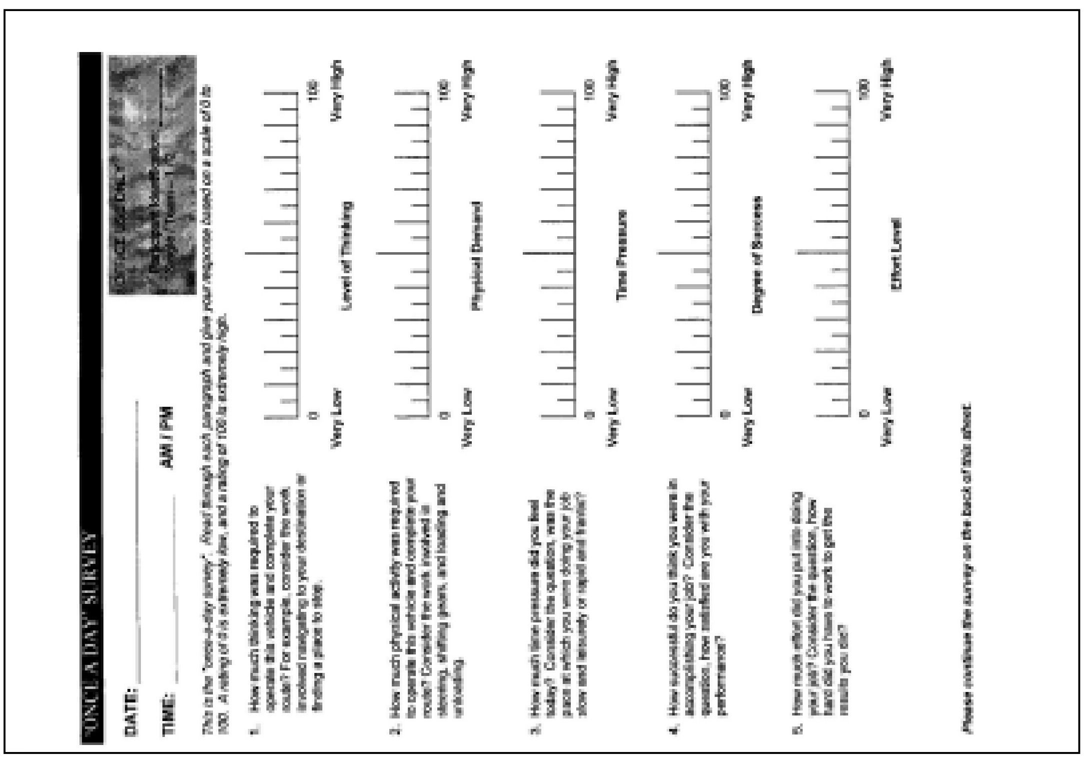
ANXIOLYTICS
___ Klonopin
___ Xanax
___ Buspar
___ Valium
___ Ativan
___ Serax
___ Librium

MOOD STABILIZERS
___ Lithium
___ Depakote
___ Depakene
___ Tegretol
___ Neurontin
___ Lamictal

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

ANTIPSYCHOTICS
___ Risperdal
___ Zyprexa
___ Clozaril
___ Seroquel
___ Haldol
___ Trilafon
___ Thorazine
___ Stelazine
___ Mellaril

A1 (continued). General Survey (Page 5).


'ONCE A DAY' SURVEY

DATE: ______________________

TIME: ______________ AM / PM

OFFICE USE ONLY
Participant Identification: ______
Single / Team – 1 / 2

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 Very Low — Level of Thinking — 100 Very High

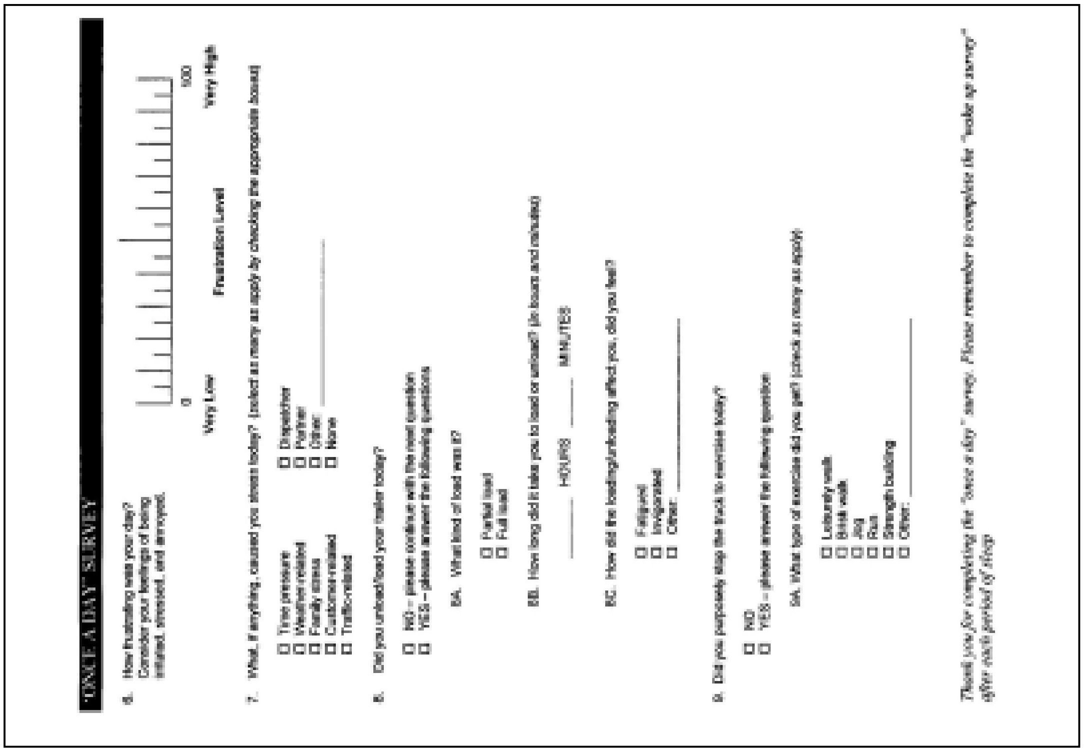
2. How much physical activity was required to operate this vehicle and complete your route? Consider the work involved in steering, shifting gears, and loading and unloading.
0 Very Low — Physical Demand — 100 Very High

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 Very Low — Time Pressure — 100 Very High

4. How successful do you think you were in accomplishing your job? Consider the question, how satisfied are you with your performance?
0 Very Low — Degree of Success — 100 Very High

5. How much effort did you put into doing your job? Consider the question, how hard did you have to work to get the results you did?
0 Very Low — Effort Level — 100 Very High

Please continue the survey on the back of this sheet.


'ONCE A DAY' SURVEY

6. How frustrating was your day? Consider your feelings of being irritated, stressed, and annoyed.
0 Very Low — Frustration Level — 100 Very High

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.

A2. Once a Day Survey.

'WAKE-UP' SURVEY

OFFICE USE ONLY
Participant Identification: ________
Single / Team: 1 / 2

DATE: ______________________

TIME: ______________ AM / PM

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
2. What time did you fall asleep? ______________ AM / PM
3. What time did you finally wake? ______________ AM / PM
4. What time did you finally get up? ______________ AM / PM
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.

'WAKE-UP' SURVEY

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)*

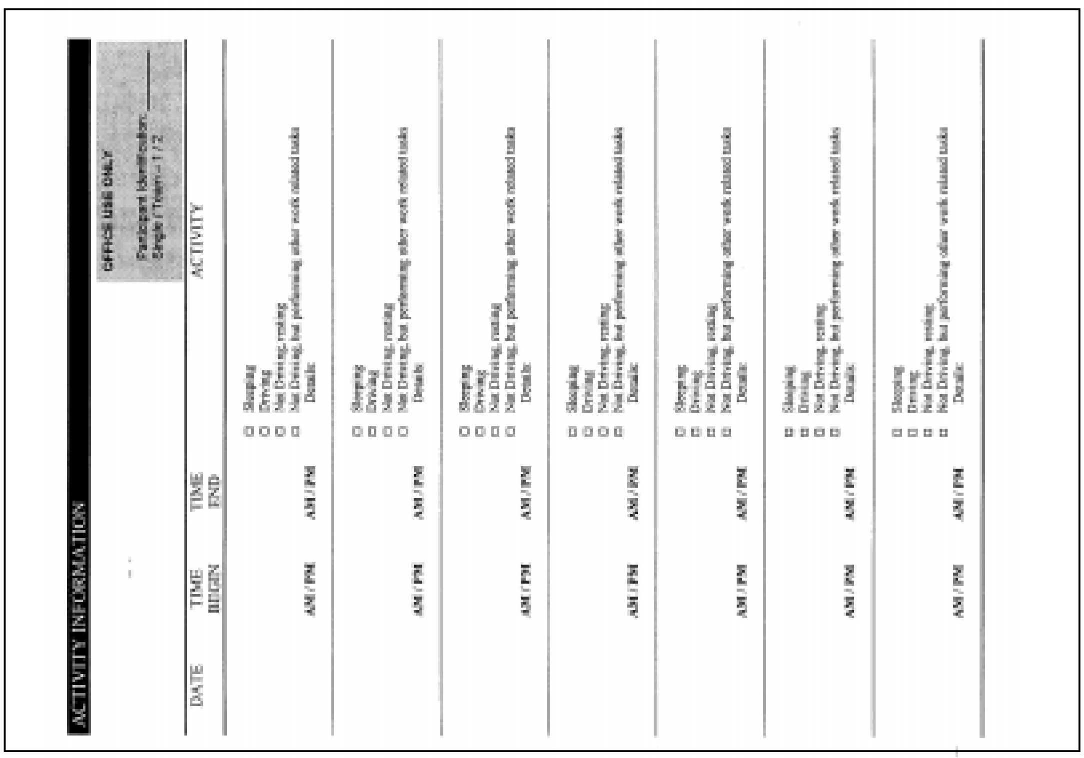
    ☐ 1. None or very little
    ☐ 2. Some
    ☐ 3. A lot
    ☐ 4. Extreme difficulty

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.

A3. Wake Up Survey.



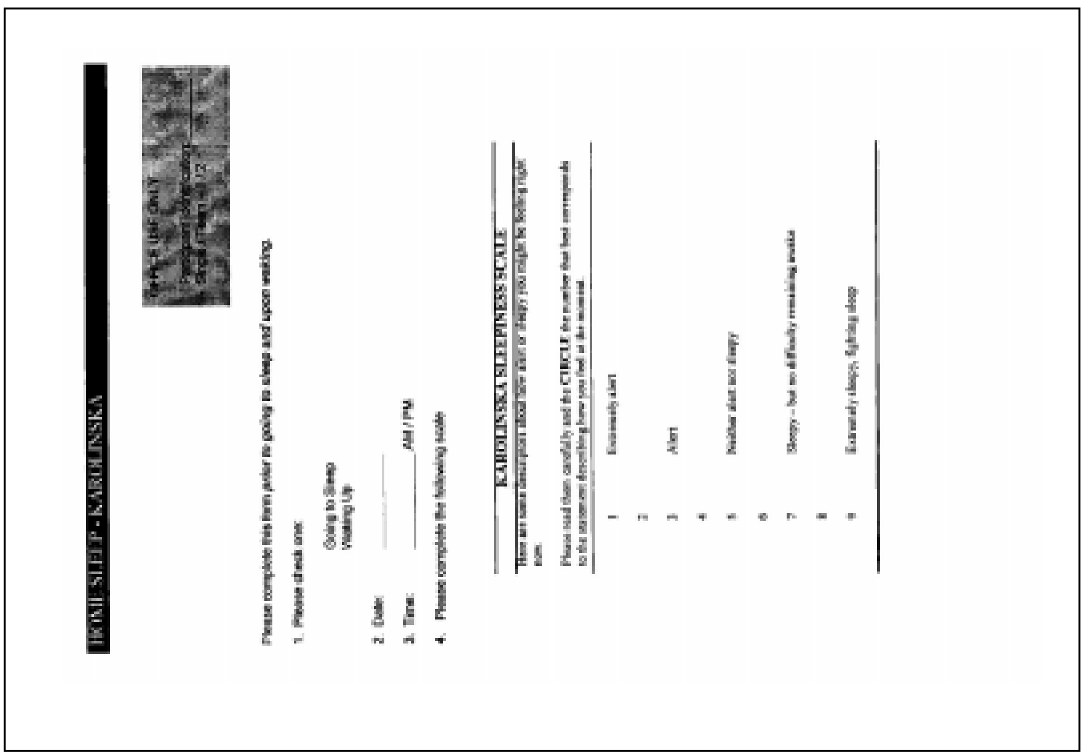
ACTIVITY INFORMATION

OFFICE USE ONLY

Participant Identification: ______
Single / Team – 1 / 2

DATE	TIME BEGIN	TIME END	ACTIVITY
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:
	AM / PM	AM / PM	☐ Sleeping ☐ Driving ☐ Not Driving, resting ☐ Not Driving, but performing other work related tasks Details:

A4. Activity Log



HOME SLEEP - KAROLINSKA

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

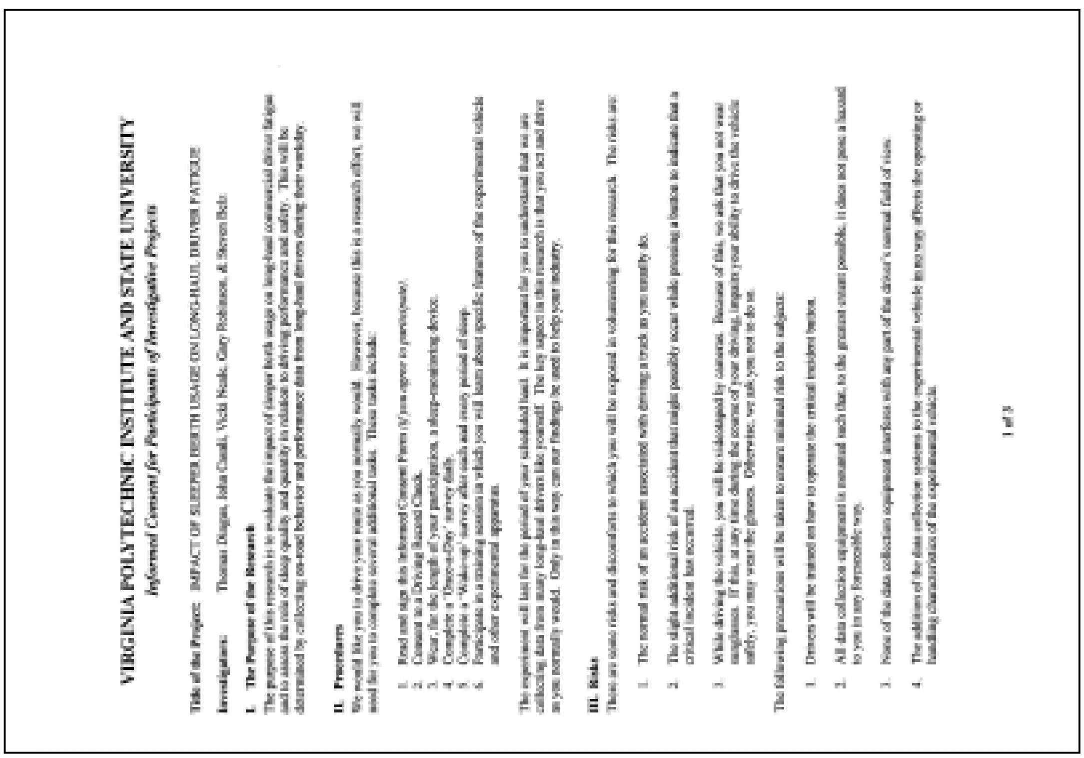
A5. Karolinska Home Sleep Surve

APPENDIX B

Participant Protection

B1: Informed Consent for Participants of Investigative Projects

B2: NIMH Certificate of Confidentiality



B1. Informed Consent for Participants of Investigative Projects (Pages 1 & 2)

INFORMED CONSENT — IMPACT OF SLEEPER BERTH USAGE ON DRIVER FATIGUE

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) 231-5281

3 of 3

B1 (Continued). Informed Consent for Participants of Investigative Projects (Page 3)

CONFIDENTIALITY CERTIFICATE

MH-99-12

Issued to

Virginia Polytechnic Institute and State University

conducting research known as

"Impact Of Sleeper Berth Usage on Driver Fatigue"

In accordance with the provisions of section 301(d) of the Public Health Service Act 42 U.S.C. 241(d), this Certificate is issued in response to the request of the Principal Investigators, Thomas A. Dingus, Ph.D., CHFP, and John G. Casali, Ph.D., CPE, to protect the privacy of research subjects by withholding their identities from all persons not connected with this research. Drs. Dingus and Casali are primarily responsible for the conduct of this research which is funded by the Federal Highway Administration.

Under the authority vested in the Secretary of Health and Human Services by section 301(d), all persons who:

1. are enrolled in, employed by, or associated with the Virginia Polytechnic Institute and State University and its contractors or cooperating agencies, and

2. have in the course of their employment or association access to information which would identify individuals who are the subjects of the research pertaining to the project known as "Impact of Sleeper Berth Usage on Long-Haul Driver Fatigue",

are hereby authorized to protect the privacy of the individuals who are the subjects of that research by withholding their names and other identifying characteristics from all persons not connected with the conduct of that research.

This research will examine the effects of variations in sleep quality on driving performance and safety. It will also provide a baseline assessment of sleeper berth sleep quality in existing equipment when drivers follow current regulations, and in modified sleeper environments.

Approximately 50 subjects will participate in this study. Background information will be collected, subjects will operate vehicles equipped with measurement devices and cameras and sleep monitors will be used. Other data will be collected.

Page 2 – Confidentiality Certificate

A Certificate of Confidentiality is needed because sensitive information pertaining to mental health, substance use, sleep patterns and potential driving errors will be generated. The certificate will help researchers avoid involuntary disclosures which could expose subjects, and their families, to adverse economic, legal, psychological and social consequences. The researchers are particularly desirous of avoiding involuntary disclosures that might adversely affect the subjects employment status, or subject them to liability for driving errors.

All subjects will be assigned a coded number and identifying information and records will be kept in locked files at the Institution.

This research will begin on March 1, 1999, and will end on July 31, 2001.

As provided in section 301 (d) of the Public Health Service Act 42 U.S.C. 241(d):

> "Persons so authorized to protect the privacy of such individuals may not be compelled in any Federal, State, or local civil, criminal, administrative, legislative, or other proceedings to identify such individuals."

This Certificate does not govern the voluntary disclosure of identifying characteristics of research subjects but only protects subjects from compelled disclosure of identifying characteristics. Researchers are therefore not prevented from the voluntary disclosure of such matters as child abuse or a subject's threatened violence to self or others; however, the consent form should indicate clearly a researcher's intention to make any such voluntary disclosure.

This Certificate does not represent an endorsement of the research project by the Department of Health and Human Services. This Certificate is now in effect and will expire on July 31, 2001. The protection afforded by this Confidentiality Certificate is permanent with respect to subjects who participate in the research during the time the Certificate is in effect.

March 1, 1999

William T. Fitzsimmons
Executive Officer
National Institute of Mental Health

B2. Certificate of Confidentiality.

APPENDIX C

Training Manual

Center for Transportation Research
Virginia Tech

Sleeper Berth Fatigue Study

Participant's Manual

NOTICE:

Please do not turn engine off unless refueling

IN CASE OF EMERGENCY, CONTACT:

Steven Belz, Research Assistant	(540) 239-1966 (Cellular Phone) (540) 951-8061 (Home Phone, Call wireless phone first. Leave message if no answer)
Center for Transportation Research	(540) 231-7740 (Phone) (540) 231-5214 (Fax)

See Page 17 for instructions if using VT-CTR supplied cellular/wireless telephone.

Sleeper Berth Fatigue Study

Participant's Manual

Table of Contents

Chapter 1

Sleeper Berth Fatigue Study

Participant's Manual

Participant Protection

We have done several things to ensure that everyone who participates in this research project will be safe and protected.

Institutional Review Board and Informed Consent

The Virginia Tech Institutional Review Board (IRB) has approved this study. This review and approval by the University's IRB ensures the ethical conduct of the research.

Informed consent provides a way to guarantee your rights as a participant. Further, it outlines the expectations on behalf of the researchers. Participants must be fully informed about the research project, the risks, benefits, and the expectations of the researchers and agree to participate in writing. Appendix A contains a copy of the Informed Consent Form. Additionally, you will receive a copy of the informed consent you signed indicating your willingness to participate in this research project.

Federal Certificate of Confidentiality

We have obtained a Certificate of Confidentiality from the Federal government. This Certificate of Confidentiality is intended to protect your privacy. Appendix B contains a copy of the Federal Certificate of Confidentiality. You should take notice of this certificate and read it carefully.

Chapter

2

Sleeper Berth Fatigue Study

Participant's Manual

Tractor Information

This section provides some general information about each of the tractors used in this research project. There is also information about features specific to each tractor.

Peterbilt – Model 379

Length	28 Feet, 4 Inches
Height – 5th Wheel	47 Inches
– Stack	12 Feet, 6 Inches
Weight	17,965 lbs
Engine	Cummins #N14 500E 500 HP, 1750 Ft-lbs Torque
Transmission	Eaton-Fuller Drive Train 9 Speed (12 Speed with Deep Reduction)
Fuel Capacity	220 Gallons (Diesel, 110 Gallons each side)

Air Windows — This vehicle is equipped with air windows which close quickly; make sure nothing is in the way before closing.

Axle Oil Level — Direct read window on front axle.

Engine Brake — 3 Setting Engine Brake

Fire Extinguisher — Located inside vehicle, behind driver-side sleeper compartment door.

Fuel Tanks — 2 Tanks, located on either side of tractor, need to be filled separately. Total capacity: 220 Gallons (110 gallons / tank)

Hood Release — Located outside vehicle, either side of hood. Hood pulls forward.

Towing — Before towing, remove the Eaton-Vorad RADAR unit on the front bumper and store it in the truck cab. There is a wrench in the glove compartment for performing this task.

Volvo – VN Series L4 Integrated Sleeper

Length	28 Feet, 6 Inches
Height – 5th Wheel	47 Inches
– Stack	12 Feet, 7 Inches
Weight	17,840 lbs
Engine	Volvo Engine VED12D 425 HP, 1450 Ft-lbs Torque
Transmission	Eaton-Fuller Drive Train 10 Speed (15 Speed with Deep Reduction)
Fuel Capacity	300 Gallons (Diesel, 150 Gallons each side)

Axle Oil Level — Located behind cap on front axle.

Battery / Fuel Doors — Located below driver / passenger doors.

Bump Idle — This vehicle will automatically turn off if the vehicle is left to idle longer than 20 minutes. To enable longer idling times, activate the idle bump – located on cruise control switch. Turn cruise control on (switch) and tap button on end of control.

Engine Brake — 2 Setting Engine Brake

Fire Extinguisher — Located inside vehicle, behind driver-side sleeper compartment door.

Fuel Tanks — 2 Tanks, located on either side of tractor, need to be filled separately. Capacity: 300 Gallons (150 gallons / tank)

Hood Release — Located inside vehicle, right of steering wheel on lower dash.

Chapter 3

Sleeper Berth Fatigue Study

Participant's Manual

Travel and Permitting / Interstate Travel

General

We have attempted to obtain all of the permits required to legally operate within the lower 48 states. The only exception to this is the State of Oregon; this permit will have to be acquired upon entry into the state.

Please complete the vehicle mileage record for the entirety of your trip.

Idaho

Paperwork for the State of Idaho is located in the blue information folder.

Kentucky

KYU Number Decals are located on the exterior of the truck cab.

New Mexico

The cab card is located in the blue information folder.

New York

Decals are located on the exterior of the truck cab; the cab card is located in the blue information folder.

Oregon

A temporary permit will have to be acquired upon entry into Oregon. Please inform us if you are planning to enter Oregon and we will provide you with the cash necessary to purchase the permit. When you make a permit purchase, please keep the receipt along with the permit so that we may verify the cash expenditure on our records. Neither Virginia Tech nor the Center for Transportation Research will be held responsible if you choose to enter the State of Oregon without first acquiring the proper permit(s).

As of November 1, 1999, the Oregon Department of Transportation's Motor Carrier Transportation Branch's (MCTB) Ports of Entry (POE) revised hours for registration

services. MCTB implemented new registration hours at all Port of Entry locations around the state. Office hours will be from 8 am to 5 pm, Monday through Friday. The only exception is the Farewell Bend Port of Entry, which will operate 24 hours / day, 7 days a week.

The following table lists the Ports of Entry for Oregon, their hours of operation, and locations.

Ashland Port of Entry Interstate 5, MP 18 Ashland, Oregon 97520 Telephone 541-776-6117 Fax 541-488-5846 8am-5pm, Monday-Friday	Cascade Locks Port of Entry 500 SE Frontage Road I-84, MP 44.05 Cascade Locks, Oregon 97014 Telephone 541-374-8079 Fax 541-374-2340 8am-5pm, Monday-Friday	Farewell Bend Port of Entry Highway 30, I-84 Junction Huntington, Oregon 97907 Telephone 541-869-2260 Fax 541-869-2027 24 hours a day, 7 days a week
Klamath Falls Port of Entry 4947 Highway 97N Klamath Falls, Oregon 97601 Telephone 541-883-5696 Fax 541-883-5584 8am-5pm, Monday-Friday	Portland Interstate Bridge 12348 N Center Ave. (Jantzen Beach) Portland, Oregon 97217 Telephone 503-283-5700 Fax 503-283-5850 8am-5pm, Monday-Friday	Salem Motor Carrier Services 550 Capitol St. NE Salem, Oregon 97310-1380 Telephone 503-378-5849 Fax 503-378-6880 8am-5pm, Monday-Friday
Umatilla Port of Entry PO Box 290 1601 SW Highway 730E Umatilla, Oregon 97882-0770 Telephone 541-922-3761 Fax 541-922-2876 8am-5pm, Monday-Friday	Woodburn Port of Entry I-5S, MP 274 Woodburn, Oregon 97071-0249 Telephone 503-982-0800 Fax 503-982-1201 8am-5pm, Monday-Friday	

NOTE: These times are subject to change by the State of Oregon.

Tennessee

Now that IFTA is in place, the State of Tennessee no longer requires an "HF-Number".

Chapter 4

Sleeper Berth Fatigue Study

Participant's Manual

General Study Procedures

While Driving

The purpose of this study is to learn how drivers operate their vehicles in the "real world". For this reason, we request that you drive as you normally would. This includes following your normal schedule and not adjusting your driving behavior in any way for this study.

When the dash-mounted alertness scale lights up (you will also hear a "chirp"), indicate your response by pushing the "Driver 1" or "Driver 2" button, then the button to the left of the appropriate description.

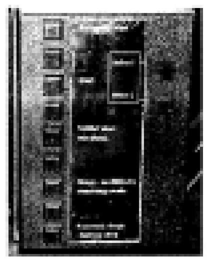


FIGURE 4.1 The Alertness Scale.

NOTE: If you accidentally push the wrong button (e.g., you are "Driver 1" and you inadvertently select "Driver 2"), you have 30 seconds to make the correct selection. If you are unable to make the correct selection within that time period, please make a note including the day and time of the misselection.

Once A Day

Complete the "Once a Day" survey. Since the survey contains questions about events that happened throughout the day, the best time to complete this survey is likely to be late in the day before you go to sleep. We recognize that schedules in this field are erratic and that filling out this form at exactly the same time each day is not feasible, but please try to fill it out at approximately the same time each day.

8

Before Going to Sleep (even if just a nap)

Put on the Nightcap Sleep Monitor (as described in Chapter 6).

Push the button on the Nightcap Activation Box so that the red light is activated (as described in Chapter 6).

Indicate your level of alertness on the alertness scale mounted in the sleeper berth by pushing the "Driver 1" or "Driver 2" button, then the button to the left of the appropriate description.

Upon Waking

Remove the Nightcap Sleep Monitor

Indicate your level of alertness on the alertness scale mounted in the sleeper berth by pushing the "Driver 1" or "Driver 2" button, then the button to the left of the appropriate description.

Complete the "Wake-Up" survey every time you awaken from sleeping longer than 10 minutes (including naps).

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Chapter

5

Sleeper Berth Fatigue Study

Participant's Manual

Data Collection Systems: General

Nightcap Activation Box

You will need to activate this box everytime you go to sleep - even if you are just going to take a nap.

If you should push the button on the Nightcap Activation Box (Figure 5.1) and if there is not a response from the unit (e.g., the button does not light up), then the data collection system is not working. Please follow the instructions in Chapter 8 to notify the Center for Transportation Research.

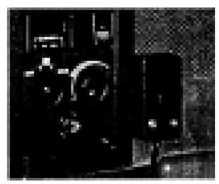


FIGURE 5.1 Above. The Nightcap Activation Box (located to the right of the air conditioning controls).

Incident Detection Box

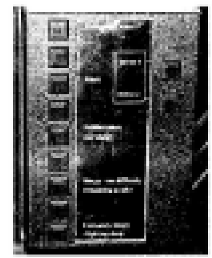
The button located on the Incident Detection Box is to be depressed when you want to be certain an significant event was recorded by the data collection systems. For example, a passenger car cuts you off. When this button is pressed a microphone is activate which allows you to briefly describe what just happened and why you believe it is important (affects your driving, safety, etc.).

If you should push the button on the Incident Detection Box (Figure 5.2) and if the button does not light up (e.g., a button is backlit), then the data collection system is not working. Please follow the instructions in Chapter 8 to notify the Center for Transportation Research.

FIGURE 5.2 Above. The Incident Detection Box (located above the radio controls).

Alertness Scale

Two alertness scales (Figure 5.3) are located within the truck. One is mounted on the dash (Figure 5.4) while the other is located in the sleeper berth (Figure 5.5). These devices are intended to allow you to tell us your level of alertness. The unit mounted on the dash will activate (the buttons will illuminate and an auditory chirp presented) at random times while you are driving. When the dash-mounted alertness scale lights up (you will also hear a 'chirp'), indicate your response by pushing the 'Driver 1' or 'Driver 2' button, then the button to the left of the appropriate description.



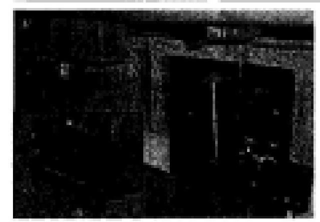


FIGURE 5.3 Above, Left. The Alertness Scale.

FIGURE 5.4 Above. The dash-mounted Alertness Scale.

FIGURE 5.5 Left. The sleeper berth Alertness Scale (located in the upper left corner, mounted on underside of shelf as shown in insert).

NOTE: If you accidentally push the wrong button (e.g., you are 'Driver 1' and you inadvertently select 'Driver 2'), you have 30 seconds to make the correct selection. If you realize after 30 seconds that you inadvertently made the wrong selection, please make a note including the day and time of the misselection.

Chapter
6

Sleeper Berth Fatigue Study

Participant's Manual

Data Collection Systems: Survey

Overview

As part of the agreement to participate in the study, you agreed to fill out two surveys, one concerning sleep quality and the second, your daily activities. These surveys are stored in a binder in the truck cab.

Completing the Surveys

Each person (this is especially important if you are a member of a team) has their own set of surveys contained in their binder.

Select the appropriate survey

The appropriate survey is determined as follows:

- "Wake-Up Survey" – Fill this form out every time you wake up from a period of sleep
- "Once a Day Survey" – Fill this form out at approximately the same time each day.

Chapter
7

Sleeper Berth Fatigue Study

Participant's Manual

Data Collection Systems: Nightcap Sleep Monitoring Device

General Instructions

Before going to sleep

1. Please complete the 'Once-A-Day' Survey before going to sleep, if you have not already done so. The end of the work period is generally the best time to complete this survey, so if you are just taking a nap, this step is not necessary.
2. Put on the Nightcap following the instructions presented below making sure the time you begin trying to go to sleep and time when the Nightcap is turned on are the same.
3. Indicate your level of alertness on the alertness scale mounted in the sleeper berth by pushing the 'Driver 1' or 'Driver 2' button, then the button to the left of the appropriate description.

When you get up

4. Indicate your level of alertness on the alertness scale mounted in the sleeper berth by pushing the 'Driver 1' or 'Driver 2' button, then the button to the left of the appropriate description.
5. Please complete the 'Wake-Up' Survey within 10 minutes of waking up.
6. Be sure to fill in / write the time you turned the Nightcap off on the questionnaire.

Attaching the body-movement sensor and eye sensor mount with bandana

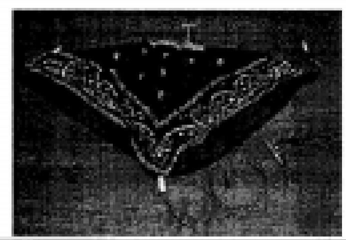


FIGURE 7.1 The Nightcap. Note the eye movement sensor at top of bandana.

1. Before putting on the bandana, plug the eye sensor into its mount (inside the bandana) through the hole cut in the fabric. The eye sensor's two-holed plastic end-piece fits into the receptacle (with two pins) on eye sensor mount.

FIGURE 7.2 The Nightcap with the eye movement sensor located directly above the eyelid to which you plan to attach the eye sensor.

2. Next, put on the bandana as shown in Figure 2 (above), making sure the eye sensor mount is directly above the eyelid to which you plan to attach the eye sensor.
   - Make sure the sensor's "lead" (the piece going from the mount to the adhesive strip attached to eyelid) will hang straight down to your eyelid (Figure 1) and also ensures that it will have some slack when the adhesive strip is attached to your eyelid.
3. Bring the two wires over the top of your head and secure them over the bandana knot in back with a second knot as shown in Figure 3 (below).

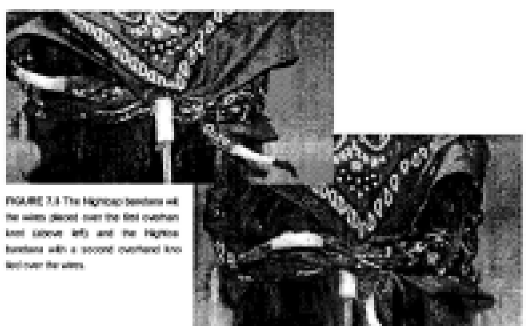


FIGURE 7.3 The Nightcap bandana with the wires placed over the first overhand knot (above left) and the Nightcap bandana with a second overhand knot tied over the wires.

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4. Make any adjustments necessary to ensure comfort but be sure the lead to the eyelid portion of the sensor continues to hang straight down to your eyelid and the body sensor remains in a vertical orientation.
5. Once you have the bandana properly positioned, secure the bandana to your forehead with one piece of adhesive tape attached to the bandana between the two sensors (see Figure 1).

Attaching the eye sensor to eyelid

Use a new eye sensor every time you put the Nightcap on. You should have 25 new eye sensors (in cardboard holders) in your kit. Throw used eye sensors away – do not use the same sensor for more than one data collection period.

Remove the paper covering from the adhesive sensor and attach sensor to your eyelid as parallel and as close as possible to the eyelash but completely on the eyelid (see Figure 4, below).

- If the adhesive part of sensor is not exactly parallel to your eyelash this is OK but if it is crimping a fold of skin, try to remove the crimp by stretching out the skin.
- If you have to remove the eye sensor to reposition it, use a new sensor (you have extras).

FIGURE 7.4 The sensor should be attached to the eyelid as parallel and as close as possible to the eyelash, but completely on the eyelid.

Attaching the grounding patch

Use a new grounding patch every time you put the Nightcap on. You should have 25 new grounding patches (in plastic packages) in your kit. Throw used grounding patches away – do not use the same grounding patch for more than one data collection period.

Remove the paper covering from the adhesive sensor and attach sensor to your forehead or cheekbone.

Attach grounding wire to grounding patch.

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Activating Nightcap Unit (Sleeper Berth Use Only)

When in the sleeper berth, the nightcap should be plugged directly into the Nightcap Activation Box (Figure 7.5) and the button should be depressed. If the button does not light up red, then the data collection system is not working. Please follow the instructions in Chapter 8 to notify the Center for Transportation Research.

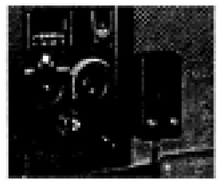

FIGURE 7.5 Right: The Nightcap Activation Box located to the right of the air conditioning controls.

Activating Nightcap Unit (Home Use Only)

The Nightcap Unit has an on/off switch. When you turn on the unit, a green light will flash once a second for about ten seconds to indicate normal operation.

- If this light flashes very quickly, you should replace the battery with a new battery provided in the kit.
- A good place for the Nightcap box while sleeping is beneath your pillow.
- Remember to turn off the Nightcap in the morning!

Changing Nightcap Battery (Home Use Only)

Battery should be replaced if, when activated, the green light flashes more quickly than once a second for 10 seconds.

- Remove the sliding panel on the back of the Nightcap Unit, note how the old battery is attached.
- Carefully remove the old battery and avoid pulling on the wires.
- Attach the new battery in the same manner as the old one was attached.

If you should push the button on the Nightcap box and if there is not an appropriate response from the unit (for example, an illuminated red light if on the road OR a green light that flashes for 10 seconds and then stops if at home) then the data collection system is not working. Please follow the instructions in Chapter 8 to notify the Center for Transportation Research.

Chapter

8

Sleeper Berth Fatigue Study

Participant's Manual

Contacting the Center for Transportation Research

Should you need to contact the Center for Transportation Research in an emergency, for truck-related or study-related concerns, or some other reason, please follow the protocol presented below.

Have the following information ready:

a) the truck you are driving (Volvo or Peterbilt),

b) your location,

c) your reason for calling (emergency, mechanical problems, or something else)

d) your condition (if an emergency)

Wireless Phone Operation

These procedures are also printed on the back cover of this manual and an additional copy is located in the portable phone case.

Calling the Center for Transportation Research

1. Retrieve phone from storage.
2. Open case and insert power plug into cigarette receptacle.
3. Press PWR button.
4. If it is between the hours of 8 and 5 PM EST, call the Center for Transportation Research by entering the following number (540-231-7740). Otherwise, call the researcher 'on duty' by entering the following number (540-239-1065).
5. Press the SND button
6. Listen for a brief series of tones
7. Type in the following long distance PIN number: 8324 (TECH)

8. Press the SND button

9. Wait for the phone to ring.

10. If there is no answer, or you receive a message that the person you are trying to call is out of range, try again. If you are still unable to contact that individual, try one of the following phone numbers:

(M-F, 8 AM – 5 PM EST)	(540) 231-7740 (Phone)
All Other Times	(540) 239-1965
	(540) 951-8061 (if no answer at above number)

11. Press the END/CLR button to hang-up.

A representative from the Center for Transportation Research should return your call shortly – if you do not receive a response in 10 minutes, repeat the above procedure.

Answering the Phone

1. Lift receiver

2. Press the PWR button and greet the caller

These procedures are also printed on the back cover of this manual and an additional copy is located in the portable phone case.

Chapter 9

Sleeper Berth Fatigue Study

Participant's Manual

Emergency Procedures

In the unlikely event of damage to the vehicle or related equipment, or the illness/injury suffered by the operator, begin the following protocol:

1. **STOP.** Failure to stop at the scene of an accident in which you were involved is a criminal offense (which could result in the revocation of your license).

2. Set out Warning Devices – one each 100 feet to the front and rear of your unit and one opposite the scene (to increase visibility). If the accident occurs at the crest of a hill, set the warning devices further out, but not exceeding 500 feet. These devices are located in the storage bins beneath the mattress in the sleeper berth.

3. Assist injured persons, but do not move them unless absolutely necessary.

4. Notify police.

NOTE: 911 Phone Calls can be made without the use of a PIN number.

5. Contact your company terminal or agent and the Center for Transportation Research (see Chapter 8) so that we may contact the insurance company without further delay.

6. **ADMIT NO WRONG-DOING, PLACE NO BLAME, PROMISE NOTHING, and DO NOT ARGUE.** Be polite. Give your name, your carrier name, and offer to provide your driver's license information.

7. **DECLINE COMMENT TO ANYONE** other than official law enforcement and medical representatives.

8. Fill out a preliminary accident report card (next page) – be sure to get the names of all witnesses (both for you and against you). If witnesses refuse to leave their names, get their automobile license numbers (including state issuing) if at all possible.

9. Stay at the location of the accident until instructed by your carrier / the Center for Transportation Research to proceed.

Preliminary Accident Report Card
Use Back of this Page to Record Additional Information if Necessary.

DATE: ____________

TIME: ____________

EXACT LOCATION: ____________________

____

OWNER #1 NAME: ____________

VEHICLE: YEAR ____ MAKE ________ MODEL ________

LICENSE: STATE ____ NUMBER ________

INSURANCE COMPANY: ________ POLICY #: ________

PASSENGERS: NAME ____________________

ADDRESS ____________________

DESCRIPTION OF DAMAGE: ____________________

____

____

OWNER #2 NAME: ____________

VEHICLE: YEAR ____ MAKE ________ MODEL ________

LICENSE: STATE ____ NUMBER ________

INSURANCE COMPANY: ________ POLICY #: ________

PASSENGERS: NAME ____________________

ADDRESS ____________________

DESCRIPTION OF DAMAGE: ____________________

____

____

30

WITNESSES: NAME ____________________

ADDRESS ____________________

LICENSE: STATE ____ NUMBER ________

NAME ____________________

ADDRESS ____________________

LICENSE: STATE ____ NUMBER ________

POLICE NAME ________________ BADGE # ________

DEPARTMENT ____________________

NAME ________________ BADGE # ________

DEPARTMENT ____________________

ACCIDENT DIAGRAM Include relevant aspects of the accident scene – including terrain, obstruction to view (e.g., buildings, trees, parked cars), location and type of traffic signs and signals, path of travel of involved vehicle before impact, at impact, and after impact, and type of road. Include measurements where possible (e.g., lane width, sight distances, and distances to fixed landmarks); allow 2 ½ feet per pace.

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APPENDIX D

Proposed Research Claims & Methodology

D1: Original Research Proposal

D2: Modified Original Research Proposal

ORIGINAL RESEARCH PROPOSAL

Background

Per mile driven, commercial motor vehicles are two-thirds more likely than other vehicles to be involved in fatal accidents (NHTSA, 1990). Driver fatigue is recognized as a major causal factor in accidents involving long-distance commercial motor vehicle (CMV) operators. To provide an efficient and cost-effective means for drivers to sleep, sleeper berths are provided on tractors to allow long distance CMV drivers to obtain rest between periods of driving. However, the sleeper berth environment and/or manner in which the truck drivers actually use the sleeper berth many not contribute to quality rest. For example, extraneous environmental variables such as noise and vibration may interfere with the sleep of one member of a team as the other member drives. Similarly, the quality of rest may be interrupted by movement of the tractor may if a driver attempts to do so while the trailer is being loaded or unloaded.

Research Claims

The objective of this proposed study is to assess the impact of sleeper berth usage on the level of operator alertness. Based on evidence presented in the research literature, the following hypotheses were originally proposed regarding relationships among driving behaviors, driver performance, and rest quality in a sleeper-berth environment:

Proposed Research Claim 1a: Objective (Nightcap) and subjective (questionnaire) measures of sleep quality are directly correlated.

Proposed Research Claim 1b: Objective (Perclose Alertness Monitor) and subjective (Karolinska Sleep Scale) measures of fatigue are directly correlated.

Proposed Research Claim 2: The rest obtained in a sleeper berth for team drivers (*e.g.*, while the vehicle is in motion) will be of lower quality than for single drivers (*e.g.*, while the vehicle is stopped).

Proposed Research Claim 3: The rest obtained in a sleeper berth will be of lower quality than rest obtained at home.

Proposed Research Claim 4a: Driving performance will decrease due to fatigue over the course of the trip (across days).

Proposed Research Claim 4b: Driving performance will decrease due to fatigue during the driving shift.

Proposed Research Claim 5a: Driving performance is directly correlated with the quality of sleep in the proceeding sleep period.

Proposed Research Claim 5b: Driving performance is directly correlated with the quantity of sleep in the proceeding sleep period.

Proposed Research Claim 6a: Quality of sleep in the sleep period immediately preceding a driving shift is more important than the cumulative quality of sleep attained to that point.

Proposed Research Claim 6b: Quantity of sleep in the sleep period immediately preceding a driving shift is more important than the cumulative quantity of sleep attained to that point.

Methodology

The experiment described herein was directed at: 1) establishing the relationship between objective and subjective measures of sleep quality, and 2) determining how sleeper berth usage affects operator fatigue. A comprehensive experimental plan incorporating regression, analysis of variance (ANOVA), and analysis of covariance (ANCOVA) techniques is presented as proposed means to by which to meet these goals.

Participants. A total of 48 licensed, Class A, commercial motor vehicle operators, including both owner-operators and drivers employed by small firms, were to use two Center for Transportation Research (CTR) owned tractors in hauling their normal cargo to perform the data collection runs. Participants would have been required to possess a valid Class A commercial motor vehicle operator's license, have had vision and hearing in the normal range, and have agreed to adhere to all laws regarding operation of a Class 8 tractor including those pertaining to alcohol and drug use. Normal hearing is defined by the Federal Highway Administration (1994) as having a pure-tone hearing threshold in the better ear of not more than 40 dB at 500, 1000, and 2000 Hz. Similarly, normal vision is defined as having a minimum visual acuity of 20/40 in each eye and a distant binocular acuity corrected to at least 20/40 (Federal Highway Administration, 1994). Since drivers were to have been required to have a current medical physical in order to possess a commercial driver's license, these items would not have been included in the screening process. Within each sleep schedule, one half of the drivers recruited would have been solo drivers while the other half would have been team drivers. There were no gender restrictions within this study.

Independent Variables. The experimental design would have utilized a three-way, mixed factor design examining the following independent, fixed-effects variables: Staffing (2 levels, between subjects), Wake/Sleep Schedule (2 levels, between subjects), and Trip Length (11 levels, within subjects). All main effects and interactions would have been resolved in an Analysis of Variance (ANOVA). Selected covariates would have then be considered in separate post-hoc analyses.

Finally, regression would have been used to describe the continuous change in sleep quality over the entire trip. Figure D1 depicts the proposed experimental design graphically.

Staffing, a between subjects variable, was proposed to have been manipulated at two levels. One half of the drivers recruited would have been solo or single drivers while the other half would have been team drivers.

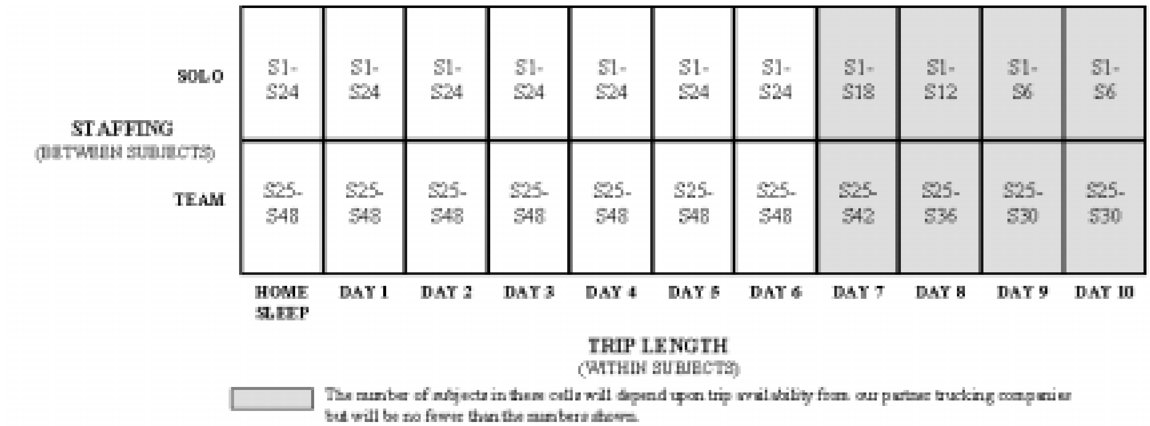


Figure D1. Graphical Depiction of the experimental design.

Data collection was proposed to have occurred over eight to ten 24-hour periods and will yield data for approximately 480 person days of driving (48 drivers x 10 person days each). Up to three nights of home sleep data for each driver would have also been collected prior to the beginning of the run for an additional (possible) 144 rest intervals. Based upon sleep quality and driver performance measures, it is likely that post hoc tests would have been used to separate out the effects of time in terms of short, medium, and long trips.

Dependent Variables. The dependent measures to be included in this research effort are comprised of each of the four major categories of fatigue-related measures: performance, physiological, subjective, and behavioral/cognitive measures and are listed in Table D1. Each of these measures has, through previous research, been identified as being sensitive to the measurement of fatigue while enabling current researchers to conduct data collection which is naturalistic, unobtrusive, and non-invasive. Additional measures, while they may have been demonstrated to be sensitive to fatigue, would not have met the previously described requirements of being unobtrusive (especially true of additional behavioral/cognitive measures), noninvasive, and able to be implemented in an integrated data collection system requiring minimal driver effort. The instrumentation describing how each of these variables is to be collected is discussed in considerable detail in a later section.

Unplanned lane deviation, steering position, steering velocity, presence of abrupt lateral maneuvers, average vehicle velocity, velocity variance, presence of abrupt braking maneuvers, time to collision, and number of near misses comprise the subset of performance-based metrics of fatigue. Each of these measures has, through previous research, been identified as being sensitive to the measurement of fatigue. Similarly, performance measures offer an ideal opportunity to collect naturalistic, unobtrusive, and non-invasive data related to fatigue and alertness.

TABLE D1

Dependent Measures Grouped by the Four Major Categories of Fatigue-Related Measures: Performance, Physiological, Subjective, and Behavioral / Cognitive Measures

CATEGORY	DEPENDENT MEASURES
Performance	Unplanned Lane Deviation Steering Position Steering Velocity Abrupt Lateral Maneuvers Average Vehicle Velocity Velocity Variance Abrupt Braking Maneuvers Time to Collision Number of Near Misses
Physiological	Eyelid Closure Eye Movement
Subjective	Observer Ratings of Drowsiness Karolinska Sleep Scale 'Wake-Up' Survey 'Once a Day' Survey
Behavioral / Cognitive	Evaluation of Driver Mannerisms Simple Response Vigilance Task

Physiological measures include eyelid closure and eye movement. Additional measures, especially those frequently employed in evaluating sleep and sleep quality (*e.g.*, EEG, EOG, EMG) were not chosen due to the relative complexity of their set-up and operation. Similarly, heart rate was not included since integrating such a measure with the existing data collection system would have required a tether connecting the driver to truck during the driving task, thus increasing the obtrusiveness of the system.

The observer ratings of drowsiness, Karolinska Sleep Scale and two survey instruments comprise the subset of subjective measures. The Karolinska Sleep Scale and observer ratings of drowsiness (video analysis) were demonstrated to be the subjective measures most sensitive to detecting levels of fatigue and alertness. The Karolinska Sleep Scale will be presented subsequent to the occurrence of a critical incident and at regular intervals during the driving task. Observer ratings of drowsiness will be assessed from video segments triggered by the critical incidents and recorded during the experiment by trained observers after the completion of the driver's experimental run.

The responses to a variety of questions querying the driver's activities and subjective self-assessment of well-being will be assessed through the use of two survey instruments. The first of these survey instruments will be completed 'once a day' and focus on the events of the preceding 24-hours that may have contributed to the operator's level of fatigue (Appendix A). Many of the questions represented in this survey are identical to those used by Wierwille, Hanowski, and Dingus (1998) for their work in the local short-haul trucking industry; such similarity will hopefully enable meaningful comparisons between the two trucking environments. The second survey, or ‘wake-up’ survey, is derived from the St. Mary's Hospital (SMH) Scale (Ellis, Johns, Lancaster, Raptopoulos, Angelopoulos, and Priest, 1981) and is designed to query individuals about quality aspects of their previous night’s sleep. Each of the items on the SMH has demonstrated test- (administered 1-2 hours after waking) retest (administered approximately four hours later) reliability among healthy, normal volunteers; correlations ranged from 0.67 to 1.00. If two of the most subjective questions are removed, the lowest correlation for the remaining questions rises to 0.89 (Ellis *et al.* 1981).

Both the ‘once a day’ survey and the ‘wake-up’ surveys will be presented in a pencil/paper format and will be stored in the truck cab (out of the way, so as not to contribute to the clutter but easily accessible should they be needed). These questions have been altered slightly from their original format in order to increase applicability to the current study. For example, all references to time of day (*e.g.*, normally sleeping at night and awake during day) have been removed due to the erratic sleep patterns of the truck drivers.

Given the validity-related concerns, regarding the potential for subtle changes in environment and operator motivation affecting operator fatigue levels, associated with the reviewed off-line cognitive / behavioral measures, it did not seem prudent to include such measures. Similarly, the more involved on-line tests (those involving more than the simple key press) associated with the cognitive/behavioral measures will not be incorporated as they would likely interfere with the on-line collection of subjective fatigue data. As a result, experimenters will review the videotaped segments subsequent to the completion of the trip in order to detect any driver mannerisms indicative of fatigue. Additionally, the cognitive and behavioral measures employed in this research effort are limited to a simple response vigilance / reaction time task built into Karolinska Sleepiness Scale. Simple reaction time, or the time between a stimulus and a driver’s response, will comprise a straightforward simple response vigilance task. The stimulus will be provided by an indicator informing the driver of the need to respond to the KSS display mounted on the dash (discussed in more detail later) and the operator’s response will compose the selection of fatigue level on the display.

Selected Covariates. Several covariates have also been selected to supplement the comparisons among the independent and dependent variables, chosen on the basis that they could influence driver fatigue and alertness. These variables are not included as independent variables since they are environmental variables whose levels cannot be controlled by the experimenter. These covariates include: noise, vibration, temperature, illumination and wake/sleep schedule.

MODIFIED ORIGINAL RESEARCH PROPOSAL

Background

Per mile driven, commercial motor vehicles are two-thirds more likely than other vehicles to be involved in fatal accidents (NHTSA, 1990). Driver fatigue is recognized as a major causal factor in accidents involving long-distance commercial motor vehicle (CMV) operators. To provide an efficient and cost-effective means for drivers to sleep, sleeper berths are provided on tractors to allow long distance CMV drivers to obtain rest between periods of driving. However, the sleeper berth environment and/or manner in which the truck drivers actually use the sleeper berth many not contribute to quality rest. For example, extraneous environmental variables such as noise and vibration may interfere with the sleep of one member of a team as the other member drives. Similarly, the quality of rest may be interrupted by movement of the tractor may if a driver attempts to do so while the trailer is being loaded or unloaded.

Research Claims

The objective of this proposed study is to assess the impact of sleeper berth usage on the level of operator alertness. Based on evidence presented in the research literature, the following hypotheses were originally proposed regarding relationships among driving behaviors, driver performance, and rest quality in a sleeper-berth environment:

Research Claim 1: Objective (Nightcap) and subjective (questionnaire) measures of sleep quality are correlated.

Research Claim 2: The measures of fatigue and measures of alertness are associated with one another, and if so, to establish a functional relationship between the correlated measures.

Research Claim 3: Rest obtained in a sleeper berth will be of lower quality than the rest obtained at home.

Research Claim 4: Driving performance will decrease due to fatigue during the driving shift.

Research Claim 5: Driving performance will decrease due to fatigue over the course of the experimental session.

Research Claim 6: Driving performance will fluctuate according to human circadian sleepiness patterns and decrease during peak periods of driver drowsiness (nighttime and mid-afternoon).

Methodology

Participants. Originally, 48 drivers were to have been recruited. Of this number, one-half of the drivers recruited were to have been solo drivers while the other half were to have been team drivers. Due to a protracted data collection time period, this number was reduced to approximately eight drivers, all solo, for the subsequent iteration of the original proposal. It was envisioned that this subset would be used as a test bed for the development of a methodology that could then be applied to the entire sample size when the data collection had been completed.

Independent variables. Given the high level of importance on maintaining the observational nature of this study and the difficulty in identifying drivers who consistently adhered to a rigorous wake/sleep schedule, this factor was discarded. Similarly, since all of the participants in this study were solo drivers, comparisons between staffing arrangements could no longer be considered. Trip length was retained as the primary independent variable. Other independent variables, such as sleep location and trip length were also included. It is worth noting that all of the independent variables were to have been dictated by real world needs rather than *a priori* experimental conditions. Specifically, the independent variables were also to have been measured rather than manipulated.

Data collection was originally proposed to occur over eight to ten 24-hour periods, yielding data for approximately 480 person days of driving (48 drivers x 10 person days each). This was subsequently reduced to reflect shorter trips ranging from four to eight days in length due to experimental difficulties. In addition, the data recorded by the data collection system did not exist for the entire trip. Up to three nights of home sleep data for each driver was also to have been collected subsequent to the termination of the on-road portion of the study.

Dependent variables. The dependent measures included in this research effort remain unchanged from the original proposal.

Data analyses. The following analyses were employed using the data contained within the sleep quality and quantity and driving performance master data sets. These hypotheses form the cornerstone of this dissertation research and seek to quantifiably explain 1) the relationship between the objective and subjective measures of fatigue and sleep quality, and 2) the effect of sleeper berth usage on operator fatigue.

Research Claim 1. Objective (Nightcap) and subjective (questionnaire) measures of sleep quality are correlated.

In order to determine whether objective (Nightcap) and subjective (wake up survey) measures of sleep quality are directly correlated, four predominant measures of sleep quality and quantity have been identified: sleep latency, sleep efficiency, sleep duration, and the number of awakenings. For this analysis, four separate correlation comparisons are proposed where each of the sleep quality measures elicited from the

Wake-Up Survey will be compared with the measures recorded by the objective Nightcap device.

The basis for these comparisons would have been the correlation coefficient. A correlation coefficient is used to gauge the strength of a relationship present between two measures. The most basic, and arguably the most frequently used, is the Pearson product-moment correlation coefficient (*r*). It is used to determine if a linear association exists between two measures. Underlying the Pearson correlation coefficient are assumptions of normality and homogeneity; however, when the sample size is relatively large, the Pearson product-moment correlation is robust to violations of the aforementioned assumptions (Neter, Kutner, Nachtsheim, and Wasserman, 1996; Howell, 1992).

Spearman's correlation coefficient (r_s), also known as Spearman's Rho is a nonparametric rank procedure not constrained by the assumptions of normality or homogeneity (Neter *et al.*, 1996). While Pearson's product-moment correlation coefficient is used to determine if a linear relationship exists between two measures, Spearman's correlation coefficient is used to determine if the relationship between the measures is monotonic in nature (Ott, 1993).

It is worth mentioning that multiple formulations for Spearman's correlation coefficient exist; however, one of the easiest and most widely used involves a simple variation in the application of Pearson's product-moment correlation formula. Instead of applying this formula to the data values, the data are ranked. Pearson's product-moment-correlation formula applied to the ranked data yields Spearman's correlation coefficient as a result (Howell, 1992). The ranking procedure eliminates the requirements for the normality and homogeneity assumptions that accompany Pearson's product-moment correlation coefficient. Because the relationship between the measures being considered is unknown, both the Pearson product-moment correlation coefficient and Spearman's correlation coefficient will be calculated.

As an extension of the first hypothesis, it would have been of interest to determine which of the objective measures most accurately describe the subjective assessment of sleep quality. Therefore, the subjective measure of sleep quality would have been characterized as a function of the objective measures of sleep quality. The subjective assessment of sleep quality would have been derived from a single multiple-choice question on the Wake-Up Survey. The discrete nature of the multiple-choice item on the Wake-Up Survey limits the utility of a standard regression model; therefore, polytomous logistic regression would have been used to develop the regression model (Neter *et al.*, 1996; SAS Institute, 1995b).

Standard regression is most frequently used to model the relationship between continuous response and predictor variables. Logistic regression, in contrast, is more frequently used to model the relationship between a dichotomous (binary) response variable and a set of predictor variables. Polytomous logistic regression extends logistic regression to include response variables having more than two levels (Neter *et al.*, 1996; SAS Institute, 1995b).

Research Claim 2. That measures of fatigue and measures of alertness are associated with one another, and if so, to establish a functional relationship between the correlated measures.

The second hypothesis was designed to compare the various measures of fatigue and alertness measured in this research effort. Because fatigue is latent and cannot be measured directly, it would have been useful to compare the measures with one another in order to determine if they are associated. The three measures to have been compared are the subjective self-assessment of fatigue (Karolinska Sleep Scale), an analyst's subjective assessment of fatigue (observer ratings of drowsiness), and an objective drowsiness indicator (PERCLOS monitor).

Scatterplots were to have been generated for each of the pairwise comparisons (not shown). From these plots, a first approximation of the relationship between measures would have been made. If the data were reasonably linear, a correlation analysis ($\alpha = 0.05$) would have been performed in order to quantify the strength of the relationship between the measures shown in the scatterplot. Because the relationship between the measures being considered is unknown (*e.g.*, may or may not be linear), both the Pearson product-moment correlation coefficient and Spearman's correlation coefficient would have been calculated. If the results of the correlation analysis had indicated that a significant relationship between the measures existed, a polynomial regression model would have been applied in order to describe the nature of the relationship more precisely.

Research Claim 3: Rest obtained in a sleeper berth will be of lower quality than the rest obtained at home.

This hypothesis would have been evaluated using a multivariate approach to evaluate five different dependent measures: sleep latency, sleep efficiency, sleep duration, number of awakenings, and subjective assessment of sleep quality from the Wake-Up Survey. Such an approach is prudent and preferred over multiple univariate tests because each of the measures evaluated reflected measurement of a slightly different aspect of the same entity, sleep quality.

Specifically, Hotelling's T^2–test for equality between two mean vectors, also known as the two-sample T^2-test, would have been used to compare the sleep obtained during the homesleep and on-the-road periods. In addition to being easily calculated, Hotelling's T^2-test accommodates different sample sizes; an especially important attribute as substantially more data was collected for the on-the-road condition (up to eight days / driver) than for the homesleep condition (no more than three days / driver). Underlying Hotelling's T^2 are assumptions of multivariate normality and equality of the covariance matrices from the two measures being compared. Prior to performing Hotelling's T^2, the normality assumption will be evaluated using the Shapiro-Wilk test in order to determine if the normality assumption held for the current data set. If both sample sizes were reasonably large, however, Hotelling's T^2 would have been robust to violations of multivariate normality (Flury, 1997; Rencher, 1995). Evaluating the equality of the respective covariance matrices would have been performed through the use of the folded form F statistic. If found to have been unequal, then the Satterthwaite Correction for unequal covariances would have been applied.

If the results of the Hotelling's T^2–test indicated a significant relationship between the measures existed, then univariate t-tests would have been performed on each of the measures in order to determine which are significant. Hummel and Sligo (1971) and Rencher (1995) advocate this strategy as performing a series of univariate t-tests without first rejecting null hypothesis (H_0) from the T^2–test yields inflated alpha levels.

Research Claim 4: Driving performance will decrease due to fatigue during the driving shift.

Since driving shift length is dictated by real world needs rather than *a priori* experimental conditions, it would have been necessary to develop a measure that could be used to compare driving shifts of varying lengths. Similarly, it also would have been necessary to compare the occurrence of critical events early in a driving shift with those critical events occurring later in the driving shift. Towards this end, ρ, a measure of critical event density, is presented and would have been incorporated in order to evaluate this hypothesis (Equation D1).

$$\rho = \frac{Incidents}{TimeVolume} \qquad \text{Equation D1}$$

Where: ρ = Critical event density
Incidents = Number of critical events occurring within a given time interval
Time Volume = Amount of driving / shift time occurring within in a given time interval

Figure D2 shows a (hypothetical) graphical representation of the critical event occurrence over the course of a trip. Chronological shift order comprises the y-axis. A horizontal line designates a driving shift, or period of driving uninterrupted by a deliberate sleep period. Each driving shift within an experimental session (or trip) begins at zero and is of length proportional to the length of the driving shift (x-axis). The x-axis has been arbitrarily divided into ten, one-hour time intervals. In determining critical event density, the number of critical events occurring within a given time interval comprise the numerator while the quantity of driving across all shifts contained within the same time interval comprises the denominator.

In order to evaluate the effects of fatigue over the course of the driving shift, density values would have been calculated for each time interval. A set of time interval density values would have been calculated for each driver. Once calculated, the time interval density measures would have been used to establish a function describing the change in driving performance over the course of the driving shift for each driver (Figure D3), all drivers (Figure D4), and a 'hypothetical mean' driver (Figure D5).

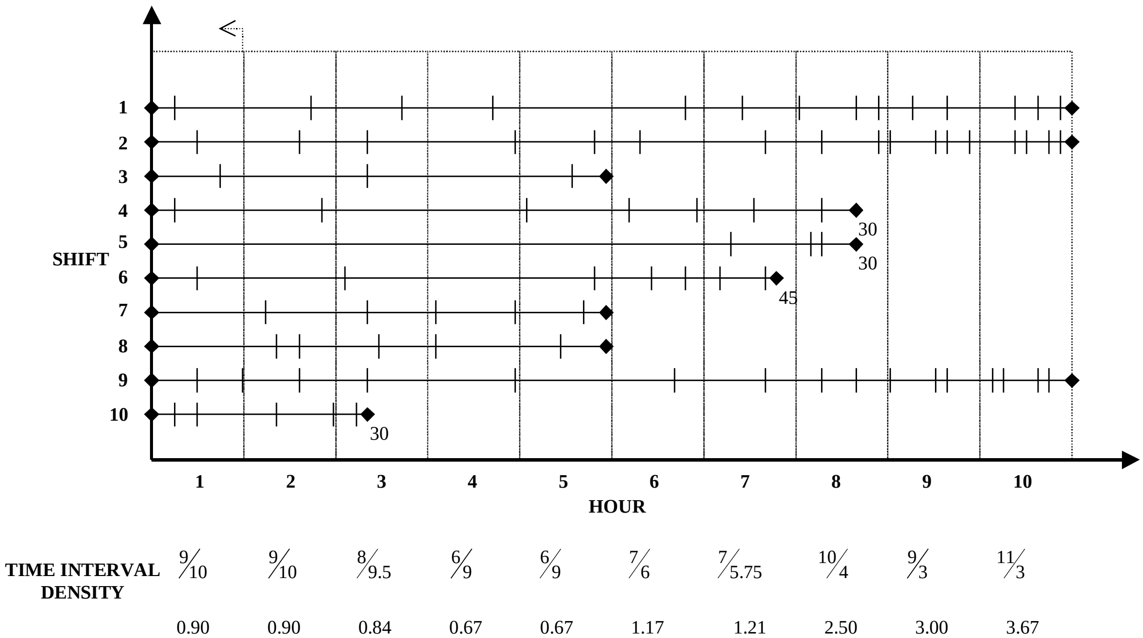


Figure D2. Graphical depiction of time interval density calculations as measured by the density of critical events over the course of a single shift.

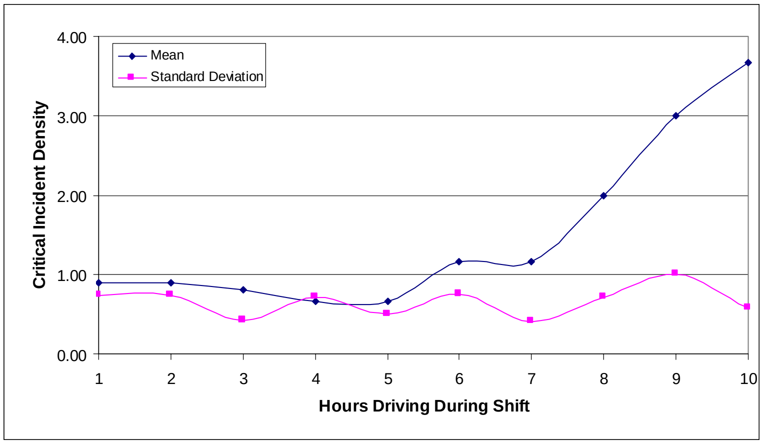


Figure D3. Critical event occurrences (density) during driving shift for a hypothetical participant.

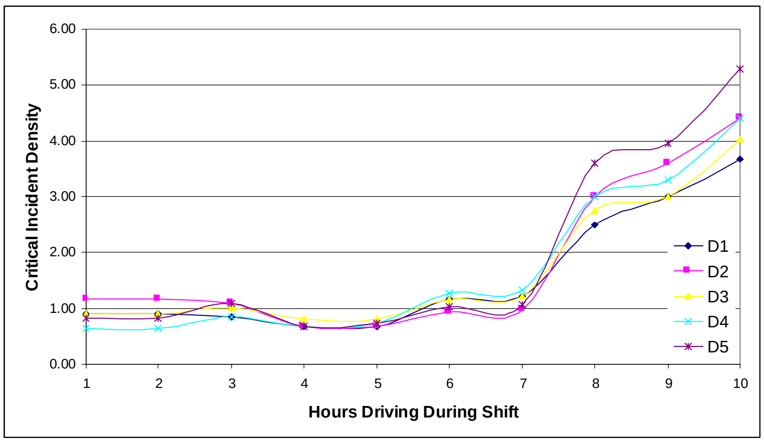


Figure D4. Critical event occurrences (density) during driving shift for a series of hypothetical participants.

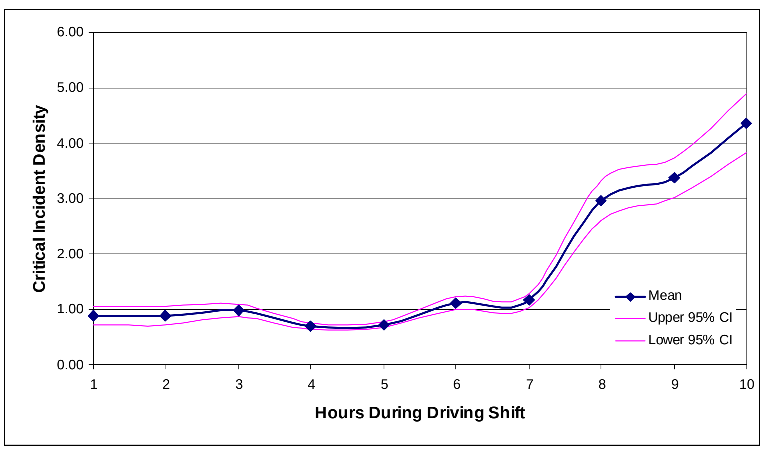


Figure D5. Critical event occurrences (density) during driving shift for a 'hypothetical mean' participant with 95% confidence intervals.

Once these critical event density functions had been established for each driver, several additional analyses would have been performed. The first, a correlation analysis, would have been performed in order to determine the strength of the relationship between the quantity of time spent driving and critical event density. Subsequently, a regression analysis would have been used to mathematically describe the critical event density as a function of time. The regression analysis would have been followed by a multiple regression analysis with repeated measures. The multiple regression analysis with repeated measures would have focused on evaluating the fatigue-related measures as predictors of critical event density. Subsequent to these regression analyses, multiple analyses of variance would have been conducted in order to determine if the characteristics of the critical events changed over the course of the driving period.

Scatter plots would have been generated showing the dispersion of the critical event density values over time. From these plots, a first approximation of the relationship between measures would have been made. A correlation analysis ($\alpha = 0.05$) would have been performed in order to quantify the strength of the relationship between the measures shown in the scatter plot. Because the relationship between the measures being considered is unknown, both the Pearson product-moment correlation coefficient and Spearman's correlation coefficient would have been calculated. If the results of the correlation analysis indicate a significant relationship between the measures existed, a polynomial regression model would have been applied in order to describe the nature of the relationship more precisely.

A polynomial regression analysis would have been applied to each data set in order to describe the relationship between the critical event density and the number of hours driving or the chronological shift order, respectively. The Y, or response variable, for both data sets is critical event density. The X, or predictor variable, for the first data set is the number of hours driving, which would have described the occurrence of critical events during the course of a driving session. In order to describe the occurrence of critical events over the course of the experimental session, the X, or predictor variable, for the second data set would have been chronological shift order.

Following the polynomial regression analysis, a multiple regression analysis with repeated measures would have been performed on each of the data sets. Where the previous regression analysis sought to describe the relationship between critical event density and the passage of time, this multiple regression analysis would have been used to evaluate the fatigue-related measures as predictors of critical event density. After performing this analysis, it would have been necessary to evaluate the distribution of the error term (Neter *et al.*, 1996). Specifically, the normality assumption would have been evaluated using a probability ratio of the residuals that result from the multiple regression model.

In addition to determining if a difference exists in the critical event density level over time, it would have been also of interest to determine what, if any, differences in critical incident characteristics occurring early in an observational period verses those occurring later in the time period. For this analysis, a multivariate analysis of variance (MANOVA) would have been performed using critical density of different trigger types as the dependent variables and time intervals as the repeated factor (independent variable). An overall MANOVA was chosen in lieu of multiple single analyses of variance in order to control the experiment-wide error rate inevitably present with multiple dependent variables. The significance of each effect would have been assessed using of Wilk's Λ, Pillai's trace, or a similar widely used multivariate test statistic (Howell, 1992; Rencher, 1995). If the null hypothesis was rejected by the multivariate test statistic, univariate *F*-tests will be performed on each dependent measure. If the univariate *F*-tests were found to be significant, Newman-Keuls post hoc analyses would have been conducted to determine the nature of the significant effects. The Newman-Keuls test uses progressive critical values accorded to the number of compared means making the test more powerful than some other potential analyses (Winer, Brown, and Michels, 1991).

Because this experimental design was to have been constructed using a repeated measures design, the Geisser-Greenhouse correction factor for the heterogeneity of covariance would have been used when calculating the repeated measures effects for each of the dependent measures. The Geisser-Greenhouse is the maximum correction for the heterogeneity of covariance (Winer, Brown, and Michels, 1991).

Research Claim 5: Driving performance will decrease due to fatigue over the course of the experimental session.

Since the length of the experimental session was dictated by real world needs rather than *a priori* experimental conditions, it was necessary to develop a measure that could be used to compare driving shifts of varying lengths. Similarly, it was also necessary to compare the occurrence of critical events in a driving shift that occurred early in the experimental session with one that occurred later. Critical event density, ρ, was introduced in the previous section and will used to evaluate this hypothesis.

Figure D6 shows a (hypothetical) graphical representation of the critical event occurrence over the course of an experimental session. Chronological shift order comprises the y-axis. A horizontal line designates a driving shift, or period of driving uninterrupted by a deliberate sleep period. Each driving shift within an experimental session (or trip) begins at zero and is of length proportional to the length of the driving shift (x-axis). Instead of calculating critical event density based on arbitrary time intervals, a critical event density will be calculated for each shift. Specifically, the number of critical events occurring within a given shift comprise the numerator while the quantity of time spent driving comprises the denominator.

In order to evaluate the effects of fatigue over the course of the experimental session, density values would have been calculated for each driving shift. A set of shift density values would have been calculated for each driver. Once calculated, the shift density measures would have been used to establish a function describing the change in driving performance over the course of the driving shift for each driver, all drivers, and a 'hypothetical mean' driver.

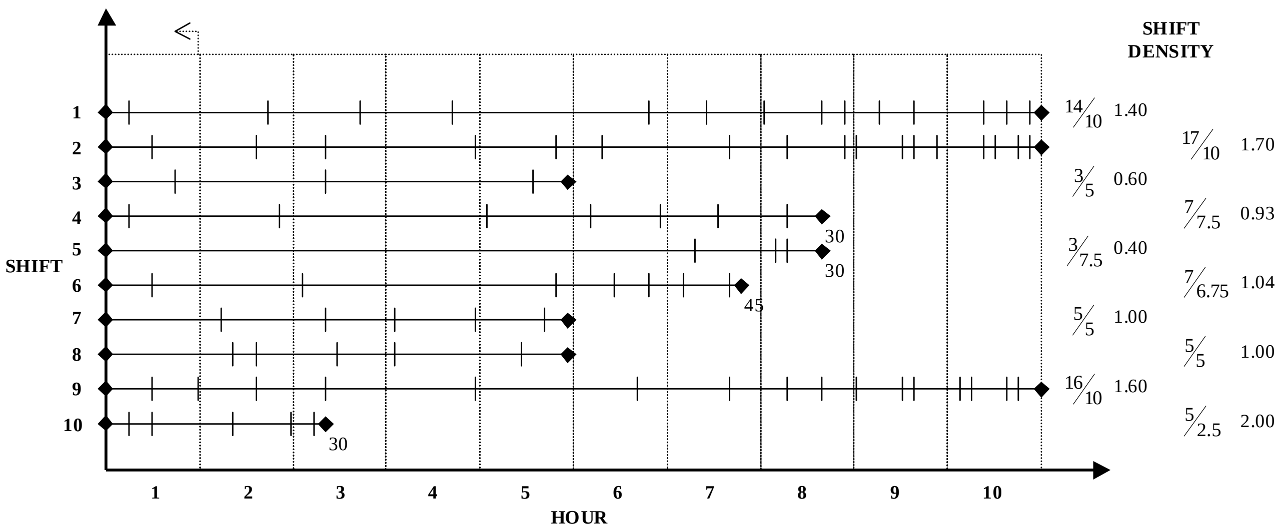


Figure D6. Graphical depiction of time interval density calculations as measured by the density of critical events over the course of a single shift.

Once these density functions have been established for each driver, several analyses would have been performed. These analyses are essentially identical to those described in the previous section. Instead of focussing on fatigue over the course of a driving shift, however, these analyses would have focused on fatigue occurring over the course of an experimental session (across multiple driving shifts). Since the analyses are similar with exception to this difference, they are not again presented in this section.

Research Claim 6: Driving performance will fluctuate according to human circadian sleepiness patterns and decrease during peak periods of driver drowsiness (nighttime and mid-afternoon).

Previous research (NTSB, 1995a, 1995b; Mitler *et al.*, 1988; Pack, *et al.*, 1995; and Wylie, et al, 1996) evaluating the proximate cause of automobile accidents indicates that crashes occurring after midnight and to a lesser extent those occurring in the late afternoon are more likely to be caused by fatigue than those occurring at other times of the day. Briefly, according to Wylie, *et al.* (1996), time of day was the most consistent factor influencing driver fatigue and alertness for commercial motor vehicle operators. Driver drowsiness was found to peak from late evening until dawn (Wylie *et al.*, 1996). Research (NTSB, 1995a, 1995b) indicates a disproportionately high proportion of fatigue-related accidents occur between the hours of 10 PM and 8 AM (74 percent); whereas, only 26 percent of those occurring between the hours of 8 AM and 10 PM were deemed to be fatigue-related.

The previously introduced critical event density, ρ, would have again comprised the dependent measure and been used to evaluate this hypothesis. Figure D7 shows a

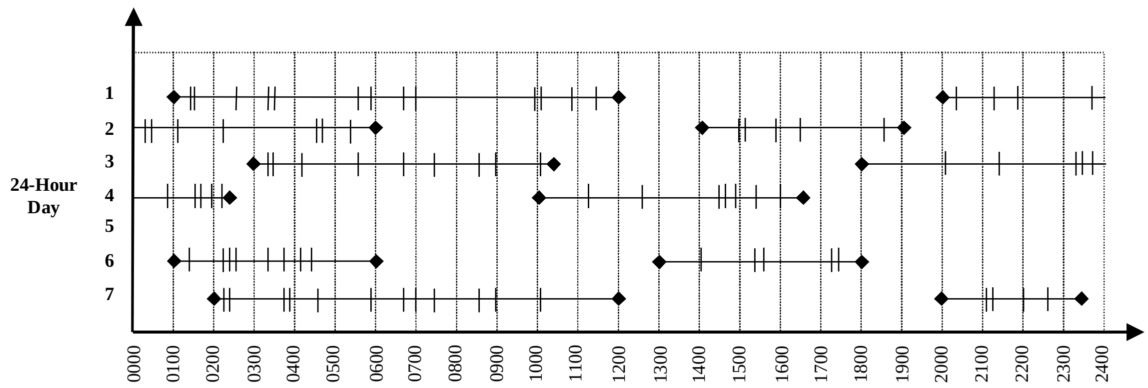


Figure D7. Graphical depiction of 24-hour density calculations as measured by the density of critical events over the course of a 24-hour day.

(hypothetical) graphical representation of the critical event occurrence over a 24-hour period. Chronological 24-hour day order comprises the y-axis. A horizontal line designates a driving shift, or period of driving uninterrupted by a deliberate sleep period. Each driving shift within an experimental session (or trip) begins at the start clock time and is of length proportional to the length of the driving shift (x-axis), continuing on the next day, if necessary. A critical event density would have been calculated for each hour of the day. Specifically, the number of critical events occurring within a defined hour of the day would have comprised the numerator while the quantity of time spent driving across all days during the defined hour would have comprised the denominator.

In order to evaluate the effects of fatigue over the course of the day, density values would have been calculated for each 24-hour period. A set of 24-hour density values would have been calculated for each driver. Once calculated, the 24-hour density measures from each driver would have been combined into a single generalized function describing the change in driver performance over the course of a 24-hour period (Figure D8).

Once these functions had been established for each driver, several analyses would have been performed. These analyses are essentially identical to those described in the previous two sections. Instead of focussing on fatigue over the course of a driving shift or experimental session, however, these analyses would have focused on fatigue occurring over the course of an 24-hour day. Since the analyses are similar with exception to this difference, they are not again presented in this section.

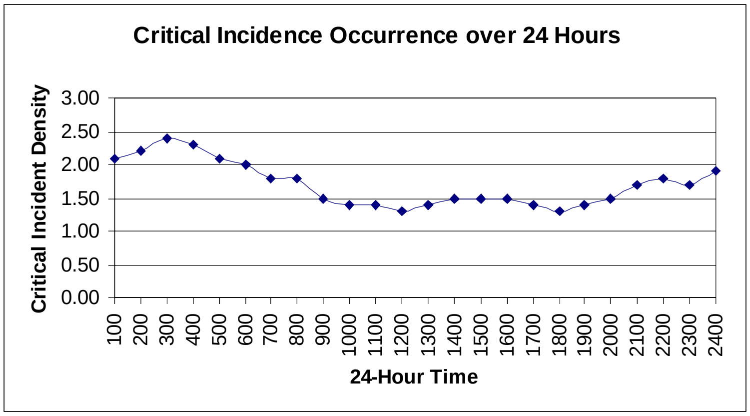


Figure D8. Critical event occurrences (density) during a 24-hour day for a hypothetical participant.

APPENDIX E

Data Summary by Participant

DATA REPORT: PARTICIPANT #1

Overall Summary

Vehicle:	Volvo L4
Trip Days:	8
Total Number of Epochs:	209
Total Number of Incidents:	626
Critical Incidents	57 (9.1%)
Non-Critical Incidents	58 (9.3%)
Invalid Incidents	511 (81.6%)

Narrative Summary

Video reduction analysis consisted of evaluating five videotapes. The Eaton Vorad RADAR system used to detect headway and calculate time to collision did not function on this trip; therefore, time-to-collision critical incidents were not recorded. No data collection was triggered as a result of the PERCLOS trigger criterion. The data collection system's internal (CMOS) clock is known to have failed at least once and suspected to have failed several additional times; however, due to the nature of the failure, the extent to which this failure affected the dataset is not precisely quantifiable. A considerable portion of the longitudinal and lateral acceleration triggers, in addition to the steering trigger, were found to be invalid as their occurrence coincided with the activation of the CB handset without any visible evidence that such triggers had otherwise occurred. Additionally, video, for which there exist no associated computer data files, was not analyzed. Similarly, computer data files, for which there exist no associated video, were not analyzed.

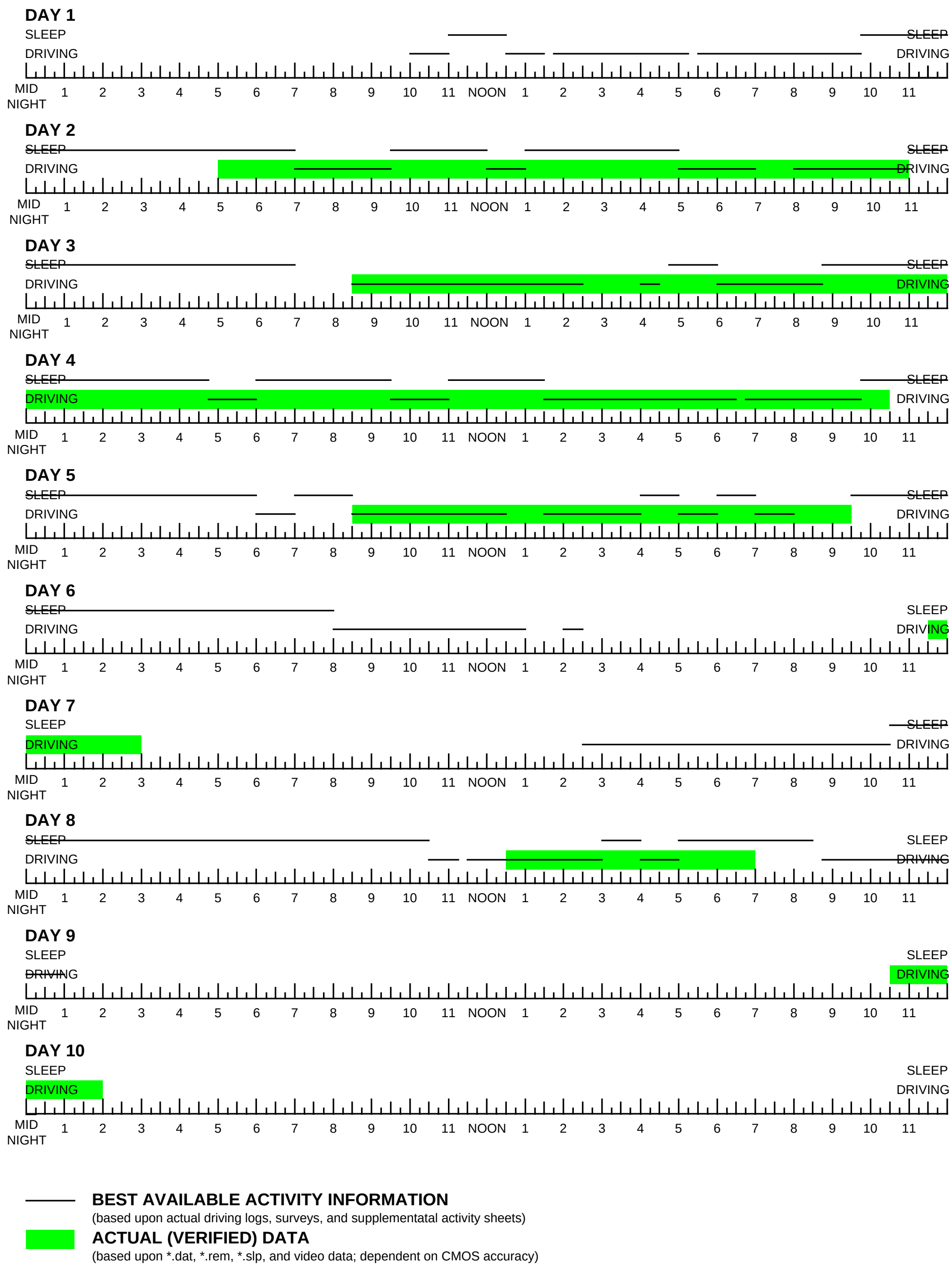
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	2	-	119	121	2
Lateral Acceleration	1	2	214	217	3
Longitudinal Acceleration	36	6	145	187	42
Time-To-Collision	-	-	-	-	-
PERCLOS	-	-	-	-	-
Karolinska Alertness Rating	-	-	4	4	-
Lane Departure	15	4	12	31	19
Incident Pushbutton	3	-	-	3	2
Timed Trigger	1	42	8	51	43
Karolinska Rating No Response	1	-	3	4	1
Lane Departure / Steering	-	2	6	8	2
Total	58	57	511	626	115

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #1.



DATA REPORT: PARTICIPANT #2

Overall Summary

Vehicle:	Volvo L4
Trip Days:	7
Total Number of Epochs:	341
Total Number of Incidents:	872
Critical Incidents	85 (9.7%)
Non-Critical Incidents	23 (2.6%)
Invalid Incidents	764 (87.6%)

Narrative Summary

Video reduction analysis consisted of evaluating five videotapes. There exist a large quantity of computer data files without associated video data and therefore were not analyzed. The PERCLOS triggers were found to indicate time periods where the driver had glanced away from the monitoring camera and therefore were not indicative of a change in a participant's state of alertness. The extent to which the failure of the data collection system's internal clock (CMOS) affected the dataset is not known for this subset of the data.

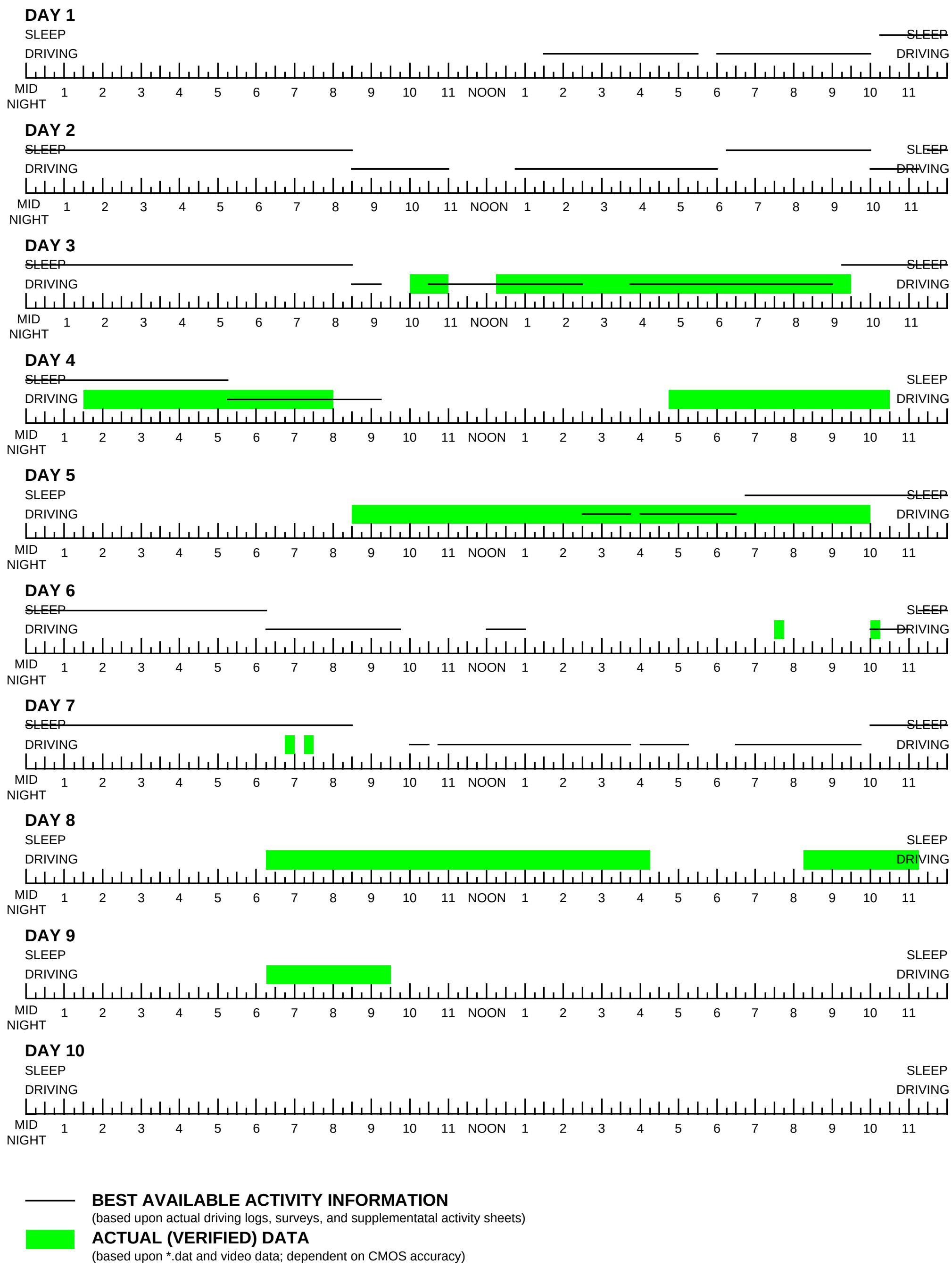
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	1	-	130	131	1
Lateral Acceleration	-	-	1	1	-
Longitudinal Acceleration	11	2	59	73	14
Time-To-Collision	65	3	307	374	67
PERCLOS	-	-	143	143	-
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	7	4	56	67	11
Incident Pushbutton	-	-	9	9	0
Timed Trigger	1	13	44	58	14
Karolinska Rating No Response	-	-	9	9	-
Lane Departure / Steering	-	1	6	7	1
Total	85	23	764	872	108

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #2.



DATA REPORT: PARTICIPANT #3

Overall Summary

Vehicle:	Volvo L4
Trip Days:	9
Total Number of Epochs:	209
Total Number of Incidents:	289
Critical Incidents	96 (33.2%)
Non-Critical Incidents	26 (9.0%)
Invalid Incidents	167 (57.8%)

Narrative Summary

Video reduction analysis consisted of evaluating two videotapes. There exist a large quantity of computer data files without associated video data and therefore were not analyzed. The extent to which the failure of the data collection system's internal clock (CMOS) affected the dataset is not known for this subset of the data.

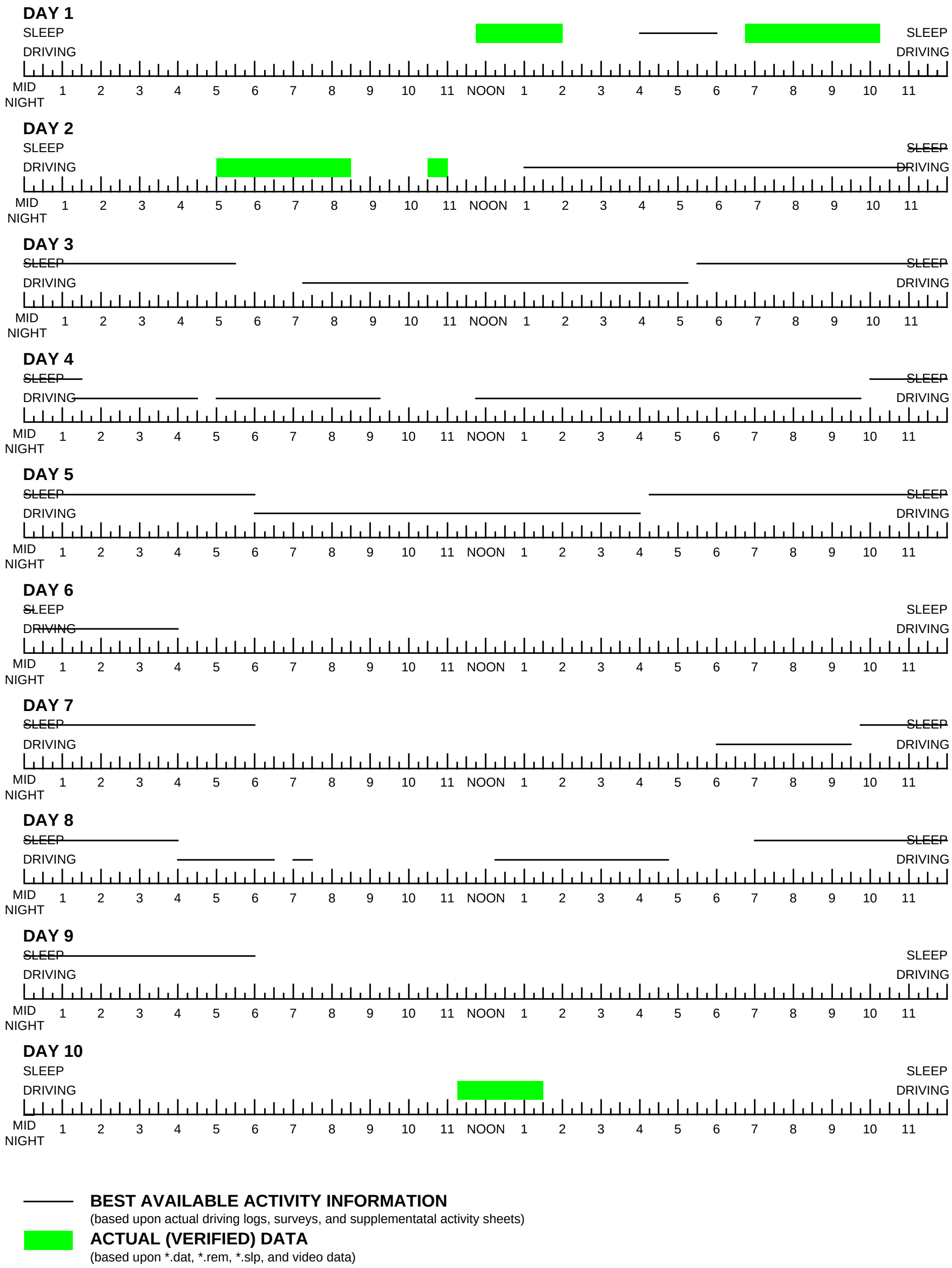
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	11	-	57	68	11
Lateral Acceleration	-	-	5	5	-
Longitudinal Acceleration	2	-	2	4	2
Time-To-Collision	79	7	57	143	86
PERCLOS	1	-	1	2	1
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	-	4	9	13	4
Incident Pushbutton	1	2	9	12	3
Timed Trigger	1	9	15	25	10
Karolinska Rating No Response	-	4	10	14	4
Lane Departure / Steering	1	-	2	3	1
Total	96	26	167	289	122

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #3.



DATA REPORT: PARTICIPANT #4

Overall Summary

Vehicle: Peterbilt 379
Trip Days: 6

Total Number of Epochs: 10

Total Number of Incidents: 33
- Critical Incidents 15 (45.5%)
- Non-Critical Incidents 1 (3.0%)
- Invalid Incidents 17 (51.5%)

Narrative Summary

Video reduction analysis consisted of evaluating portions of two of the four videotapes. A large amount of video data, for which there exist no associated computer data files, was not analyzed. Additionally, the first three epochs (4 incidents) in the computer data files did not have associated video data. The extent to which the failure of the data collection system's internal clock affected the dataset is not known for this subset of the data.

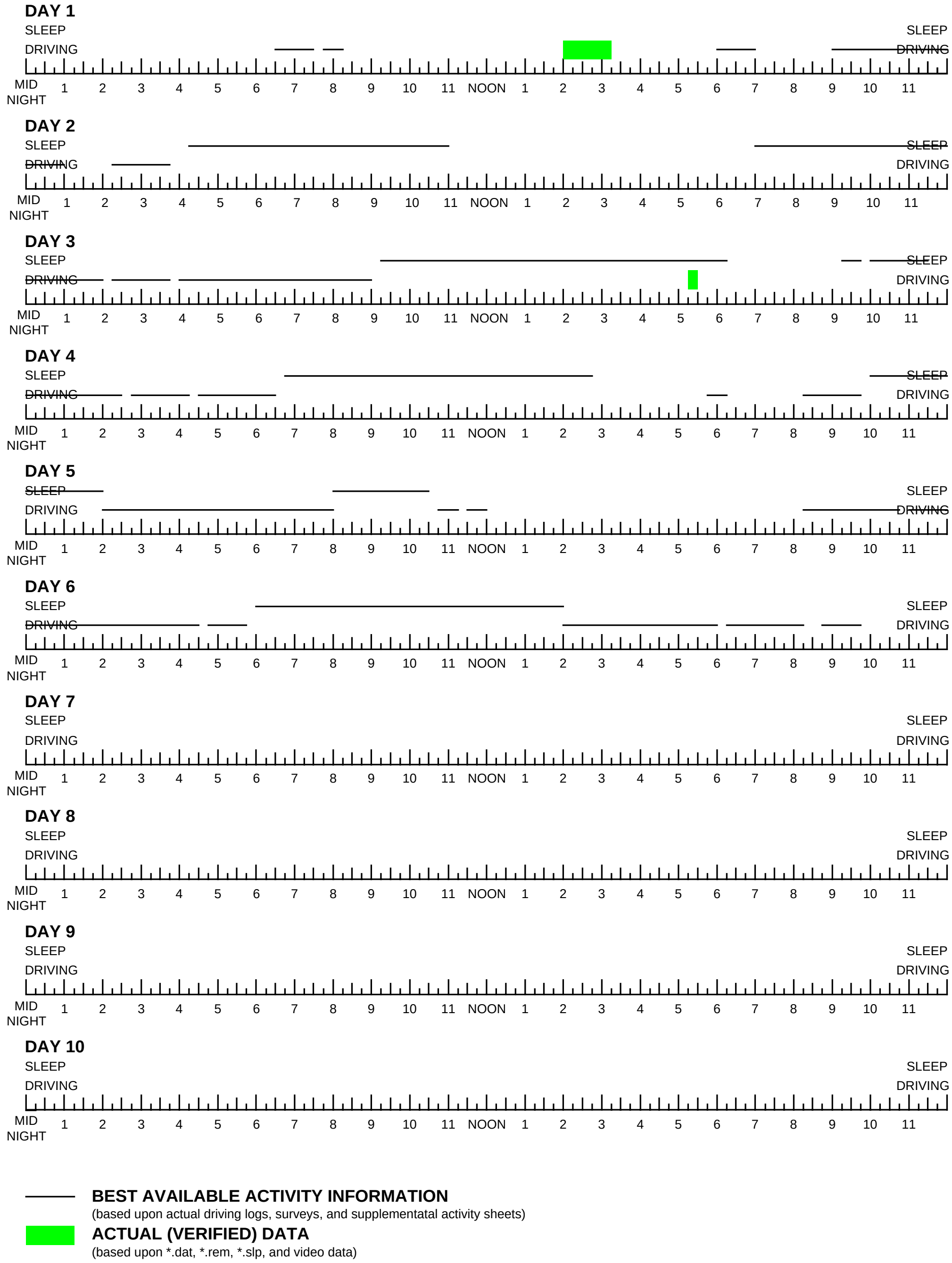
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	-	-	6	6	-
Lateral Acceleration	-	-	1	1	-
Longitudinal Acceleration	3	1	2	6	4
Time-To-Collision	10	-	6	16	10
PERCLOS	-	-	1	1	-
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	2	-	-	2	2
Incident Pushbutton	-	-	-	-	-
Timed Trigger	-	-	-	-	-
Karolinska Rating No Response	-	-	-	-	-
Lane Departure / Steering	-	1	1	1	-
Total	15	1	17	33	16

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #4.



DATA REPORT: PARTICIPANT #5

Overall Summary

Vehicle:	Peterbilt 379
Trip Days:	6
Total Number of Epochs:	21
Total Number of Incidents:	68
Critical Incidents	20 (29.4%)
Non-Critical Incidents	10 (14.7%)
Invalid Incidents	38 (55.9%)

Narrative Summary

Video reduction analysis consisted of evaluating one videotape. Several of the longitudinal and lateral acceleration triggers were found to be invalid as their occurrence coincided with the activation of the CB handset without any visible evidence that such triggers had otherwise occurred. Additional video, for which there exist no associated computer data files, was not analyzed. The extent to which the failure of the data collection system's internal clock affected the dataset is not known for this subset of the data.

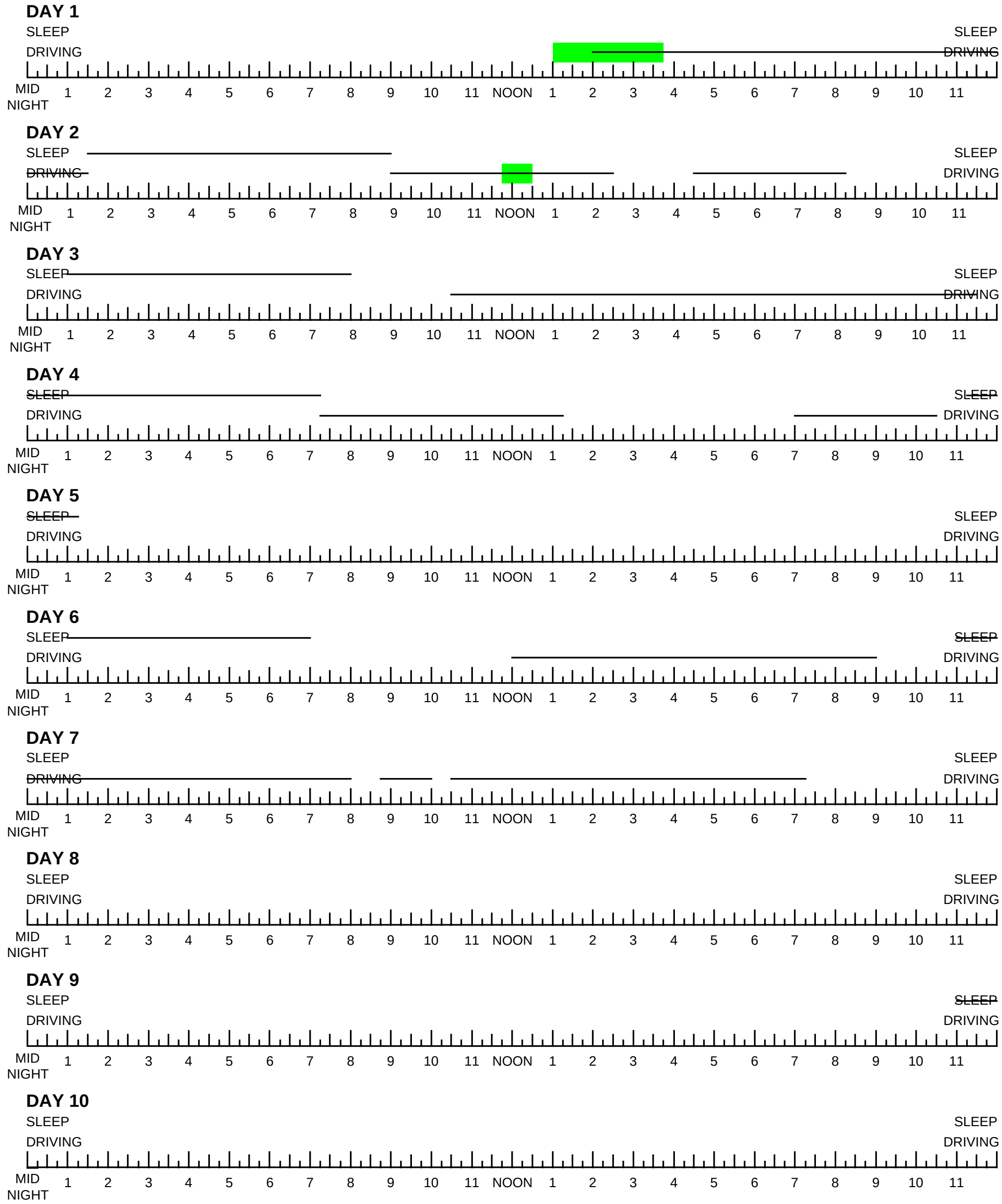
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	3	3	1	7	6
Lateral Acceleration	-	-	14	14	-
Longitudinal Acceleration	4	1	16	21	5
Time-To-Collision	13	1	1	15	14
PERCLOS	-	-	-	-	-
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	-	-	2	2	-
Incident Pushbutton	-	-	-	-	-
Timed Trigger	-	3	1	4	3
Karolinska Rating No Response	-	1	1	2	1
Lane Departure / Steering	-	1	2	3	1
Total	20	10	38	68	30

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #5.



BEST AVAILABLE ACTIVITY INFORMATION
(based upon actual driving logs, surveys, and supplementatal activity sheets)

ACTUAL (VERIFIED) DATA
(based upon *.dat, *.rem, *.slp, and video data)

DATA REPORT: PARTICIPANT #6

Overall Summary

Vehicle:	Peterbilt 379
Trip Days:	10
Total Number of Epochs:	94
Total Number of Incidents:	194
Critical Incidents	115 (59.3%)
Non-Critical Incidents	64 (33.0%)
Invalid Incidents	15 (7.7%)

Narrative Summary

Video reduction analysis consisted of evaluating two videotapes. The driver-side rear view mirror was non-functional for the duration of this trip. Several of the steering triggers were activated during low-velocity, urban driving. These were representative of normal driving, were designated as 'non-critical' incidents, and labeled 'urban' in the narrative description of the incident. Additional video, for which there exist no associated computer data files, was not analyzed. The extent to which the failure of the data collection system's internal clock affected the dataset is not known for this subset of the data. The data collection system's internal clock was unaffected for this subset of the data.

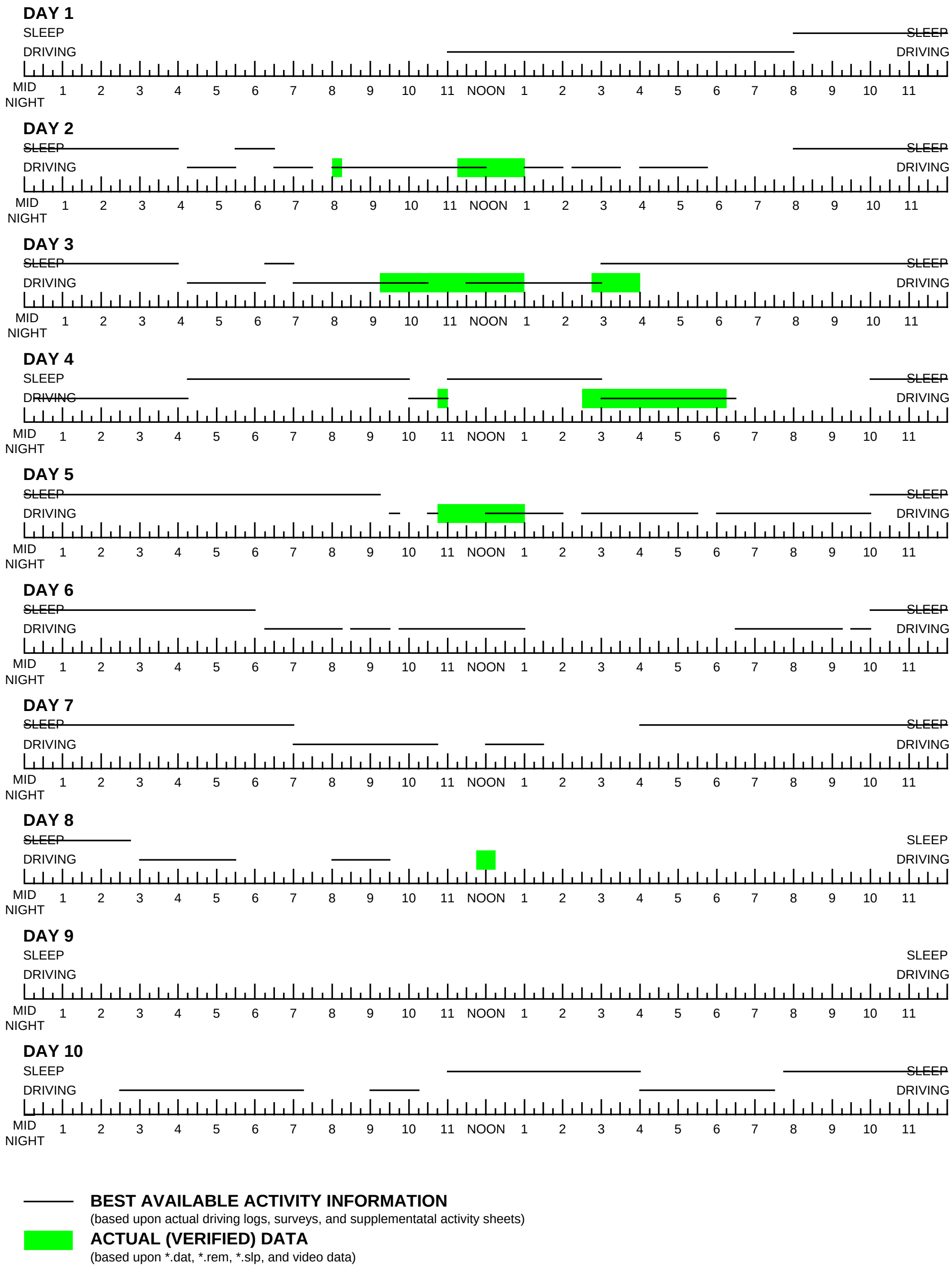
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	1	6	1	8	7
Lateral Acceleration	-	2	-	2	2
Longitudinal Acceleration	5	21	-	26	26
Time-To-Collision	104	17	9	130	121
PERCLOS	-	-	-	-	-
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	-	-	-	-	-
Incident Pushbutton	-	3	-	3	3
Timed Trigger	3	13	-	16	16
Karolinska Rating No Response	-	-	-	-	-
Lane Departure / Steering	2	2	5	9	4
Total	115	64	15	194	179

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #6.



DATA REPORT: PARTICIPANT #7

Overall Summary

Vehicle:	Volvo L4
Trip Days:	9
Total Number of Epochs:	113
Total Number of Incidents:	167
Critical Incidents	26 (15.6%)
Non-Critical Incidents	13 (7.8%)
Invalid Incidents	128 (76.6%)

Narrative Summary

Video reduction analysis consisted of evaluating one videotape. A large number of incidents triggered by the time-to-collision criterion were found to be invalid since the Vorad unit appeared to be detecting targets outside the lane of travel (*e.g.*, overhead signs, bridges). The video coverage associated with the incidents triggered by the Steering criterion could not be analyzed as the video coverage coincided with the occurrence of the criterion. That is, video coverage did not precede the occurrence of the trigger criterion; therefore, a descriptive assessment of the events leading up to the occurrence of the incident could not be made. A large number of epochs for which computer data existed had no corresponding video coverage; therefore, they were not analyzed. The Timed Trigger and Karolinska Rating No Response criteria appear to be associated with an excessive number of invalid triggers. This is due in large part to the system soliciting the driver while the driver is resting or out of the driver's seat, rather than a malfunction of the data collection system. The data collection system's internal clock was unaffected for this subset of the data.

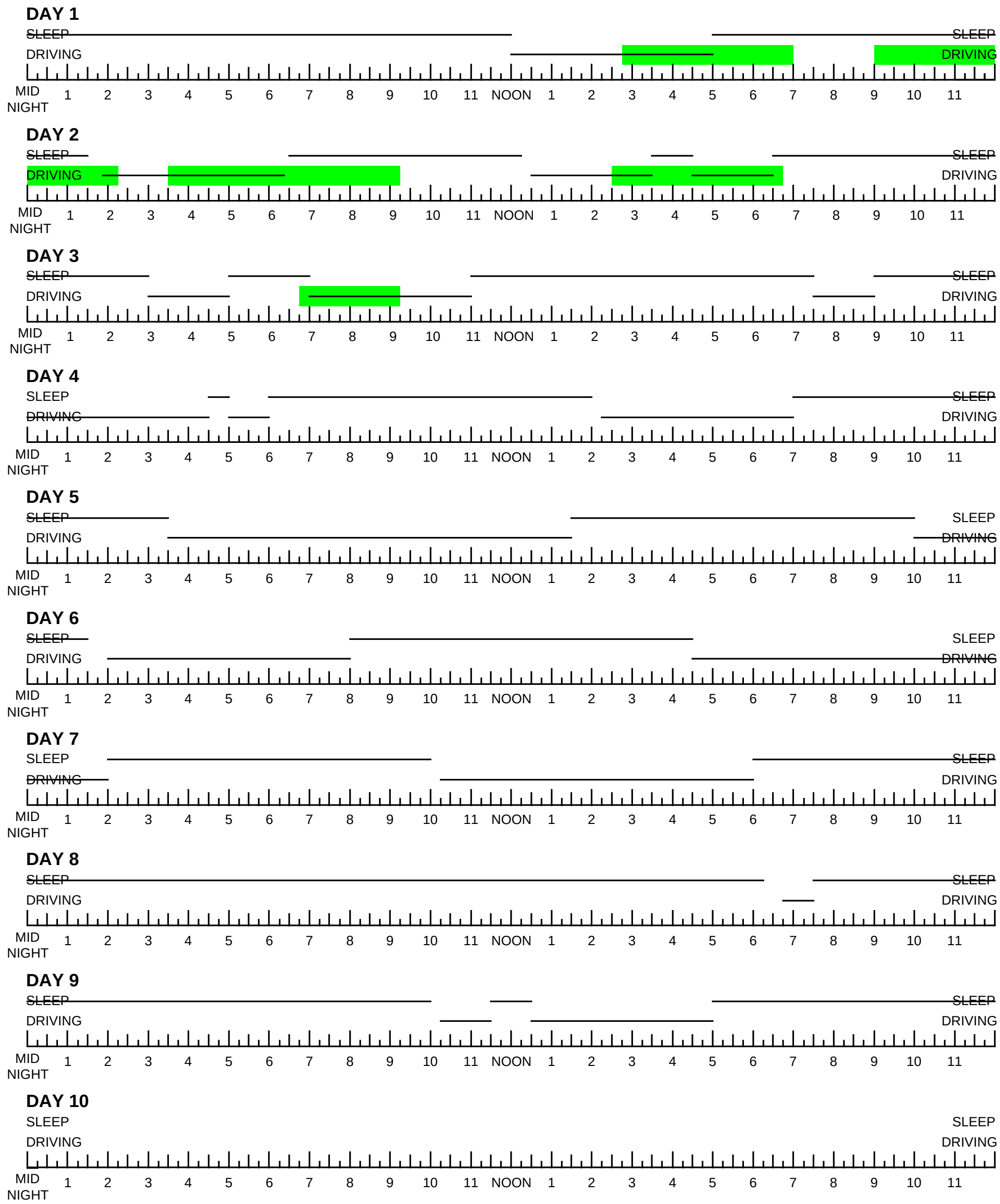
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	-	-	2	2	-
Lateral Acceleration	-	-	-	-	-
Longitudinal Acceleration	1	-	4	5	1
Time-To-Collision	12	2	67	81	14
PERCLOS	-	-	-	-	-
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	8	3	11	22	11
Incident Pushbutton	-	-	-	-	-
Timed Trigger	4	6	27	37	10
Karolinska Rating No Response	1	-	17	18	1
Lane Departure / Steering	-	2	-	2	2
Total	26	13	128	167	39

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #7.



BEST AVAILABLE ACTIVITY INFORMATION
(based upon actual driving logs, surveys, and supplementatal activity sheets)

ACTUAL (VERIFIED) DATA
(based upon *.dat, *.rem, *.slp, and video data)

DATA REPORT: PARTICIPANT #8

Overall Summary

Vehicle:	Peterbilt 379
Trip Days:	
Total Number of Epochs:	49
Total Number of Incidents:	109
Critical Incidents	52 (47.7%)
Non-Critical Incidents	10 (9.2%)
Invalid Incidents	47 (43.1%)

Narrative Summary

Video reduction analysis consisted of evaluating one videotape. The first four epochs (11 incidents) present on the tape and in the data set were eliminated from future analysis since they consisted of data generated by the VTTI driver during the delivery of the vehicle to the study participant. Several of the Steering triggered incidents were found to be invalid in that there was no visible evidence (*i.e.*, driver's hand motions, vehicle's position on the roadway) to suggest that the driver had generated a steering input. Several of the longitudinal and lateral acceleration triggers were found to be invalid as their occurrence coincided with the activation of the CB handset without any visible evidence that such triggers had otherwise occurred. Additional video, for which there exist no associated computer data files, was not analyzed. The extent to which the failure of the data collection system's internal clock affected the dataset is not known for this subset of the data.

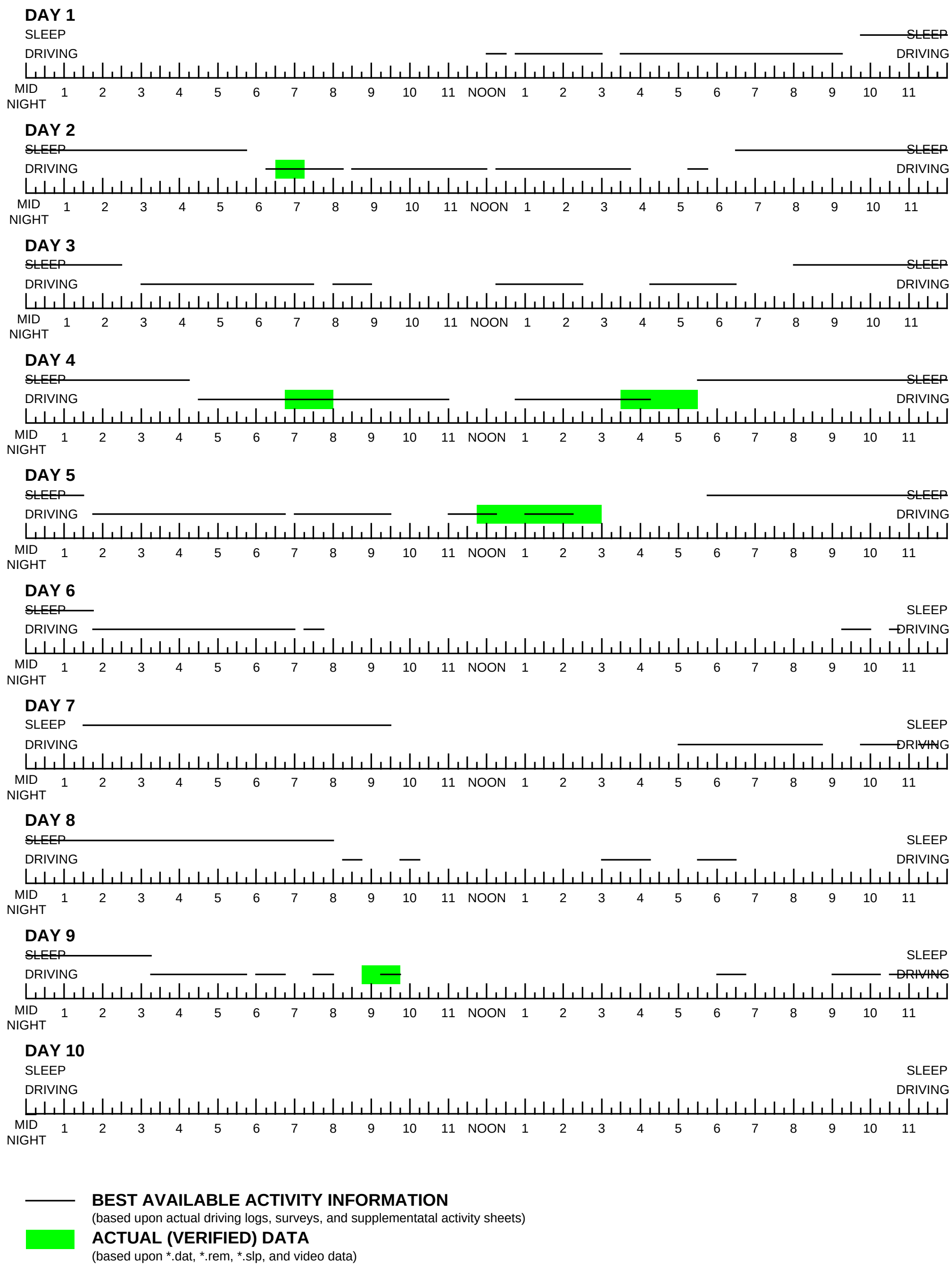
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	3	1	20	24	4
Lateral Acceleration	-	-	5	5	-
Longitudinal Acceleration	3	-	10	13	3
Time-To-Collision	46	1	3	50	47
PERCLOS	-	-	-	-	-
Karolinska Alertness Rating	-	-	-	-	-
Lane Departure	-	-	2	2	-
Incident Pushbutton	-	-	1	1	-
Timed Trigger	-	7	2	9	7
Karolinska Rating No Response	-	1	3	4	1
Lane Departure / Steering	-	-	1	1	0
Total	52	10	47	109	62

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #8.



DATA REPORT: PARTICIPANT #9

Overall Summary

Vehicle: Volvo L4
Trip Days:

Total Number of Epochs: 250

Total Number of Incidents: 447
Critical Incidents 220 (49.2%)
Non-Critical Incidents 76 (17.0%)
Invalid Incidents 151 (33.8%)

Narrative Summary

Video reduction analysis consisted of evaluating four videotapes. Data collection was somewhat sparse; however, did occur over the duration of the entire trip. No substantial data system failures.

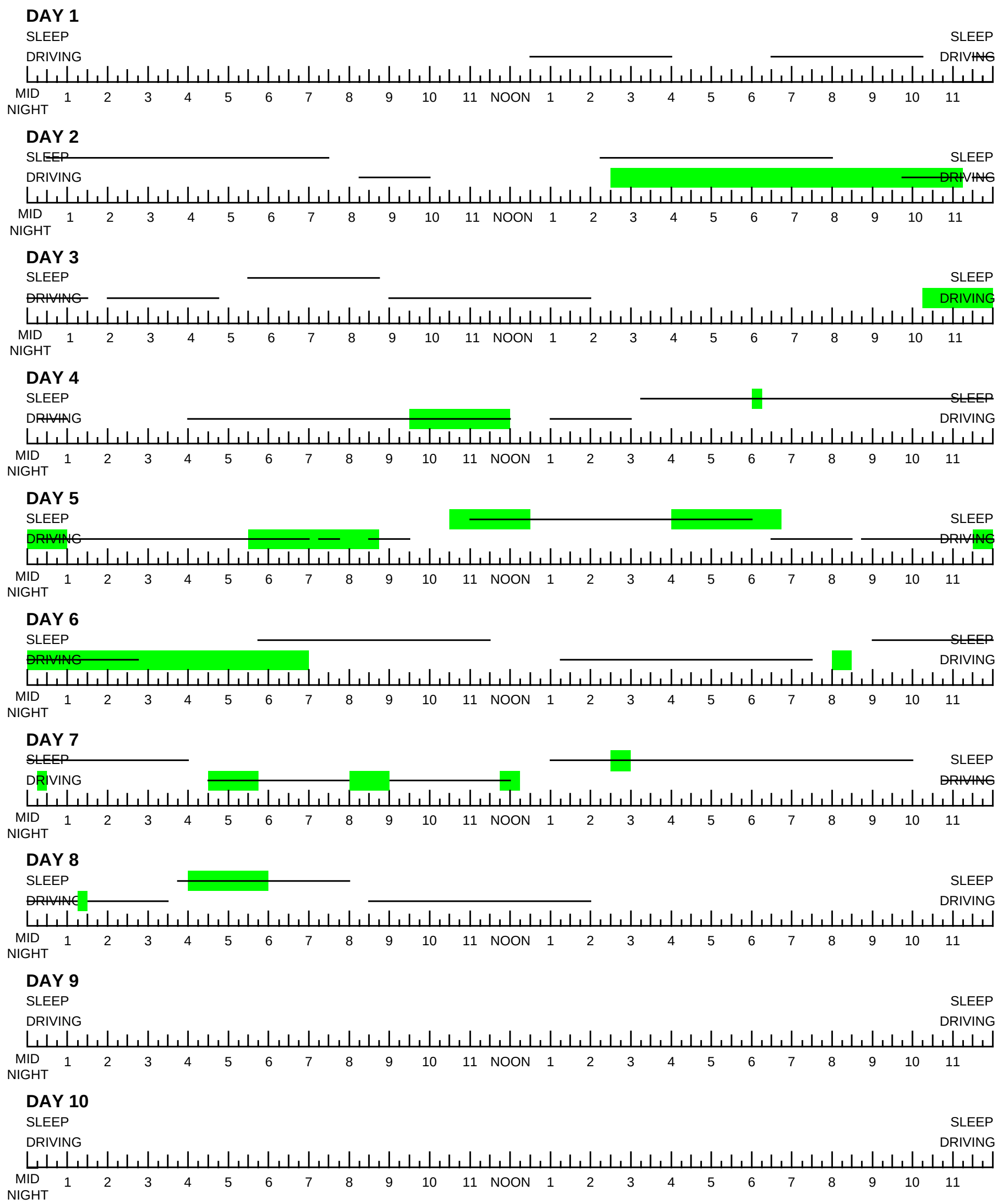
Trigger Summary

Trigger	Critical	Non-Critical	Invalid	Total[1]	Total Valid[2]
Steering	4	2	12	18	6
Lateral Acceleration	1	1	-	2	2
Longitudinal Acceleration	14	4	2	20	18
Time-To-Collision	163	14	107	284	177
PERCLOS	-	-	-	-	-
Karolinska Alertness Rating	-	-	1	1	-
Lane Departure	28	13	18	59	41
Incident Pushbutton	2	7	4	13	9
Timed Trigger	4	28	4	36	32
Karolinska Rating No Response	2	6	1	9	8
Lane Departure / Steering	2	1	2	5	3
Total	220	76	151	447	296

[1]Total = Critical + Non-Critical + Invalid Triggers
[2]Total Valid = Critical + Non-Critical Triggers

Collection Summary

Shown below is a graphical depiction of the operating schedule and corresponding data collected for Participant #9.



BEST AVAILABLE ACTIVITY INFORMATION
(based upon actual driving logs, surveys, and supplementatal activity sheets)

ACTUAL (VERIFIED) DATA
(based upon *.dat, *.rem, *.slp, and video data)

APPENDIX F

Data Handling and Analysis Software Code

F1: Visual Basic / Excel

F2: SAS System

SOFTWARE REPORT: VISUAL BASIC SCRIPTS

Summary

Each of the scripts contained within this section of the Appendix makes use of the Visual Basic for Applications scripting language and Microsoft Excel (v. 97 and 2000) spreadsheet software. They are presented in the order in which they were used to process the data. A complete flow diagram is presented in the body of the dissertation.

Format Project Data Files

Name: FormatProjectData

Required Files: Data Reduction Version 1 *.prj file
2_FPRJ_*XX*.xls – Formatted Project File is generated by this code

Purpose: To reformat the project summary files (*.prj) generated by the video reduction program.

Description: The data contained within the project summary files was in a format where each line represented one epoch of data. The first XX columns were comprised of epoch level data (*e.g.*, weather, road conditions). The next XX columns were comprised of incident level data (*e.g.*, cause, criticality) and repeated for each incident in the epoch. Subsequent to the incident data, the normalized Karolinska Sleep Data were stored; one observation per column.

This script transformed the data to a format where the first XX columns were comprised of epoch level data. The next XX columns were comprised of incident level data; however, instead of repeating these columns in the same row, each incident is represented in its own row. The normalized Karolinska Sleep values were stored in the next row, beginning in column XX.

Instructions: Import *.prj file into Excel (space delimited). Delete first row (contains text "Version 1). Insert file end marker ('1') in first three completely empty rows. Run Macro. Save file with 2_FPRJ_*XX*.xls naming convention

Code:

```
Public Sub FormatProjectFiles()
'Script breaks single line data from epoch into multiple rows
'1 is the end of file / last row marker

    'Application.ScreenUpdating = False

    Dim R1 As Range
    X = 1

    Do While Cells(X, 1).Value <> 1
        Set R1 = Range(Cells(X, 1), Cells(X, 1))
        R1.Select
        Set R2 = Range(Cells(X + 1, 1), Cells(X + 1, 1))
        R2.Select
        Selection.EntireRow.Insert
        R1.Select

        Y = 36
        Do While Cells(X, Y).Value <> "-1"
           Y = Y + 1
        Loop

        Set R3 = Range(Cells(X, 36), Cells(X, Y))
```

Code: *Format Project Data – continued*

```
            R3.Select

            Selection.Cut

            Set R4 = Range(Cells(X + 1, 1), Cells(X + 1, 1))
            R4.Select

            ActiveSheet.Paste

            Set R4 = Range(Cells(X + 1, 1), Cells(X + 1, 1))
            R4.Select

            R = X + 1
            C = 11

            Do While C > 10

            C = 1
            Do While Cells(R, C).Value <> "-1"
               C = C + 1
            Loop

            Set R5 = Range(Cells(R + 1, 1), Cells(R + 1, 1))
            R5.Select
            Selection.EntireRow.Insert
            R4.Select

            Set R6 = Range(Cells(R, 12), Cells(R, C))
            R6.Select
            Selection.Cut

            Set R5 = Range(Cells(R + 1, 1), Cells(R + 1, 1))
            R5.Select
            ActiveSheet.Paste

            Set R5 = Range(Cells(R + 1, 1), Cells(R + 1, 1))
            R5.Select

            R = R + 1
            Loop
            X = R + 1
        Loop

        Set R7 = Range(Cells(1, 1), Cells(1, 1))
        R7.Select

        X = 1

        Set R8 = Range(Cells(X, 1), Cells(X, 1))
        R8.Select

        Do While Cells(X, 1).Value <> 1
            If Cells(X, 1).Value > 1 Then
               For Count = 1 To 35
                  Selection.Insert Shift:=xlToRight
               Next Count
            ElseIf Cells(X, 1).Value = "0" Then
               For Count = 1 To 46
                  Selection.Insert Shift:=xlToRight
               Next Count
               X = X - 1
            ElseIf Cells(X, 1).Value = "-1" Then
               Selection.EntireRow.Delete
               X = X - 1
            End If
            X = X + 1
            Set R8 = Range(Cells(X, 1), Cells(X, 1))
            R8.Select
        Loop
        'Application.ScreenUpdating = True
    End Sub
```

Project Data Reports

Name: ProjectDataReports

Required Files: 2_FPRJ_*XX*.xls – Formatted Project Files
3_PDR_*XX*.xls – Project Data Report (file generated by this code)

Purpose: To create a formatted listing of each epoch and related incidents.

Description: This code employs the Formatted Project File data and generates a formatted table of each epoch and related incident. Epoch level data included in the table are Epoch ID, Sync Start, Sync Stop, and Filename. Incident level data within each table include Incident ID, Trigger, Sync Start, Sync Stop, and Status (Critical, Non-Critical, Invalid, No Video).

Instructions: Open the 2_FPRJ_*XX*.xls file. Open an empty file and name according to 3_PDR_*XX*.xls format, where XX matches the subject number of the Formatted Project File. Change code (Find and Replace) to reflect current subject ID. Run Macro. Save 3_PDR_*XX*.xls file.

Code:

```
Sub ProjectDataReports()

'   Copy information from the Formatted Data File to the New Project
Data Report.

    Windows("2_FPRJ_09.xls").Activate
    ActiveWindow.ScrollColumn = 1
    Columns("A:C").Select
    Selection.Copy
    Windows("3_PDR_09.xls").Activate
    Columns("A:C").Select
    ActiveSheet.Paste

    Windows("2_FPRJ_09.xls").Activate
    ActiveWindow.LargeScroll ToRight:=2
    Columns("AJ:AK").Select
    Selection.Copy
    Windows("3_PDR_09.xls").Activate
    Columns("H:I").Select
    ActiveSheet.Paste
    Columns("I:I").Select
    Application.CutCopyMode = False
    Selection.Cut
    Columns("G:G").Select
    ActiveSheet.Paste

    Windows("3_PDR_09.xls").Activate
    Range("G1:H1").Select
    Selection.Delete Shift:=xlUp

    Windows("2_FPRJ_09.xls").Activate
    Columns("AL:AL").Select
    Selection.Copy
    Windows("3_PDR_09.xls").Activate
    Columns("F:F").Select
    ActiveSheet.Paste
    Range("F1").Select
    Application.CutCopyMode = False
    Selection.Delete Shift:=xlUp

    Columns("G:G").Select
    Selection.Insert Shift:=xlToRight

    Windows("2_FPRJ_09.xls").Activate
    Range("AO:AO,AQ:AR").Select
```

Code: *Project Data File – continued*

```
Range("AQ1").Activate
Selection.Copy
Windows("3_PDR_09.xls").Activate
Columns("L:N").Select
ActiveSheet.Paste
Range("L1:N1").Select
Application.CutCopyMode = False
Selection.Delete Shift:=xlUp

'Identify / Decode Status

X = 1
Do While Cells(X, 1).Value <> 1
  If Cells(X, 13).Value = 1 Then
    Cells(X, 11).Value = "No Driver"
  ElseIf Cells(X, 14).Value = 1 Then
    Cells(X, 11).Value = "No Video"
  ElseIf Cells(X, 14).Value = "" Then
    Cells(X, 11).Value = ""
  Else: Select Case Cells(X, 12).Value
    Case 0
      Cells(X, 11).Value = "Non-Critical"
    Case 1
      Cells(X, 11).Value = "Critical"
    Case 2
      Cells(X, 11).Value = "Invalid"
    Case Else
      Cells(X, 11).Value = ""
  End Select
  End If
  X = X + 1
Loop

X = 1
ID_E = 1
ID_I = 1

'Identify / Decode Trigger Value

Do While Cells(X, 1).Value <> 1
  Select Case Cells(X, 6).Value
    Case 1
      Cells(X, 7).Value = "Steering"
    Case 2
      Cells(X, 7).Value = "Lateral Acceleration"
    Case 4
      Cells(X, 7).Value = "Longitudinal Acceleration"
    Case 8
      Cells(X, 7).Value = "Time To Collision"
    Case 16
      Cells(X, 7).Value = "PERCLOS"
    Case 32
      Cells(X, 7).Value = "Karolinska Rating"
    Case 64
      Cells(X, 7).Value = "Lane Departure"
    Case 128
      Cells(X, 7).Value = "Incident Pushbutton"
    Case 256
      Cells(X, 7).Value = "Timed Trigger"
    Case 512
      Cells(X, 7).Value = "Karolinska Rating No Response"
    Case 1024
      Cells(X, 7).Value = "Lane Departure / Steering"
    Case Else
      Cells(X, 7).Value = ""
  End Select
  If Cells(X, 2).Value <> "" Then
     Cells(X, 1).Value = ID_E
     ID_E = ID_E + 1
  End If
  If Cells(X, 6).Value <> "" Then
```

Code: *Project Data File – continued*

```
        Cells(X, 5).Value = ID_I
        Cells(X, 10).FormulaR1C1 = "=IF(RC[-1]>RC[-7],RC[-7]-RC[-
2],RC[-1]-RC[-2])"
        ID_I = ID_I + 1
      End If
      X = X + 1
    Loop

    Cells(1, 1).Value = ""

    X = 1
    Do While Cells(X, 1).Value <> 1
      Set R1 = Range(Cells(X, 1), Cells(X, 10))
      R1.Select
      If Cells(X, 9).Value = "" Then
         Selection.EntireRow.Delete
         X = X + 2
      Else
         X = X + 1
      End If
    Loop

    'Format Report

    X = 1
    Do While Cells(X, 1).Value <> 1
      Set R1 = Range(Cells(X, 1), Cells(X, 14))
      R1.Select
      If Cells(X, 9).Value = "" Then
         R1.Activate
         Selection.Borders(xlDiagonalDown).LineStyle = xlNone
         Selection.Borders(xlDiagonalUp).LineStyle = xlNone
         Selection.Borders(xlEdgeLeft).LineStyle = xlNone
         Selection.Borders(xlEdgeTop).LineStyle = xlNone
         With Selection.Borders(xlEdgeBottom)
           .LineStyle = xlContinuous
           .Weight = xlThin
           .ColorIndex = xlAutomatic
         End With
         Selection.Borders(xlEdgeRight).LineStyle = xlNone
         Selection.Borders(xlInsideVertical).LineStyle = xlNone
         R1.Select
       End If
         X = X + 1
    Loop

    X = 1

    Do While Cells(X, 1).Value <> 1
       Set R1 = Range(Cells(X, 3), Cells(X, 3))
       R1.Select
       Selection.Copy
       Do
          Set R2 = Range(Cells(X, 3), Cells(X, 3))
          R2.Select
          If Cells(X, 5).Value <> "" Then ActiveSheet.Paste
          X = X + 1
       Loop Until Cells(X, 1).Value <> ""
    Loop

    Cells(1, 1).Value = 1

    Application.CutCopyMode = False
    Rows("1:2").Select
    Selection.Insert Shift:=xlDown
    Columns("A:A").Select
    Selection.ColumnWidth = 4
    With Selection
        .HorizontalAlignment = xlGeneral
        .VerticalAlignment = xlBottom
        .WrapText = False
```

Code: *Project Data File – continued*

```
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    Columns("B:C").Select
    Selection.ColumnWidth = 8
    With Selection
        .HorizontalAlignment = xlGeneral
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    Columns("D:D").Select
    Selection.ColumnWidth = 12
    Columns("E:E").Select
    Selection.ColumnWidth = 4
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    Columns("F:F").Select
    Selection.EntireColumn.Hidden = True
    Columns("G:G").Select
    Selection.ColumnWidth = 22
    Columns("H:I").Select
    Selection.ColumnWidth = 8
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    Columns("J:J").Select
    Selection.EntireColumn.Hidden = True
    Columns("K:K").Select
    Selection.ColumnWidth = 10
    Columns("L:N").Select
    Selection.EntireColumn.Hidden = True
    Cells.Select
    With Selection.Font
        .Name = "Arial"
        .Size = 8
        .Strikethrough = False
        .Superscript = False
        .Subscript = False
        .OutlineFont = False
        .Shadow = False
```

Code: *Project Data File – continued*

```
        .Underline = xlUnderlineStyleNone
        .ColorIndex = xlAutomatic
    End With

    Range("A2").Select
    ActiveCell.FormulaR1C1 = "ID"
    Range("B2").Select
    ActiveCell.FormulaR1C1 = "Start"
    Range("C2").Select
    ActiveCell.FormulaR1C1 = "End"
    Range("D2").Select
    ActiveCell.FormulaR1C1 = "Filename"
    Range("E2").Select
    ActiveCell.FormulaR1C1 = "ID"
    Range("G2").Select
    ActiveCell.FormulaR1C1 = "Trigger"
    Range("H2").Select
    ActiveCell.FormulaR1C1 = "Start"
    Range("I2").Select
    ActiveCell.FormulaR1C1 = "End"
    Range("K2").Select
    ActiveCell.FormulaR1C1 = "Status"
    Columns("E:E").Select
    Selection.Insert Shift:=xlToRight
    Selection.ColumnWidth = 0.5
    Range("A2:L2").Select
    Selection.Font.Bold = True
    With Selection
        .HorizontalAlignment = xlGeneral
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .ShrinkToFit = False
        .MergeCells = False
    End With
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    Selection.Borders(xlEdgeTop).LineStyle = xlNone
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .Weight = xlMedium
        .ColorIndex = xlAutomatic
    End With
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Range("A2:D2").Select
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    With Selection.Borders(xlEdgeTop)
        .LineStyle = xlContinuous
        .Weight = xlThin
        .ColorIndex = xlAutomatic
    End With
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .Weight = xlMedium
        .ColorIndex = xlAutomatic
    End With
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Range("F2:L2").Select
```

Code: *Project Data File – continued*

```
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    With Selection.Borders(xlEdgeTop)
        .LineStyle = xlContinuous
        .Weight = xlThin
        .ColorIndex = xlAutomatic
    End With
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .Weight = xlMedium
        .ColorIndex = xlAutomatic
    End With
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Range("A1:L1").Select
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    With Selection.Borders(xlEdgeTop)
        .LineStyle = xlContinuous
        .Weight = xlMedium
        .ColorIndex = xlAutomatic
    End With
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone

    ActiveSheet.Shapes.AddLabel(msoTextOrientationHorizontal, 52.5, 
38.25, 0# _
        , 0#).Select
    Selection.ShapeRange(1).TextFrame.AutoSize = msoTrue
    Selection.Characters.Text = "EPOCH"
    With Selection.Characters(Start:=1, Length:=5).Font
        .Name = "Arial"
        .FontStyle = "Bold"
        .Size = 8
        .Strikethrough = False
        .Superscript = False
        .Subscript = False
        .OutlineFont = False
        .Shadow = False
        .Underline = xlUnderlineStyleNone
        .ColorIndex = xlAutomatic
    End With
    Selection.ShapeRange.IncrementLeft -51.75
    Selection.ShapeRange.IncrementTop -37.5
    Selection.ShapeRange.ScaleWidth 5.55, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 0.84, msoFalse, msoScaleFromTopLeft
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlTop
        .Orientation = xlHorizontal
        .AutoSize = False
    End With
    ActiveSheet.Shapes.AddLabel(msoTextOrientationHorizontal, 221.25, 
89.25, 0# _
        , 0#).Select
    Selection.ShapeRange(1).TextFrame.AutoSize = msoTrue
    Selection.Characters.Text = "INCIDENT"
    With Selection.Characters(Start:=1, Length:=8).Font
        .Name = "Arial"
        .FontStyle = "Bold"
        .Size = 8
        .Strikethrough = False
        .Superscript = False
        .Subscript = False
        .OutlineFont = False
        .Shadow = False
        .Underline = xlUnderlineStyleNone
        .ColorIndex = xlAutomatic
    End With
```

Code: *Project Data File – continued*

```
    Selection.ShapeRange.IncrementLeft -32.25
    Selection.ShapeRange.IncrementTop -88.5
    Selection.ShapeRange.ScaleWidth 6.95, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 0.79, msoFalse, msoScaleFromTopLeft
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlTop
        .Orientation = xlHorizontal
        .AutoSize = False
    End With

    X = 4
    Do While Cells(X, 1).Value <> "1"
      Set R1 = Range(Cells(X, 3), Cells(X, 3))
      R1.Select
      If Cells(X, 2).Value = "" Then
         Selection.Font.ColorIndex = 2
      End If
      X = X + 1
    Loop

    Range("A1").Select

End Sub
```

Intermediate Mannerisms Macro

Name: Mannerisms

Required Files: 2_IRFPRJ_*XX*.xls – Formatted Project Files
4_IMM_*XX*.xls – Intermediate Mannerisms Macro

Purpose: This script generates a listing of all of the ORD measurement times for each epoch from which the schedule of the measurement of mannerisms will be derived.

Description: Approximately half way through analyzing the data for the first time, it was decided that the measurement of driver mannerisms should coincide with the measurement of Observer Ratings of Drowsiness. This script generates a listing of all of the ORD measurement times for each epoch. This file is then incorporated into a Visual Basic / Excel GUI environment used by the data analyst to record driver mannerisms.

Instructions: Open the 2_FPRJ_*XX*.xls file. Add 'End' in Column B at the first empty row. Open an empty file and name according to 4_IMM_*XX*.xls format, where *XX* matches the subject number of the Formatted Project File. Change code (Find and Replace) to reflect current subject ID. Run Macro. Save 4_IMM_*XX*.xls file.

Code:

```
Sub Mannerisms()
'
' Macro1 Macro
' Macro recorded 6/27/00 by Steven M. Belz
'

'
FPRJ = "2_FPRJ_09.xls"
IMM = "4_IMM_09.xls"

    Dim ORDArray(100) As Single

    Windows(FPRJ).Activate
    Range("A1").Select

    RowOrig = 1
    RowNew = 1
    Epoch = 0
    Participant = 8
    ContCount = 0

    Do While Cells(RowOrig, 1).Value <> 1
        EPBeg = Cells(RowOrig, 2).Value
        EPEnd = Cells(RowOrig, 3).Value
        RowOrig = RowOrig + 1
        Do While Cells(RowOrig, 36).Value <> ""
           RowOrig = RowOrig + 1
        Loop
        C = 48
        Do While Cells(RowOrig, C) <> ""
           ORDArray(C - 47) = Cells(RowOrig, C).Value
           C = C + 1
        Loop
        NumORD = C - 48
        Windows(IMM).Activate
        If EPBeg <> "" Then
           Epoch = Epoch + 1
        End If
        For Counter = 1 To NumORD
           If Counter = 1 Then
              ORDBeg = EPBeg
           Else
              ORDBeg = ORDEnd
           End If
```

Code: *Mannerisms – continued*

```
                ORDMid = ORDBeg + 300
                ORDEnd = ORDBeg + 600

                If ORDBeg > EPEnd Then
                   ORDMid = EPEnd
                End If

                If ORDMid > EPEnd Then
                   ORDMid = EPEnd
                End If

                If ORDEnd > EPEnd Then
                   ORDEnd = EPEnd
                End If

                ContCount = ContCount + 1

                Cells(RowNew + Counter, 1).Value = ContCount
                Cells(RowNew + Counter, 2).Value = Counter
                Cells(RowNew + Counter, 3).Value = Participant
                Cells(RowNew + Counter, 4).Value = Epoch
                Cells(RowNew + Counter, 5).Value = EPBeg
                Cells(RowNew + Counter, 6).Value = EPEnd
                Cells(RowNew + Counter, 7).Value = ORDBeg
                Cells(RowNew + Counter, 8).Value = ORDMid
                Cells(RowNew + Counter, 9).Value = ORDEnd
                Cells(RowNew + Counter, 10).Value = ORDArray(Counter)

             Next Counter
             RowNew = RowNew + Counter
             Windows(FPRJ).Activate
         Loop

         Windows(IMM).Activate

         Cells(RowNew + 1, 1).Value = "End"
         For X = RowNew To 1 Step -1
            If Cells(X, 1).Value = "" Then
               Set R1 = Range(Cells(X, 1), Cells(X, 1))
               R1.Select
               Selection.EntireRow.Delete
            End If
         Next X

     End Sub
```

Remove Invalid Epochs from Formatted Project Files

Name: 5_MNC_*XX*.xls
5_Man_*XX*.xls

Required Files: 4_IMM_*XX*.xls – Intermediate Mannerisms Macro

Purpose: To analyze Mannerisms on a schedule coinciding with Observer Ratings of Drowsiness.

Description: This is a Visual Basic / Excel GUI environment used to reanalyze driver Mannerisms on the same schedule as the Observer Ratings of Drowsiness.

Instructions: Open generic 5_MNC_*XX*.xls file. Open 4_IMM_*XX*.xls file. Copy 4_IMM_XX.xls file into 5_MNC_XX.xls file (through END statement). Click the 'Do Not Touch This Button' Button. Save as 5_MNC_*XX*.xls subject specific file. Analyze mannerisms. Save as 5_Man_*XX*.xls file.

Code: Excel Based GUI Software

Remove Invalid Epochs from Formatted Project Files

Name: RemoveInvalid

Required Files: 2_FPRJ_*XX*.xls – Formatted Project Files
7_IRFPRJ_*XX*.xls – Invalid Removed Project Files

Purpose: To remove those epochs containing ONLY invalid incidents. NOTE: Any epoch with at least one valid / non-critical incident will be retained.

Description: This script searches the Formatted Project File and removes any epoch where all of the incidents within that epoch are invalid.

Instructions: Open Formatted Project File. Run Macro. Save Resulting File according to 7_IRFPRJ_*XX*.xls convention.

Code:

```
Sub RemoveInvalid()

Row = 1

Do While Cells(Row, 2).Value <> 1
   Set R1 = Range(Cells(Row, 1), Cells(Row, 1))
   R1.Select
   If Cells(Row, 47).Value <> "" Then
      Selection.EntireRow.Delete
   End If
   Row = Row + 1
Loop

Row = 1
Do While Cells(Row, 2).Value <> 1
   Keeper = 0
   If Cells(Row, 3).Value <> "" Then
      Z = 1
      NRow = Row
      Row = Row + 1
      Do While Cells(Row, 41).Value <> ""
         If (Cells(Row, 41).Value <> 2) Then
            Keeper = 1
         End If
         'Cells(Row, 1).Value = Keeper
         Row = Row + 1
         Z = Z + 1
      Loop
    End If
    Set Position = Range(Cells(Row, 1), Cells(Row, 1))
    Set Epoch = Range(Cells(NRow, 1), Cells(NRow, 1))
    Epoch.Select
    'Epoch.Value = Keeper
    If Keeper = 0 Then
       For Y = 1 To Z
          Selection.EntireRow.Delete
       Next Y
       Row = NRow
    End If
    Set Position = Range(Cells(Row, 1), Cells(Row, 1))
    Position.Select
Loop

Set Home = Range(Cells(1, 1), Cells(1, 1))
Home.Select
```

Project Data Reports – Invalid Removed

Name: InvRemProjectDataReports

Required Files: 7_IRFPRJ_*XX*.xls – Invalid Removed Formatted Project Files
8_IRPDR_*XX*.xls – Invalid Removed Project Data Report (file generated by this code)

Purpose: To create a formatted listing of each epoch and related incidents.

Description: This code employs the Invalid Removed Formatted Project File data and generates a formatted table of each epoch and related incident. Epoch level data included in the table are Epoch ID, Sync Start, Sync Stop, and Filename. Incident level data within each table include Incident ID, Trigger, Sync Start, Sync Stop, and Status (Critical, Non-Critical, Invalid, No Video).

Instructions: Open the 7_IRFPRJ_*XX*.xls file. Open an empty file and name according to 8_IRPDR_*XX*.xls format, where XX matches the subject number of the Formatted Project File. Change code (Find and Replace) to reflect current subject ID. Run Macro. Save 8_IRPDR_*XX*.xls file.

Code: See code for ProjectDataReports

Rewrite Concatenated DAT File – Invalid Removed

Name: ReWrite

Required Files: 7_IRFPRJ_*XX*.xls – Invalid Removed Formatted Project Data File
Mega-C_*XX*.DAT – Concatenated DAT File (Comma Delimited)
MegNew_*XX*.DAT – Concatenated DAT File, Invalid Removed (Comma Delimited, file generated by this code)
Time_*XX*.DAT – Start and Stop Times of Each Epoch (file generated by this code)

Purpose: The purpose of this script is twofold. The first purpose is to remove any invalid data from the Mega-C_*XX*.DAT data file – this will be important later when this file is broken into epoch level DAT files. The second purpose is to generate a file containing all of the start and stop times for each epoch. This will be further processed in order to determine the elapsed time between two epochs and will aid generating the participant reports (assessing data completeness).

Description: This code employs the Invalid Removed Formatted Project File data and generates a formatted table of each epoch and related incident. Epoch level data included in the table are Epoch ID, Sync Start, Sync Stop, and Filename. Incident level data within each table include Incident ID, Trigger, Sync Start, Sync Stop, and Status (Critical, Non-Critical, Invalid, No Video).

Instructions: Open the 7_IRFPRJ_*XX*.xls file. Open an empty file and name according to 8_IRPDR_*XX*.xls format, where XX matches the subject number of the Formatted Project File. Change code (Find and Replace) to reflect current subject ID. Run Macro. Save 8_IRPDR_*XX*.xls file.

Code:

```
Sub ReWrite()

Dim X As Long


    Windows("7_IRFPRJ_09.xls").Activate

    Columns("B:C").Select
    Selection.Copy
    Sheets.Add
    ActiveSheet.Paste

    X = 1

    Do While Cells(X, 1).Value <> "End"
       Set R1 = Range(Cells(X, 1), Cells(X, 1))
       R1.Select

       If Cells(X, 1).Value = "" Then
          Selection.EntireRow.Delete
       Else: X = X + 1
       End If

    Loop

    X = 1
    i = 1

    Set Home = Range(Cells(1, 1), Cells(1, 1))
    Home.Select

    Open "C:\Mega\Mega-C_09.Dat" For Input As #1
    Open "C:\Mega\MegNew_09.Dat" For Output As #2
    Open "C:\Mega\Time_09.Dat" For Output As #3
```

Code: *Rewrite Concatenated DAT File – Invalid Removed – continued*

```
    Input #1, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13,
C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26
    Input #1, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13,
C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26

    While Not EOF(1)

        EPBeg = Cells(X, 1).Value
        EPEnd = Cells(X, 2).Value

        Do While (C1 < EPBeg) And (Not EOF(1))
           Input #1, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12,
C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26
           Debug.Print C1
        Loop

        If C1 = EPBeg Then
           Print #3, "Epoch: " & i
           Write #3, C1, C2
           i = i + 1
        End If

        Do While C1 < EPEnd
           Input #1, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12,
C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26
           Write #2, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12,
C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26
        Loop

        Write #3, C1, C2
        Print #3, " "

        X = X + 1
    Wend

    Close #1
    Close #2
    Close #3

    Sheets("Sheet1").Select
    ActiveWindow.SelectedSheets.Delete

    Set Home = Range(Cells(1, 1), Cells(1, 1))
    Home.Select


End Sub
```

Time / Date Splitter

Name: InvRemProjectDataReports

Required Files: Time_*XX*.DAT **-** Start and Stop Times of Each Epoch

Purpose: To determine the elapsed time between each epoch in order to ascertain the time period during which the data collection system was active.

Description: This code employs the Time_*XX*.DAT data file and is comprised of a variety of string calculation functions to change the Time and Date format from the DAT file from a string to time and date formats that can be used in time-based calculations. This macro also generates a formatted report of the elapsed time between epochs. Differences greater than seventy-five minutes are indicated in bold and are indicative of a system shut down. Several consecutive differences ranging from 45 to 75 minutes is likely indicative of a driver sleeping (only timed trigger is being activated).

Instructions: Open the Time_*XX*.DAT file. Run Macro.

Code:

```
Sub TimeDateSplit()

    Dim sOrigStr As String      'Date/Time String from *.DAT Files -
                                '[MM/DD/YYYY](HH:MM:SS.SS)
    Dim sTime As String         'Time substring within sOrigStr
    Dim sDate As String         'Date substring within sOrigStr
    Dim sTotal As String        'Concatenation of sTime and sTotal

    Dim iRow As Integer     'Location within Excel Spreadsheet
    Dim iOSLen As Integer   'sOrigStr Length
    Dim iTimeBeg As Integer 'sTime Substring Beginning Location
    Dim iTimeLen As Integer 'sTime Substring Length
    Dim iDateLen As Integer 'sDate Substring Length


    iTimeBeg = 0
    iDateLen = 0
    iRow = 0

    LastRow = Range("A65000").End(xlUp).Row

    For iRow = 1 To LastRow
        If Cells(iRow, 2).Value <> "" Then

            iTimeBeg = 0
            iDateLen = 0

            Set R1 = Range(Cells(iRow, 2), Cells(iRow, 2))
            R1.Select

            sOrigStr = Selection.Value

            RTrim (sOrigStr)
            LTrim (sOrigStr)

            Do
                iDateLen = iDateLen + 1
            Loop Until Mid(sOrigStr, iDateLen, 1) = "]"

            iTimeBeg = iDateLen + 2

            iOSLen = Len(sOrigStr)
            iEnd = iOSLen - iTimeBeg - 1

            sDate = Mid(sOrigStr, 2, iDateLen - 2)
            sTime = Mid(sOrigStr, iTimeBeg, iEnd)
            sTotal = sDate & " " & sTime
```

Code: *Time / Date Splitter – continued*

```
            Set R2 = Range(Cells(iRow, 4), Cells(iRow, 4))
            R2.Select
            Selection.NumberFormat = "mm/dd/yyyy hh:mm AM/PM"
            Selection.Value = (sTotal)

        End If
    Next iRow

    For iRow = 6 To LastRow Step 4
        Set R1 = Range(Cells(iRow, 6), Cells(iRow, 6))
        R1.Select
        Selection.NumberFormat = "[h]:mm:ss"
        Selection.Value = Cells(iRow, 4) - Cells(iRow - 4, 4)
        If Selection.Value > 0.052083333 Then
           Selection.Font.ColorIndex = 3
           Selection.Font.FontStyle = "Bold"
        End If
    Next iRow

    Set Home = Range(Cells(1, 1), Cells(1, 1))
    Home.Select

    Selection.EntireRow.Insert
    Selection.EntireRow.Insert
    Range("B1").Select
    ActiveCell.FormulaR1C1 = "DAT File Time Stamp"
    Range("D1").Select
    ActiveCell.FormulaR1C1 = "Epoch Start/Stop Times"
    Range("F1").Select
    ActiveCell.FormulaR1C1 = "Between Epoch Interval"
    Range(Cells(1, 1), Cells(1, 6)).Select
    Selection.Font.Bold = True
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    Selection.Borders(xlEdgeTop).LineStyle = xlNone
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .Weight = xlMedium
        .ColorIndex = xlAutomatic
    End With
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Columns("B:B").EntireColumn.AutoFit
    Columns("D:D").EntireColumn.AutoFit
    Columns("F:F").EntireColumn.AutoFit
    Columns("E:E").Select
    Selection.ColumnWidth = 2
    Columns("C:C").Select
    Selection.ColumnWidth = 2
    Columns("F:F").Select
    With Selection
        .HorizontalAlignment = xlCenter
        .VerticalAlignment = xlBottom
        .WrapText = False
        .Orientation = 0
        .AddIndent = False
        .ShrinkToFit = False
        .MergeCells = False
    End With
    Range("A1").Select

End Sub
```

Generate Flat Project Data Report

Name: GenerateFlatPDR

Required Files: 8_IRPDR_*XX*.xls – Invalid Removed PDR File

Purpose: To generate a 'flat' PDR file without formatting.

Description: This macro copies the information from the invalid removed project data file to the current sheet in Flat.xls and removes all empty rows and formatting.

Instructions: Open Flat.xls. Change participant number. Run macro. Save as PDR*XX*.csv

Code:

```
Sub GenerateFlatPDR()

Windows("8_IRPDR_03.xls").Activate
Subject = 3

iLastRow = Range("A65000").End(xlUp).Row

Set R1 = Range(Cells(3, 1), Cells(iLastRow, 15))
R1.Select

Selection.Copy

Windows("Flat.xls").Activate

Range("A1").Select
Selection.PasteSpecial Paste:=xlFormulas, Operation:=xlNone,
SkipBlanks:= _
  False, Transpose:=False

For iRow = 1 To (iLastRow - 2)
    Set R2 = Range(Cells(iRow, 6), Cells(iRow, 6))
    R2.Select
    If Cells(iRow, 6) = "" Then
        Selection.EntireRow.Delete
    End If
Next iRow

iLastRow = Range("A65000").End(xlUp).Row

For iRow = 1 To (iLastRow)
    If Cells(iRow, 1) = "" Then
        Cells(iRow, 1).Value = Cells(iRow - 1, 1).Value
        Cells(iRow, 2).Value = Cells(iRow - 1, 2).Value
        Cells(iRow, 3).Value = Cells(iRow - 1, 3).Value
        Cells(iRow, 4).Value = Cells(iRow - 1, 4).Value
    End If
Next iRow

Columns("E:E").Select
Selection.Delete Shift:=xlToLeft

Columns("A:A").Select
Selection.Insert Shift:=xlToRight

Set Home = Range(Cells(1, 1), Cells(1, 1))
Home.Select

For iRow = 1 To iLastRow
    Cells(iRow, 1).Value = Subject
Next iRow

End Sub
```

Self Assessment of Fatigue Dataset

Name: AlertSubSet.XLS

Required Files: PDR*XX*.csv – Comma-delimited Project Data Report (from IRPDR File)
MegNew_*XX*.dat – Comma-delimited Data File with Invalid Epochs Removed
Man*XX*.csv – Comma-delimited Mannerisms Data File
AlertSet.dat – Comma-delimited file containing observer rating of drowsiness and Karolinska data before and after occurrence of timed-trigger event (File created by this code).

Purpose: To generate AlertSet.dat, a comma-delimited file containing observer rating of drowsiness and Karolinska data before and after occurrence of timed-trigger event.

Description: This code functions as a query to build a data subset of information from the above files concerning data that were recorded immediately before and subsequent to the occurrence of a timed-trigger event.

Instructions: Open AlertSubset.XLS and rename participant variable to coincide with current participant. Run AlertSubSet.

Code:

```
Sub AlertSubSet()

Dim iRow As Integer
Dim Manners(1 To 25, 0 To 10) As Variant


Open "C:\Data\PDR5.csv" For Input As #1
Open "C:\Data\MegNew_05.dat" For Input As #2
Open "C:\Data\Man5.csv" For Input As #3
Open "C:\Data\AlertSet.dat" For Output As #4

iRow = 1


Do While Not EOF(1)

    iType = 0
    iEpEnd = 0

    If Not EOF(1) Then
        Do
            Input #1, iSubjNo, iEpochNo, iEpBeg, iEpEnd, iFilename,
iSeq, iTrigVal, sTrigVal, iInBeg, iInEnd, iDuration, iType, iType,
iNoDriver, iNoVideo
        Loop Until (iTrigVal = 256) Or (EOF(1))
    Else: End
    End If

    Subject = iSubjNo
    Epoch = iEpochNo
    IncBeg = iInBeg
    IncEnd = iInEnd
    Debug.Print " "
    'Debug.Print "PDR FILE:", Subject, Epoch, IncBeg, IncEnd

    C1 = 0
    Do While IncBeg > C1
        Input #2, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12,
C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26
    Loop

    HoldVal = C24
    'Debug.Print "DAT FILE", C1, C23
```

Code: *Rewrite Concatenated DAT File – Invalid Removed – continued*

```
    Do While (HoldVal = C24) And Not (EOF(2))
        Input #2, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12,
C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26
    Loop

    Response = C23
    RxnTime = C24
    'Debug.Print Response, RxnTime

    C1 = 0
    If Not (EOF(3)) Then
        Do
            Input #3, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10
        Loop Until (C5 >= iEpBeg) Or (EOF(3))
        HoldVal = C5
    End If

    iRow = 1

    Do While (C5 = HoldVal) And Not (EOF(3))
        Manners(iRow, 0) = 1
        Manners(iRow, 1) = C1
        Manners(iRow, 2) = C2
        Manners(iRow, 3) = C3
        Manners(iRow, 4) = C4
        Manners(iRow, 5) = C5
        Manners(iRow, 6) = C6
        Manners(iRow, 7) = C7
        Manners(iRow, 8) = C8
        Manners(iRow, 9) = C9
        Manners(iRow, 10) = C10
        'Debug.Print "HoldVal: ", HoldVal
        'Debug.Print Manners(iRow, 0), Manners(iRow, 1), Manners(iRow,
2), Manners(iRow, 3), Manners(iRow, 4), Manners(iRow, 5), Manners(iRow,
6)
        Input #3, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10
        iRow = iRow + 1
        If EOF(3) Then
            Manners(iRow, 0) = 1
            Manners(iRow, 1) = C1
            Manners(iRow, 2) = C2
            Manners(iRow, 3) = C3
            Manners(iRow, 4) = C4
            Manners(iRow, 5) = C5
            Manners(iRow, 6) = C6
            Manners(iRow, 7) = C7
            Manners(iRow, 8) = C8
            Manners(iRow, 9) = C9
            Manners(iRow, 10) = C10
            iRow = iRow + 1
        End If
    Loop



    If iTrigVal = 256 Then

        iRow = 0
        Do
            iRow = iRow + 1
        Loop Until Manners(iRow, 8) > IncBeg

        Before = Manners(iRow - 1, 2)
        After = Manners(iRow, 2)

        Debug.Print "iRow:", iRow
        Debug.Print "Start: ", Before
        Debug.Print "Stopper: ", After
        Debug.Print "IncBeg: ", IncBeg
        Debug.Print "Manners: ", Manners(iRow, 7)
```

Code: *Rewrite Concatenated DAT File – Invalid Removed – continued*

```
        Print #4, Subject, Epoch, IncBeg, IncEnd, Response, RxnTime,
Manners(Before, 7), Manners(Before, 8), Manners(Before, 9),
Manners(Before, 10), Manners(After, 7), Manners(After, 8),
Manners(After, 9), Manners(After, 10)
    End If
Loop

Close #1
Close #2
Close #3
Close #4


End Sub
```

Temporal Separation Data Set

Name: TemporalQuery

Required Files: NewCode.XLS – Excel Data File containing TemporalQuery (Macro1)
Epoch level data files
Temp.csv - Comma-delimited Project Data Report
ORD.csv – Comma-delimited data file containing observer rating of drowsiness and mannerisms data.

Purpose: This code functions as a query to build a data subset of information from the above files concerning data that were recorded during a time-to-collision triggered event.

Description: NewCode.XLS contains the macro.

Instructions: Open ORD.csv, NewData.xls, and Temp.csv in Microsoft Excel. Change the participant number in TemporalQuery code. Run TemporalQuery. Copy block of data from current sheet to another sheet. Run for each participant.

Code:

```
Sub TemporalQuery()

Dim sFilename As String
Dim sFilepath As String

Dim iRow As Integer
Dim C As Integer

Dim Mannerisms(1 To 37) As Variant

ORD_Row = 1
OutRow = 1
PDR_Row = 1

    Windows("NewCode.xls").Activate

    Cells(1, 1).Value = "Participant ID"
    Cells(1, 2).Value = "Epoch Begin"
    Cells(1, 3).Value = "Epoch End"
    Cells(1, 4).Value = "Incident Begin"
    Cells(1, 5).Value = "Incident End"

    Cells(1, 7).Value = "Vel-Mean"
    Cells(1, 8).Value = "Vel-SD"
    Cells(1, 9).Value = "Vel-n"
    Cells(1, 10).Value = "Vel-Min"
    Cells(1, 11).Value = "Vel-Max"
    Cells(1, 12).Value = "Vel-Med"

    Cells(1, 14).Value = "TTC-Mean"
    Cells(1, 15).Value = "TTC-SD"
    Cells(1, 16).Value = "TTC-n"
    Cells(1, 17).Value = "TTC-Min"
    Cells(1, 18).Value = "TTC-Max"
    Cells(1, 19).Value = "TTC-Med"

    Cells(1, 20).Value = "Hd-Mean"
    Cells(1, 21).Value = "Hd-SD"
    Cells(1, 22).Value = "Hd-n"
    Cells(1, 23).Value = "Hd-Min"
    Cells(1, 24).Value = "Hd-Max"
    Cells(1, 25).Value = "Hd-Med"

    Cells(1, 26).Value = "ORD ID"
    Cells(1, 27).Value = "ORD Beg"
    Cells(1, 28).Value = "ORD Mid"
    Cells(1, 29).Value = "ORD End"
    Cells(1, 30).Value = "ORD Value"
    Cells(1, 31).Value = "hair_"
    Cells(1, 32).Value = "brow_raise_"
    Cells(1, 33).Value = "brow_lower_"
    Cells(1, 34).Value = "eye_periph_"
```

Code: *Temporal Separation Data Set – continued.*

```
Cells(1, 35).Value = "eye_rub_"
Cells(1, 36).Value = "eye_blink_"
Cells(1, 37).Value = "eye_slwcls"
Cells(1, 38).Value = "eye_unfrol"
Cells(1, 39).Value = "eye_procls"
Cells(1, 40).Value = "eye_stare"
Cells(1, 41).Value = "eye_glass"
Cells(1, 42).Value = "face_nrml"
Cells(1, 43).Value = "face_t-1"
Cells(1, 44).Value = "face_t-2"
Cells(1, 45).Value = "face_cont"
Cells(1, 46).Value = "face_rub"
Cells(1, 47).Value = "mouth_ywn"
Cells(1, 48).Value = "mouth_lps"
Cells(1, 49).Value = "mouth_tng"
Cells(1, 50).Value = "mouth_oth"
Cells(1, 51).Value = "neck_rub"
Cells(1, 52).Value = "neck_HPC"
Cells(1, 53).Value = "body_"
Cells(1, 54).Value = "oth_eat"
Cells(1, 55).Value = "oth_drink"
Cells(1, 56).Value = "oth_tobac"
Cells(1, 57).Value = "oth_chew"
Cells(1, 58).Value = "oth_radio"
Cells(1, 59).Value = "oth_cb"
Cells(1, 60).Value = "oth_fgtdrow"
Cells(1, 61).Value = "oth_oth"
Cells(1, 62).Value = "oth_o_des"

Windows("Temp.csv").Activate

LR_PDR = Range("A65000").End(xlUp).Row

For PDR_Count = 1 To LR_PDR

    If (Cells(PDR_Row, 7).Value = 0) Then
        End
    End If

    Windows("Temp.csv").Activate

    Do While (Cells(PDR_Row, 7).Value <> 8)
        PDR_Row = PDR_Row + 1
    Loop

    EpochBeg = Cells(PDR_Row, 3).Value
    EpochEnd = Cells(PDR_Row, 4).Value
    IncidBeg = Cells(PDR_Row, 9).Value
    IncidEnd = Cells(PDR_Row, 10).Value

    If IncidEnd > EpochEnd Then
        IncidEnd = EpochEnd
    End If

    sFilename = Cells(PDR_Row, 5).Value
    sSubjNum = Mid(sFilename, 2, 2)
    If Mid(sSubjNum, 1, 1) = 0 Then
        sSubjNum = Mid(sFilename, 3, 1)
    End If
    If sSubjNum <> "" Then
        sSubjNum = CInt(sSubjNum)
    End If
    sFilepath = "C:\Data\" & sFilename


    Windows("ORD.csv").Activate

    'Debug.Print "ORD_Row: ", ORD_Row
    'Debug.Print "SubjNum: ", sSubjNum

    Do While Cells(ORD_Row, 3).Value <> sSubjNum
        ORD_Row = ORD_Row + 1
    Loop

    Do While EpochBeg > Cells(ORD_Row, 5).Value
        ORD_Row = ORD_Row + 1
    Loop

    ORD_Holdval = Cells(ORD_Row, 4)

    Do While ORD_Holdval = Cells(ORD_Row, 4)
```

Code: *Temporal Separation Data Set – continued.*

```
            Do While Cells(ORD_Row, 8) < IncidBeg
                Mannerisms(1) = Cells(ORD_Row, 2)
                For C = 2 To 37
                    Mannerisms(C) = Cells(ORD_Row, C + 5)
                Next C
                ORD_Row = ORD_Row + 1
            Loop
        ORD_Holdval = ORD_Holdval + 1
        Loop

        Workbooks.OpenText Filename:=sFilepath, Origin:=xlWindows, _
            StartRow:=1, DataType:=xlDelimited, TextQualifier:=xlDoubleQuote, _
            ConsecutiveDelimiter:=True, Tab:=True, Semicolon:=False,
Comma:=False, _
            Space:=True, Other:=False, FieldInfo:=Array(Array(1, 1), Array(2,
1), Array(3 _
            , 1), Array(4, 1), Array(5, 1), Array(6, 1), Array(7, 1), Array(8,
1), Array(9, 1), Array(10, _
            1), Array(11, 1), Array(12, 1), Array(13, 1), Array(14, 1),
Array(15, 1), Array(16, 1), _
            Array(17, 1), Array(18, 1), Array(19, 1), Array(20, 1), Array(21,
1), Array(22, 1), Array( _
            23, 1), Array(24, 1), Array(25, 1), Array(26, 1))


        LastRow = Range("A65000").End(xlUp).Row
        HoldVal = ""

        For iRow = 1 To LastRow
            If (Cells(iRow, 19).Value > 100) Then
                Cells(iRow, 19).Value = HoldVal
            ElseIf (Cells(iRow, 19).Value < 1) Then
                Cells(iRow, 19).Value = ""
            End If

            HoldVal = Cells(iRow, 19).Value

            If Cells(iRow, 26).Value = 1000 Then
                Cells(iRow, 26).Value = ""
            End If

            If Cells(iRow, 8).Value < 1 Then
                Cells(iRow, 8).Value = ""
            End If

            If Cells(iRow, 19).Value > 0 And Cells(iRow, 8).Value > 0 Then
                Cells(iRow, 27).Value = Cells(iRow, 19) / (Cells(iRow, 8) *
0.44704)
            End If
        Next iRow


        iRow = 1
        Do While Cells(iRow, 1) < IncidBeg
            iRow = iRow + 1
        Loop

        SelBegin = iRow - 1

        Do While Cells(iRow, 1) < IncidEnd
            iRow = iRow + 1
        Loop

        SelEnd = iRow - 1

        Dim Velocity As Range
        Set Velocity = Worksheets(sFilename).Range(Cells(SelBegin, 8),
Cells(SelEnd, 8))

        Dim TTC As Range
        Set TTC = Worksheets(sFilename).Range(Cells(SelBegin, 26), Cells(SelEnd,
26))

        Dim Headway As Range
        Set Headway = Worksheets(sFilename).Range(Cells(SelBegin, 27),
Cells(SelEnd, 27))

        Windows("NewCode.xls").Activate

        OutRow = OutRow + 1
```

Code: *Temporal Separation Data Set – continued.*

```
            Cells(OutRow, 1).Value = sSubjNum

            Cells(OutRow, 2).Value = Application.WorksheetFunction.Average(Velocity)
            Cells(OutRow, 3).Value = Application.WorksheetFunction.StDev(Velocity)
            Cells(OutRow, 4).Value = Application.WorksheetFunction.Count(Velocity)
            Cells(OutRow, 5).Value = Application.WorksheetFunction.Min(Velocity)
            Cells(OutRow, 6).Value = Application.WorksheetFunction.Max(Velocity)
            Cells(OutRow, 7).Value = Application.WorksheetFunction.Median(Velocity)

            Cells(OutRow, 8).Value = Application.WorksheetFunction.Average(TTC)
            Cells(OutRow, 9).Value = Application.WorksheetFunction.StDev(TTC)
            Cells(OutRow, 10).Value = Application.WorksheetFunction.Count(TTC)
            Cells(OutRow, 11).Value = Application.WorksheetFunction.Min(TTC)
            Cells(OutRow, 12).Value = Application.WorksheetFunction.Max(TTC)
            Cells(OutRow, 13).Value = Application.WorksheetFunction.Median(TTC)

            Cells(OutRow, 14).Value = Application.WorksheetFunction.Average(Headway)
            Cells(OutRow, 15).Value = Application.WorksheetFunction.StDev(Headway)
            Cells(OutRow, 16).Value = Application.WorksheetFunction.Count(Headway)
            Cells(OutRow, 17).Value = Application.WorksheetFunction.Min(Headway)
            Cells(OutRow, 18).Value = Application.WorksheetFunction.Max(Headway)
            Cells(OutRow, 19).Value = Application.WorksheetFunction.Median(Headway)

            Cells(OutRow, 21).Value = EpochBeg
            Cells(OutRow, 22).Value = EpochEnd
            Cells(OutRow, 23).Value = IncidBeg
            Cells(OutRow, 24).Value = IncidEnd

            For C = 1 To 37
                Cells(OutRow, 25 + C).Value = Mannerisms(C)
            Next C

            Application.DisplayAlerts = False
            Workbooks(sFilename).Close
            Application.DisplayAlerts = True

            PDR_Row = PDR_Row + 1
        Next PDR_Count

    End Sub
```

Code: *Temporal Separation Data Set – continued.*

SOFTWARE REPORT: SAS SCRIPTS

Summary

Each of the scripts contained within this section of the Appendix makes use of the SAS System for Windows (v. 6.12 and 7). A complete flow diagram is presented in the body of the dissertation.

Modifying Delimiters in Data Files

Name: ChgDelimiter

Required Files: Mega_*XX*.DAT – Concatenated DAT File (Space Delimited)
Mega-C_*XX*.DAT – Concatenated DAT File (Comma Delimited)

MegNew_*XX*.DAT – Concatenated DAT File, Invalid Removed (Comma Delimited)
Mstr_*XX*.DAT (Concatenated DAT File, Invalid Removed (Space Delimited)

Purpose: To change formatting in flat data files from being space delimited to comma delimited or vice versa.

Description: This code changes the delimiter in flat DAT files from comma to space, or vice versa. Visual Basic reads comma delimited text more easily and space delimited text is more easily implemented into SAS with a standard FILENAME designator rather than the IMPORT designator.

Instructions: Establish a library named SPLIT. Associate with a file folder named 'D:\sbsas\'
Run appropriate portion of code.

Code:

```
/*Change delimiter from space to comma*/

OPTIONS obs=max;

FILENAME concat 'C:\Mega\Mega_XX.dat';
LIBNAME split 'D:\sbsas\';

DATA SPLIT.base;
   INFILE concat missover;
   INPUT  Sync           /*Column 1  : Sync Number (also in video)   */
          EstTime : $25.  /*Column 2  : Date & Time                   */
          SteerPos       /*Column 3  : Steering Position  (radians)  */
          NAcclPos       /*Column 4  : Normalized Accel Position     */
          NBrakPos       /*Column 5  : Normalized Brake Position     */
          LatAccl        /*Column 6  : Lateral Acceleration  (g)     */
          LongAccl       /*Column 7  : Longitudinal Acceleration  (g)*/
          Velocity       /*Column 8  : Velocity (mph)                */
          Distance       /*Column 9  : Distance (miles)              */
          Trigger        /*Column 10 : Event Trigger Signals         */
          IncidPB        /*Column 11 : Incident Push Button          */
          TrnSignl       /*Column 12 : Turn Signals (1=right,2=left) */
          LnOffst        /*Column 13 : Lane Offet (Meters)           */
          LnOffstC       /*Column 14 : Lane Offet Confidence         */
          RdCurv         /*Column 15 : Road Curvature (Meters/Second)*/
          RdCurvC        /*Column 16 : Road Curvature Confidence     */
          OutLight       /*Column 17 : Outside Light Level           */
          Autotrax       /*Column 18 : Autotrax Event                */
          FrntRg         /*Column 19 : Front Range (meters)          */
          FrntRgRt       /*Column 20 : Front Range Rate (meters / s) */
          PerClos        /*Column 21 : Per Close Value               */
          DQBID          /*Column 22 : (Driver Query Box)            */
          DQBSR          /*Column 23 : (Driver Query Box) Sleepiness */
          DQBSRRT        /*Column 24 : (Driver Query Box) Sleepiness */
```

Code: *Modifying Delimiters in Data Files – continued*

```
            SideSens        /*Column 25 : Side Sensors                 */
            TTC             /*Column 26 : Time to Collision in Seconds  */
            ;
   Run;


PROC EXPORT DATA=Split.base
      outfile="D:\sbsas\Mega-C_XX.dat"
      dbms=dlm;
      delimeter=’ ’;
Run;


/*   Change Delimiter from Comma to Space   */


OPTIONS obs=max;
LIBNAME split ’D:\sbsas\’;

PROC IMPORT Datafile=’D:\sbsas\MegNew01.dat’
   out=Split.base
   dbms=dlm
   replace;
   delimiter=’,’;
   getnames=no;
Run;

PROC EXPORT DATA=Split.base
      outfile="D:\sbsas\Mstr_01.dat"
      dbms=dlm;
      delimeter=’ ’;
Run;
```

Create Epoch Level DAT Files

Name: FileSplitter

Required Files: Mstr_*XX*.DAT (Concatenated DAT File, Invalid Removed (Space Delimited)
s*XX*n001 – s*XX*n00*N* (Sequentially numbered DAT Files, Space Delimited)

Purpose: To split the concatenated DAT file into smaller, more manageable Epoch-Level DAT files.

Description: This code splits the concatenated DAT file into smaller, more manageable Epoch-Level DAT files. The files are named in the following format [s*XX*n00*N*] where *XX* corresponds to the subject number and *N* corresponds to the epoch number.

Instructions: Establish a library named SPLIT. Associate with a file folder named 'D:\sbsas\' Rename file path in code to match appropriate file location. Run code. Files will be located in user's personal SAS directory.

Code:

```
OPTIONS obs=max;

FILENAME concat ’D:\sbsas\concatdat2.txt’;
LIBNAME split ’D:\sbsas\’;

DATA SPLIT.base;
   INFILE concat missover;
   INPUT  Sync     /*Column 1  : Sync Number (also in video)*/
          EstTime  /*Column 2  : Estimated Time from data start (s)*/
          SteerPos /*Column 3  : Steering Position  (radians)*/
          NAcclPos /*Column 4  : Normalized Accelerator Pos*/
          NBrakPos /*Column 5  : Normalized Brake Position*/
          LatAccl  /*Column 6  : Lateral Acceleration  (g)*/
          LongAccl /*Column 7  : Longitudinal Acceleration  (g)*/
          Velocity /*Column 8  : Velocity (mph)           */
          Distance /*Column 9  : Distance (miles) */
          Trigger  /*Column 10 : Event Trigger Signals*/
          IncidPB  /*Column 11 : Incident Push Button*/
          TrnSignl /*Column 12 : Turn Signals (1=right,2=left) */
          LnOffst  /*Column 13 : Lane Offet (Meters) */
          LnOffstC /*Column 14 : Lane Offet Confidence*/
          RdCurv   /*Column 15 : Road Curvature (Meters/Second)*/
          RdCurvC  /*Column 16 : Road Curvature Confidence*/
          OutLight /*Column 17 : Outside Light Level*/
          Autotrax /*Column 18 : Autotrax Event*/
          FrntRg   /*Column 19 : Front Range (meters) */
          FrntRgRt /*Column 20 : Front Range Rate (meters/s)*/
          PerClos  /*Column 21 : Per Close Value*/
          DQBID    /*Column 22 : Driver (1 or 2) */
          DQBSR    /*Column 23 : Sleepiness Rating*/
          DQBSRRT  /*Column 24 : Sleepiness Rating Reaction Time*/
          SideSens /*Column 25 : Side Sensors (1=Left,2=Right,3=Both)*/
          TTC      /*Column 26 : Time to Collision in Seconds*/
          ;
   RUN;

LIBNAME split ’D:\sbsas\’;
PROC SORT
   DATA = SPLIT.base
   OUT = SPLIT.basesort;
BY Sync Trigger;
RUN;



/*
Generates ’Event’ Variable to count and identify the number of Critical
Incidents
```

Code: *Create Epoch Level DAT Files – continued.*

```
*/
LIBNAME split ’D:\sbsas\’;
DATA SPLIT.baseevnt1 (Drop = SyncTest);
   SET SPLIT.basesort;
   RETAIN Event;
   SyncTest = LAG(Sync);
   IF SyncTest+1 NE Sync then Event + 1;
RUN;

LIBNAME split ’D:\sbsas\’;
DATA SPLIT.baseevnt2;
   SET SPLIT.baseevnt1;
BY Event Sync;
IF (First.Event = 1) AND (Last.Event = 1) Then DELETE;
RUN;

LIBNAME split ’D:\sbsas\’;
DATA SPLIT.baseevnt3 (DROP=Event);
   SET SPLIT.baseevnt2;
RUN;

LIBNAME split ’D:\sbsas\’;
DATA SPLIT.baseevnt4 (DROP = SyncTest);
   SET SPLIT.baseevnt3;
   RETAIN Event;
   SyncTest = LAG(Sync);
   IF SyncTest+1 NE Sync then Event + 1;
RUN;

LIBNAME split ’D:\sbsas\’;
DATA _Null_;
   SET SPLIT.baseevent;
BY Event Sync;

FileLabel = "s02" || "n" || PUT (Event, Z3.);
File Outer FileVar=FileLabel mod;
Put FileLabel Trigger;

RUN;
```

Additional File and Data Set Restructuring

Name: Miscellaneous

Required Files: Miscellaneous

Purpose: To restructure data sets in order to prepare them for data analysis.

Description: Restructures data sets in order to prepare them for data analysis.

NOTE: Where the following code has been designed to be resuable by more than one SAS data set, filenames have not been listed.

Instructions: Ensure that SAS Dataset has been created and is active during current session prior to continuing.

Code:

```
/*Creates SAS Data Set named TTC located in the \SBSAS\ directory on the
D: disk*/



/*Import procedure for importing comma delimited data file (located in
the \SBSAS\ directory on the D: disk) into the SAS System.  If the data
file being imported contains column headers, then ‘getnames’ property
should be set to ‘yes’, else, ‘no’.  If the ‘getnames’ property is set
to ‘no’ then the default variable names are VAR1…VARN where N is the nth
column (not variable) imported.*/

LIBNAME TTC 'D:\sbsas\';

PROC IMPORT Datafile='D:\sbsas\FILENAME.csv'
   out=TTC.SAS_DATASET_NAME
   dbms=dlm
   replace;
   delimiter=',';
   getnames=yes;
        Run;



        /*Export procedure for exporting a SAS Data set to a comma-
delimited file (located in the \SBSAS\ directory on the D: disk).  This
procedure will export the column names and store them in the first row
of the resulting comma-delimited data file.*/

        PROC EXPORT data=ttc.SAS_DATASET_NAME
           outfile="d:/sbsas/FILENAME.csv"
           dbms=dlm;
           delimiter=',';
        run;
```

Code: *Additional File and Data Set Restructuring – continued*

```
        /*Reformulation of Driver Mannerisms Data.  Uses data imported
from timed trigger data subset.  Transforms original mannerisms
variables into ten meta variables. Creates new SAS Data set with
reformulated variables (sans original)*/

        DATA TTC.NEW_SAS_DATASET_NAME;
        SET TTC.EXISTING_SAS_DATASET_NAME;

        Subj = VAR1;
        Response = VAR3;
        RxnTime = VAR4;
        ORDVal = VAR5;

        Hair = VAR6;
        Brow = VAR7 + VAR8;
        Eye1 = VAR9 + VAR10 + VAR11 + VAR15 + VAR16;
        Eye2 = VAR12 + VAR13 + VAR14;
        Face = VAR18 + VAR19 + VAR20 + VAR21;
        Mouth = VAR22 + VAR23 + VAR24 + VAR25;
        Neck = VAR26 + VAR27;
        Body = VAR28;
        Other1 = VAR29 + VAR30 + VAR31 + VAR32;
        Other2 = VAR33 + VAR34;

        Drop VAR1-VAR69;

        Run;



        /*Reformulation of Driver Mannerisms Data.  Uses data imported
from time to collision trigger data subset.  Requires SAS version 7 or
higher (Version 6.12 is limits variable names to 8 characters.
Transforms original mannerisms variables into ten meta variables.
Creates new SAS Data set with reformulated variables (sans original
mannerisms variables)*/

        DATA TTC.NEW_SAS_DATASET_NAME;
        SET TTC.EXISTING_SAS_DATASET_NAME;

        Hair = hair_;
        Brow = brow_raise_ + brow_lower_;
        Eye1 = eye_periph + eye_rub + eye_blink + eye_stare + eye_glass;
        Eye2 = eye_slwcls + eye_unfrol + eye_procls;
        Face = face_t-1 + face_t-2 + face_rub + face_cont;
        Mouth = mouth_ywn + mouth_lps + mouth_tng + mouth_oth;
        Neck = neck_rub + neck_hpc;
        Body = body_;
        Other1 = oth_drink + oth_tobac + oth_chew + oth_eat;
        Other2 = oth_radio + oth_cb;

        Drop hair_--oth_o_des;

        Run;
```

Data Analysis

Name: Miscellaneous

Required Files: Miscellaneous

Purpose: To perform a variety of inferential and descriptive statistical techniques on the collected data subset.

Description: This code performs a regression analysis in order to determine the predictive ability of various potential measures of fatigue against ORD and MANNERISMS.

NOTE: Where the following code has been designed to be resuable by more than one SAS data set, filenames have not been listed.

Instructions: Ensure that SAS Dataset has been created and is active during current session prior to continuing.

Code:

```
/*MULTIPLE REGRESSION ANALYSIS*/
/*Multiple Regression in order to determine to what extent the
independent variables measured (existing, valid indicators of fatigue)
could predict a dependent measure (e.g., TTC_MIN).  SAS requires that
these be modeled exactly opposite of the hypothesis (i.e., the
hypothesis states that TTC_MIN is a predictor of the existing measures);
however, in regression, the order is communitive and does not affect the
quality of the fit of the resulting equation.*/

LIBNAME TTC 'D:\sbsas\';

PROC REG data=SAS_DATASET_NAME;
   Model DEP_VAR_NAME = ORD_Value
                        HAIR
                        BROW
                        EYE1
                        EYE2
                        FACE
                        MOUTH
                        NECK
                        BODY
                        OTHER1
                        OTHER2 / selection = stepwise;
Run;


/*TTEST ANALYSIS*/
/*T-Test Analysis of Differences in observer ratings of drowsiness for
period immediately preceding and immediately following a driver's
response to the Karolinska Alertness Survey*/

Diff = A_ORD - B_ORD;

PROC MEANS;
   VAR A_ORD B_ORD;
Run;

Proc MEANS N Mean StdErr T PRT;
   VAR DIFF;
Run;



/*MANOVA ANALYSIS*/
/*Multivariate Analysis of Variance of difference in fatigue level
between timed trigger and time-to collision values*/

PROC GLM DATA=SAS_DATASET_NAME;
CLASSES SUBJECT ALERT;
MODEL ORD_Value
      Hair_
      Brow_raise_
```

Code: *Data Analysis – continued*

```
      Brow_lower_
      Eye_periph
      Eye_rub
      Eye_blink
      Eye_clwcls
      Eye_unfrol
      Eye_procls
      Eye_stare
      Eye_glass
      Face_nrml
      Face_t-1
      Face_t-2
      Face_cont
      Face_rub
      Mouth_ywn
      Mouth_lps
      Mouth_tng
      Mouth_oth
      Neck_rub
      Neck_HPC
      Body_
      Oth_drink
      Oth_eat
      Oth_tobac
      Oth_chew
      Oth_rad
      Oth_cb
      Oth_fgt = SUBJECT ALERT/SS3;
MEANS ALERT / TUKEY;
MANOVA H=ALERT/canonical summary;
RUN;



/*DISCRIMINANT ANALYSIS*/
/*Discriminant Analysis of temporal separation data (TTC_MIN, HD_MIN,
and HD_MEAN).  Group variable separates high (>=0.5) and low (<0.5)
levels of observer ratings of drowsiness*/

PROC DISCRIM data=ttc.base2 method=normal all;
Class group;
Var TTC_MIN HD_MEAN HD_MIN;
Priors equal;
        Run;



        /*CLUSTER ANALYSIS*/
        /*Cluster Analysis of temporal separation data (TTC_MIN, HD_MIN,
and HD_MEAN).  Sequence variable is created to identify order or
sequence of observer ratings of drowsiness.*/

        LIBNAME ttc 'D:\sbsas\';
        PROC SORT
           DATA = EXISTING_SAS_DATASET_NAME;
           OUT = NEW_SAS_DATASET_NAME;
        BY ORD_Value;
        RUN;

        /*Export data to comma-delimited file.  Import into Excel.
Create SEQUENCE variable.  Number observations from 1 to N.  Import file
into SAS*/

        PROC CLUSTER data=SAS_DATASET_NAME s standard outtree=one
method=average rsquare pseudo ccc;
          var TTC_MIN HD_MIN HD_MEAN;
          id Sequence;
        Run;

        PROC TREE data=one out=treeout nclusters=11;
          copy sequence TTC_MIN HD_MIN HD_MEAN;
          id Sequence;
        Run;

        PROC PLOT data=one;
           plot _ccc_*_ncl_ / haxis=0 to 20 by 2;
        run;
```

Code: *Data Analysis – continued*

```
PROC SORT data=treeout; by cluster;
PROC PRINT data=treeout;
variables sequence cluster;
run;

PROC PRINCOMP data=SAS_DATASET_NAME out=scores;
   var ttc_min hd_min hd_mean;
run;

PROC SORT data=treeout; by sequence;
PROC SORT data=scores; by sequence;

DATA comb; MERGE scores treeout; by sequence;

PROC PLOT data=comb;
   PLOT  prin1*prin2='*';
   PLOT prin1*prin2=cluster;
   PLOT prin1*prin2=prin3/contour=11;
   PLOT prin1*prin2=sequence;
run;
```

VITA

Steven M. Belz was born on February 25, 1973 in Eau Claire, Wisconsin. He received his Bachelor of Science degree in Industrial and Systems Engineering from Virginia Polytechnic Institute and State University in May 1995. He earned a Master of Science in Industrial and Systems Engineering at Virginia Polytechnic Institute and State University in December 1997. Upon completion of his Doctorate of Philosophy in the same program he plans to apply his knowledge within Corporate Design and Usability as a Senior Human Factors Engineer at the Eastman Kodak Company.

Before he began work on his Master of Science degree at Virginia Polytechnic Institute and State University he worked for Montgomery County Public Schools as an assistant engineer where his primary responsibility was updating facility designs to be in compliance with the Americans with Disabilities Act. During his Master's degree, he also spent a summer working for the Wireless Consumer Product Group at Lucent Technologies. While at Lucent, his primary responsibility was to develop and test level and pattern characteristics of the auditory alerter in new mobile telecommunications devices. He was also responsible for designing and developing GUI interfaces for Intranet sites and developing the initial systems requirements for an Intranet-based reporting of competitive product analyses.

As a graduate student, he was the recipient of an Eisenhower Graduate Research Fellowship awarded by the Federal Highway Administration. He was also awarded a graduate fellowship for Intelligent Vehicle Highway Systems by General Motors, received the Pratt fellowship, and was awarded the Paul E. Torgersen Research Excellence Award for excellence in graduate research. His research interests include transportation systems, telecommunications, human-computer interaction, multimedia development, and the development of usability assessment methods. He is a member of Alpha Pi Mu, the Institute of Industrial Engineers, and the Human Factors and Ergonomics Society.