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16. Abstract

A driver drowsiness detection/alarm/countermeasures system was specified, tested and evaluated, resulting in the development of revised algorithms for the detection of driver drowsiness. Previous algorithms were examined in a test and evaluation study, and were found to be ineffective in detecting drowsiness. These previous algorithms had been developed and validated under simulator conditions that did not emphasize the demand for maintaining the vehicle in the lane as would be expected in normal driving. Revised algorithms were them developed under conditions that encouraged more natural lane-keeping behavior by drivers in the simulator. In these revised algorithms, correlations between dependent drowsiness measures and independent performance-related measures were lower than expected. However, classification accuracy improved when a criterion of "drowsiness *or* performance" was used, with performance assessed directly from a lane-related measure.

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EXECUTIVE SUMMARY

This document reports on the development of revised algorithms for the detection of driver drowsiness. The reported study follows a study, reported on in Part II of this final report series, in which a complete drowsy driver detection, alarm, and countermeasures system (DDDACS) was tested and evaluated. The algorithms used in the test and evaluation study were found to be ineffective in detecting drowsiness. Further investigation pinpointed a hypothetical cause of the ineffectiveness of the algorithms: they were developed and validated under experimental conditions that did not place any restrictions on the lane positioning of the simulated vehicle, while they were tested and evaluated under conditions in which large lane deviations caused detection based on driving performance and the resulting alarms and countermeasures.

The present study sought to correct the problem through development of revised algorithms under conditions in which large lane exceedances were curtailed. Specifically, a lane departure warning system was implemented. This system activated vibration in the seat back and the seat pan of the driver's seat if the vehicle exceeded either the center or the right-hand lane boundary by more than approximately three feet. The effect of the vibration resembled that of the rumble strips currently installed along the shoulders of many U.S. roadways. This system was accompanied by financial incentives to encourage the driver to stay within the lane boundaries. The system was highly effective in encouraging lane-keeping behavior in the simulator similar to lane-keeping behavior in actual vehicles.

Twelve sleep-deprived subjects drove an automobile simulator from approximately 12:00 A.M. to 2:30 A.M. Following a data truncation procedure based on the number of times the lane departure warning system was activated, usable data were obtained from part or all of the experimental sessions of each of these subjects. Each subject received a training session including practice in carefully observing the lane boundaries. A lane-

minder device, which produced a warbling tone when the lane boundary was exceeded on either side or the vehicle, was used in the training. However, the lane departure warning system was not used until the data-gathering session.

Objective performance measures and subjective ratings were collected during the experimental sessions. Performance measures included many dependent and independent measures that had been collected previously in the algorithm development, algorithm validation, and test and evaluation experiments. Drowsiness level was continuously subjectively rated by each subject during his or her experimental session, resulting in a new dependent variable that had not previously been collected. Other new dependent variables were developed as composites of the eye-closure and subjective rating variables.

As expected, the correlations between dependent, definitional driver drowsiness measures and independent performance-related measures were lower than those that had been seen in previous experimentation. Distribution analyses were performed to determine how well the definitional measures could predict activations of the lane departure warning system, or "lane busts". It was found that the definitional measures could not predict "lane busts" without some missed detections and/or false alarms.

The new algorithms did not correlate nearly as well with the measures they were designed to predict as the previous algorithms; the multiple R-values were much lower, as expected. However, the classification accuracy of the new algorithms, particularly those with lane-related measures included as independent variables, was higher than expected and comparable to that of the previous algorithms. This classification accuracy improved further when a criterion of "drowsiness OR performance" was used, with performance assessed directly from a lane-related measure. Nearly equal accuracy levels were obtained from algorithms developed using data averaged over three-minute intervals and algorithms developed using data averaged over six-minute intervals.

The drowsiness phase of a DDDACS to be tested in full scale should use the three-minute average algorithms developed in the present study, using a "drowsiness OR performance" criterion for detection. It should also include a supplemental lane departure warning system since "lane busts" constitute well-defined, prima facie evidence that a driver is impaired.

PRESENT RESEARCH

Research Objectives

A study was recently completed in which a drowsy driver detection, alarm, and countermeasures system (DDDACS) was tested and evaluated. A full report on this study appears as Part II of this final report series and included use of a complete system. The system was designed to detect the drowsy status of a driver or a reduced driver performance level. Driver drowsiness levels were determined by the output of one of a number of algorithms designed to estimate PERCLOS (the proportion of time that a driver's eyes are 80% to 100% closed). Driver performance levels were measured by LANEX (the proportion of time any part of the vehicle exceeds the lane boundary) or an algorithm estimate of LANEX. The system was designed to be able to operate with or without the availability of lane-related information by switching between algorithms in a "step-up, step-down" process.

The results of the test and evaluation experiment were quite different than what was expected. All detections that took place during the experiment were based wholly on driver performance; no detection was based wholly or partly on drowsiness levels. Neither the driver status (drowsiness) algorithms nor the driver performance (LANEX estimation) algorithms tracked well with the measures they were designed to predict; correlations were much lower than expected. Comparisons between independent measures from the data collected in the current experiment and the data previously collected in the algorithm development experiment (Wreggit, Kirn, and Wierwille, 1993) revealed significant differences in the values of the means for many of the measures. Specifically, measures related directly or indirectly to the position of the vehicle relative to the lane had significantly lower mean values in the current experiment than in the algorithm development experiment.

It was concluded that subjects were more tolerant of lane errors in the previous algorithm development experiment than they would have been in an actual vehicle. It appeared that algorithms developed from that data set did not function well when lane errors were controlled to a level more closely reflecting full scale. Therefore, data gathering in the test and evaluation experiment was discontinued.

The primary goal of the present study was to develop new algorithms that would have a higher probability of success than the previous algorithms when used in full scale. To this end, an experiment similar in nature to the original algorithm development experiment (Wierwille et al., 1994) was designed, in which no detections, alarms, or countermeasures were used. The primary difference between the current experiment and the original algorithm development experiment is the requirement that drivers perform the lane-keeping task in a manner reflecting performance in an actual vehicle. This was accomplished through the implementation of a lane departure warning system, which will be described in detail later in this document. Also, several new definitional measures of drowsiness were developed and implemented in this experiment, so that a larger variety of algorithms could be developed, examined, and compared.

METHOD

Subjects

Twelve volunteer subjects (eight male and four female) were used in this study. The use of a two to one ratio of male to female subjects has been determined to be a more accurate representation of the population at high risk for driver drowsiness than a one to one ratio of males to females. Recent research has shown that males substantially outnumber females in drowsiness-related automobile accidents (Knipling and Wierwille, 1994). All participants were volunteers from the Blacksburg, Virginia area ranging in age from 21 to 45 years. This age range corresponds to the population most heavily involved in drowsiness-related accidents (Knipling and Wierwille, 1994).

All subjects were screened according to a questionnaire, which included questions concerning normal sleeping habits, normal working hours, smoking habits, general health, and body size. This questionnaire appears in Appendix A. It was required that all subjects possess a valid driver's license, have 20/40 vision or better (corrected or uncorrected), and have no known hearing problems.

Each subject was compensated for his or her one-time participation in the experiment. At 6:00 P.M., each subject was picked up at his or her home and received $6.00 for dinner. Each subject was paid $5.00 per hour from 6:00 P.M. until midnight and $8.00 per hour from midnight until the end of the experiment. Each subject also had the opportunity to earn a bonus of up to $12.00 for good driving performance.

During the one of the experimental sessions, it became evident that the signal from the drowsiness control (see Apparatus section) was not reaching the WIN 486-33i microcomputer and that no data from the drowsiness control were entering the data file. Since this resulted in an incomplete data set, the experimental session was terminated and the subject's data were not used. Another subject experienced symptoms of oncoming uneasiness early in the run. The experimental session was terminated at that subject's request and the subject's data were not used. The two problem subjects were paid for their time and replaced with two additional subjects, resulting in collection of valid data from a total of twelve subjects.

Apparatus

Simulator

The simulator used in this study is a computer-controlled, hydraulically powered moving-base automobile simulator that handles like a mid-sized rear wheel drive automobile. This simulator has been validated by Leonard and Wierwille (1975) and is located at the Vehicle Analysis and Simulation Laboratory at Virginia Tech. Previous studies, including the original detection algorithm development and validation experiments, the optimization of advisory and alarm stimuli experiments, and the test and evaluation experiment, have used the same simulator (Wierwille et al., 1994; Fairbanks, Fahey, and Wierwille, 1995).

The simulator has four degrees of freedom of physical motion (roll, yaw, lateral translation, and longitudinal translation). The roadway image was presented using a monochrome CRT viewed through a Fresnel lens. The image was that of a two-lane highway with side markers and a dashed center line. Light horizontal lines were embedded in the horizontal plane to enhance the image of the roadway continuing into the distance. Both straight and curved roadways were presented. A simulated automobile hood was also included in the image.

Roadway vibration and sounds, such as engine noise, tire squeal on hard turns, and tire screech on hard braking were also presented to the driver. The ambient sound level in the simulator at 60 miles per hour was set at 75.5 dBA.

Eye Closure Monitoring Equipment

A low light level camera (RCA TC1004-UO1) was used to continuously monitor a subject's entire face, including eye movements. The camera could operate at very low light levels and thus be unintrusive. The video signal was passed through a video cassette recorder and viewed by an experimenter using a Sanyo VM 4512A monitor. This experimenter manipulated a specially designed linear potentiometer to track the movement of the subject's eyelids. This tracking produced values for the measures PERCLOS and EYEMEAS. Video and audio recordings of each session were made and kept for future reference.

Subjective Drowsiness Rating Equipment

Another potentiometer was mounted on the center console of the simulator, to the right of the driver's seat. This potentiometer was labeled with the same range of drowsiness levels previously used for subjective ratings in the test and evaluation experiment ("Not Drowsy", "Slightly Drowsy", "Moderately Drowsy", "Very Drowsy", and "Extremely Drowsy"). The subject manipulated this potentiometer during the course of the experiment to rate his or her perceived level of drowsiness. An LED mounted on the dashboard flashed once per minute as a reminder to the subject to consider moving the potentiometer if there had been a change in his or her drowsiness level. The light output of the LED was of a yellow hue and its luminance was adjusted so as not to be intrusive. Output from the potentiometer produced values for the dependent measure DRVDROW.

Lane Enforcement Equipment

During the test and evaluation experiment, it became apparent that drivers were more tolerant of lane errors in the simulator than they would have been in an actual vehicle. As a result, controls that required subjects to perform the lane-keeping task in a manner more closely reflecting performance in an actual vehicle were used in the present experiment. A lane minder was activated during the training session and during the first five minutes of each experimental session. This device was activated via circuitry connected directly to the simulator and sounded a tone whenever the vehicle approached lane boundaries. The tone would increase in amplitude as the simulated vehicle approached the lane edge. As it passed over the lane edge, the tone would begin to warble. Maximum amplitude would occur when the vehicle exceeded the lane edge by more than two feet. The tone was presented via dual piezo buzzers, one to the left and the other to the right of the driver. The usage of the lane minder served to acclimate each subject to staying within the lane boundaries.

A second lane enforcement system, the "lane departure warning system", alerted drivers to extreme exceedance of lane boundaries, using seat vibration to simulate the effect of a rumble strip. Installations of rumble strips along the shoulders of roadways have proved to be highly effective in reducing drift-off-road accidents (Wood, 1994, Chaudoin and Nelson, 1985), and seat vibration has been shown to be an effective peripheral alarm stimulus for driver drowsiness (Fairbanks, Fahey, and Wierwille, 1995). The system was used throughout each experimental session and was automatically activated whenever the vehicle crossed boundaries set at equal distances approximately three feet beyond the left and right boundaries of the right lane. When these boundaries were crossed, vibration was produced in the seat back and seat pan with the use of eccentrics (unbalanced rotational masses) driven by high-quality servo motors. These motors were powered by two power supplies connected to the simulator via a signal processor.

Data Collection Equipment

During the experiment, a variety of analog sensors on the simulator were operating. Two serially interfaced microcomputers equipped with special interface cards received the analog data and converted it to digital format, calculated necessary measures on-line, and stored data for later analysis.

Timing for the system originated from a Sony MDS-302 MiniDisc recorder, a high-quality digital audio recording device capable of recording two audio channels on a 74-minute optical disc. When played, the disc can be repeated indefinitely without degradation. A signaling pulse of 18,000 Hz occurred every 15 seconds to control interval timing.

The pulses from the MDS-302 recorder were fed into a TRS-80 Model III microcomputer via a custom analog-to-digital (A/D) converter interface. A BASIC program running on the TRS-80 counted the pulses. Upon receipt of every fourth pulse (marking the passage of one minute), the TRS-80 sent a "flag" signal to a WIN 486-33i microcomputer via a serial RS-232 interface.

The WIN 486-33i microcomputer was equipped with a National Instruments AT-MIO-16 A/D converter interface card. This card allowed for rapid digital sampling of analog data on 16 different channels. The computer was programmed using Microsoft QuickBASIC to collect and store raw data and to calculate the necessary measures on-line from that data. Every minute, upon receipt of the "flag" signal from the TRS-80, the program computed the measures for that minute and saved them in a file for subsequent analysis.

All signals from various sensors on the simulator from which independent measures were derived and subsequently used in algorithm redevelopment were sampled, converted, and calculated by the WIN 486-33i. The output signals from the two potentiometers for the measures PERCLOS, EYEMEAS and DRVDROW were handled in the same manner. Also, a signal from the seat vibration system was processed by the WIN 486-33i, recording when and for how long the seat vibration was activated.

Experimental Design

The experimental design employed a multiple regression approach to data analysis. The experiment was conducted expressly for the purpose of gathering data for the development of new algorithms; therefore, all subjects were exposed to the same treatment conditions. A set of definitional measures of drowsiness was collected, as well as a set of independent driving performance measures. The independent performance measures were then used in regression analysis in various configurations to predict the definitional drowsiness measures.

Two of the definitional measures of drowsiness collected were also collected in the previous algorithm development and validation experiments (Wierwille et al., 1994).

- EYEMEAS: The mean square of the percentage of the subject's eye closure.
- PERCLOS: The proportion of time that a subject's eyes were 80% to 100% closed.

Four other definitional measures of drowsiness were collected and/or calculated for the first time in the current experiment.

- DRVDROW: The subject's online subjective rating of drowsiness, which he or she inputed using the drowsiness control. Values ranged from zero (not drowsy) to 100 (extremely drowsy).
- SLEEPER1: The sum of weighted values of EYEMEAS and DRVDROW. Weighting was accomplished using values for each measure considered to signify a "very drowsy" level of drowsiness:

  SLEEPER1 = (1/2500) (EYEMEAS) + (1/75) (DRVDROW)

- SLEEPER2: The sum of weighted values of EYEMEAS and DRVDROW. Weighting was accomplished using the mean values of three-minute averages for each measure:

  SLEEPER2 = (1/1179.8) (EYEMEAS) + (1/55.6) (DRVDROW)

- SLEEPER3: The sum of weighted values of PERCLOS and DRVDROW. Weighting was accomplished using values for each measure considered to signify a "very drowsy" level of drowsiness:

$$SLEEPER3 = (1/0.014)(PERCLOS) + (1/75)(DRVDROW)$$

A listing of the independent measures collected follows, grouped by category. All of these measures were collected in the previous algorithm development and validation experiments (Wierwille et al., 1994).

Steering-Related Measures:

- STVELV: The variance of steering velocity, where velocity was measured in degrees per second.
- LGREV: The number of times that steering excursion exceeds 15° after steering velocity passes through zero.
- MDREV: The number of times that steering excursion exceeds 5°, but does not exceed 15°, after steering velocity passes through zero.
- SMREV: The number of times that steering excursion exceeds 1°, but does not exceed 5°, after steering velocity passes through zero.
- STEXED: The proportion of time that steering velocity exceeds 125° per second.
- NMRHOLD: The number of times the hold circuit output on the steering wheel exceeds a threshold value (corresponding to holding the steering wheel still for 0.4 second or longer).
- THRSHLD: The proportion of total time the hold circuit output on the steering wheel exceeds a threshold value.

Lane-related measures:

- LNMNSQ: The mean square of lane position; "zero" position is defined as that position occurring when the vehicle is centered in the lane. (Lane position was measured in feet.)
- LANVAR: The variance of lateral position relative to the lane. (Lane position was measured in feet.)
- LANDEV: The standard deviation of lateral position relative to the lane; the square root of LANVAR.
- LANEX: The proportion of time that any part of the vehicle exceeds the lane boundary.
- LNERRSQ: The mean square of the difference (in feet) between the outside edge of the vehicle and the lane edge when the vehicle exceeds the lane. When the vehicle does not exceed the lane, the contribution to the measure is zero.
- LNRTVAR: The variance of the time derivative of lane position. (Lane position was measured in feet.)
- LNRTDEV: The standard deviation of the time derivative of lane position (square root of LNRTVAR).

Accelerometer-related measures:

- ACCVAR: The variance of the smoothed output of the accelerometer, where the output was first converted to feet per second-squared. (Smoothing was accomplished with a low-pass filter having a corner frequency at 7.25 Hz.)
- ACCDEV: The standard deviation of the smoothed output of the accelerometer. (Square root of ACCVAR).
- INTACVAR: The variance of the lateral velocity of the vehicle. (This signal will be obtained by passing the smoothed accelerometer signal through an additional low pass filter with a corner frequency of 0.004 Hz. The unit of

output was volts in which one unit (volt) corresponds to a smoothed lateral velocity of 73.34 feet per second.)

- INTACDEV: The standard deviation of the lateral velocity of the vehicle. (Square root of INTACVAR).
- ACEXEED: The proportion of time that the magnitude of lateral acceleration exceeded 0.3 g (9.66 ft/second^2).

Heading-related measures:

- HPHDGVAR: The variance of the high-pass heading signal in degrees. (The heading signal was passed through a single-pole high-pass filter with a corner frequency of 0.016 Hz.)
- HPHDGDEV: The standard deviation of the high-pass heading signal (square root of HPHDGVAR).

Lane-departure measures:

- VIBPROP: The proportion of time that the seat vibration system was activated.
- NUMVIB: The number of times that the seat vibration system was activated.

<u>Procedure</u>

Subjects who were selected by the research team after screening were contacted and scheduled for a particular date. On the scheduled day, each subject was asked to awaken by 7:00 A.M. The subject was informed that he or she should carry on normal daily activities, but should not take any naps.

Each participant was picked up by an experimenter at 6:00 P.M. and taken to dinner at a fast food restaurant. At dinner, the subject was reminded not to ingest any caffeinated substances or sugared beverages. The subject was permitted to smoke immediately following dinner, but not thereafter.

The participant was brought to the laboratory after dinner. He or she was allowed to watch television, read, study, watch a movie on a VCR, listen to music on headphones, etc. An experimenter remained with the subject until midnight to ensure no napping. During this time, the experimenter gave the participant an information sheet and an informed consent form describing the events to take place in the experiment. These documents appear in Appendix B. The subject was asked to read and sign the consent form.

At midnight, two rested experimenters arrived and relieved the experimenter who stayed with the subject. Immediately afterward, the subject entered the simulator for a training and practice driving session. The subject was instructed in procedures for terminating the experiment if it became necessary. The subject was also instructed in the operation of the drowsiness control device, with an emphasis on the importance of providing the experimenters with accurate data. The rating scale for subjective rating of drowsiness level was explained to the subject. However, the seat vibration system was not introduced to the subject before or during the practice session; this was done so that the subject would not become overly familiar with the outer lane excursion limits used in that system. The subject was asked if he or she had any questions. Once all questions were answered, the lights were dimmed and the practice driving session began. While driving during the first few minutes of this session, the subject had the opportunity to change lanes and alter speed on straight and curved roadways.

Once the subject had become accustomed to the simulator, he or she practiced staying in the right-hand lane of the simulated roadway. To help the subject in recognizing where the lane boundaries were, the experimenters activated the lane-minder device. Initially, the experimenters instructed each subject to drive out of the lane on each side to become accustomed to the lane minder. Then, the subject was instructed to stay in the right-hand lane. If the lane minder sounded frequently, the experimenters verbally reminded the subject of the importance of staying in the lane.

After a few minutes of lane-minder practice, the subject was given a few minutes of practice in adjusting the drowsiness control and using the dashboard-mounted LED as a reminder to adjust the control. After four to five more minutes, the practice session ended. The subject was excused from the simulator as the experimenters made final preparations for the data-gathering session.

Before the data gathering session, the subject was informed that cruise control would be engaged after he or she accelerated to 60 miles per hour (mph). The subject was also told that cruise control would be disengaged if a large lane excursion occurred and to maintain a speed of 60 mph whenever cruise control was disengaged. The subject was reminded to drive as if leaving the right lane could result in accident or injury and to assume that oncoming traffic was possible in the left lane.

At this time, the subject was told about the lane departure warning system and informed that excessive lane excursion on either side would result in a "rumble effect". The subject was told that he or she would have the opportunity to earn a maximum of $12 in bonus money and that the bonus was offered as an incentive to reinforce and reward good driving performance. The subject was told that $4 would be subtracted from the bonus each time the "rumble effect" came on. After three such incidents, the subject's bonus would be gone.

Once the subject understood all instructions, he or she returned to the simulator, the lights were dimmed, and the data-gathering session began. When the driver reached 60 mph and cruise control was engaged, the data-gathering computational equipment was started. The subject was asked to drive the simulator as he or she would drive an actual midsize car with automatic transmission, staying within the boundaries of the right-hand lane. The computational equipment monitored the performance measures and averaged and recorded each measure once each minute. An experimenter constantly tracked eye closure by viewing a video image of the subject's face and tracking eyelid movement with the linear potentiometer. The subject inputed his or her perceived drowsiness level throughout the run with the drowsiness control.

The lane minder system operated during the first five minutes of the experimental run. Afterwards, it was turned off, and the subject was told that the lane minder had been deactivated. If the outer lane excursion limits were exceeded at any time during the experimental session, seat back and seat pan vibration were automatically activated and remained in operation until the driver brought the vehicle back within the outer limits. Occurrences of vibration and the proportion of time within each minute that vibration was active were recorded in the data file. If vibration occurred, an experimenter immediately subjectively evaluated the drowsiness level of the subject.

At the end of the driving period, cruise control was disengaged and the subject was instructed to slow to a complete stop. The subject exited the simulator and was asked if he or she had any further questions about the experiment. If the subject had no further questions, he or she was paid, thanked, and driven home. The experimenter who drove the subject home was on a different sleep schedule than the subject and therefore was not drowsy.

Data Analysis Overview

The one-minute average data computed and stored by the WIN 486-33i computer for each minute of the experiment served as the starting point for data analysis. These data were imported into both a spreadsheet package and a statistical package. A data truncation procedure was then undertaken to ensure that only realistic data were used in subsequent analyses. An examination of the data sets for each subject revealed that if a subject exceeded the outer lane excursion limits and caused the seat vibration effect to be activated more than four times, subsequent vibration activations became frequent and sustained extreme drowsiness levels were noted. As a result, it was concluded that drivers of actual vehicles likely would have either pulled off the road to rest or become involved in an accident by the fourth activation of the seat vibration system. Using this as a guideline, data taken after the fourth vibration for each subject who activated more than four vibrations were deleted and not considered in subsequent analyses. The point at which data were truncated is shown by the double line in Table 1. Following truncation, the data for each measure were plotted and examined. One subject had a minute of data (Subject 12, minute 60) that contained outlying data points for several measures; these

	Minute of Vibration Occurrence							
Subject	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th and higher**
1	100	140	148	154				
2	57	78	124	136	137	147		
3	6†	20†	55†	70	74‡	75‡	76‡	many more
4	32	72	84	85	89	93	93	3 more
5	100							
6	61†	88	149					
8*	45	47	56	57	60	63	65	many more
9								
10	28	49	86	112	114	115	124	3 more
11	100	104	113	126	131	133	133	2 more
12	45	48	60	71	71	73	75	many more
13	95							

* Data for Subject 7 were not used; Subject 7 was replaced with Subject 13.

† Not considered as a "drowsy" activation of lane departure warning system in distribution analysis.

‡ These activations of the lane departure warning system were used in the distribution analysis in place of earlier activations not condsidered to be "drowsy" activations.

Table 1: History of Vibration Activations (data truncated for each subject after fourth vibration)

data points were clipped, limiting them to more realistic maximum values.

Additional data sets were then created in which the data were averaged over two-minute, three-minute, and six-minute intervals. The two-minute interval data were calculated by taking an average of the data for two one-minute intervals for each variable. For example, one-minute intervals one and two were averaged to give two-minute interval one, one-minute intervals three and four were averaged to give two-minute interval two, and so on. Three-minute and six-minute interval data were calculated likewise with their respective numbers of intervals used for averaging.

Following averaging, correlation analyses were performed on the four resulting data sets. Values for three driver status measures (EYEMEAS, PERCLOS, and DRVDROW) and two driver performance measures (LANDEV and LANEX) were correlated with all other values in the data set. The objectives were to determine which performance measures were the best predictors of drowsiness, to determine how well the definitional measures of drowsiness correlated with one another, and to determine the best time interval over which to average the data (1, 2, 3, or 6 minutes). Later, a similar analysis was performed in which the composite status measures SLEEPER1, SLEEPER2, and SLEEPER3 were correlated with all other measures in the data set.

For the driver status measures PERCLOS, EYEMEAS, and DRVDROW and the driver performance measures LANEX, LANDEV, and LNMNSQ, a set of distribution analyses were performed. The one-minute interval and three-minute interval data sets were used for these analyses. First, any activations of the seat vibration system for which neither the subject nor the experimenter reported that the subject had a high level of drowsiness were identified. There were four such activations, which are noted in Table 1. The activations were replaced with subsequent activations of the seat vibration system if they were available (also noted in Table 1). Driver drowsiness and performance data points recorded immediately before the remaining activations of the seat vibration system were isolated into a separate data set. In the remaining one-minute and three-minute data sets, data points occurring near activations of the seat vibration system were eliminated. In the one-minute data set, all data points occurring within 10 minutes before a vibration occurrence or within 5 minutes after a vibration occurrence were eliminated; in the three-minute data, all data points occurring within 9 minutes (3 intervals) before a vibration occurrence or within 6 minutes (2 intervals) after a vibration occurrence were eliminated. Once the data sets were separated and manipulated in this manner, histograms were charted so that the distributions of values for each of the six measures during drowsy periods and non-drowsy periods, as determined by activation of the seat vibration system, could be compared with one another.

The multiple regression analyses from which new driver status and performance algorithms were developed were performed using the three-minute interval and six-minute interval data sets (with truncation of unrealistic data, but without the data separation that was used for the histograms). As in previous experimentation, driver status algorithms were developed with the purpose of finding optimized combinations of independent measures obtainable while driving that would best predict "drowsiness" during driving sessions. Multiple regression has many advantages for use in a drowsy driver detection system that have been documented previously (Wierwille et al., 1994).

Backward stepwise multiple regression analyses were performed on all twelve subjects. The beta weights of the various measures were first examined, allowing for the removal of measures that were strongly linearly related. Any measures that contained large, equal and opposite coefficients (and thus contained approximately the same predictive information) were eliminated one at a time. Then, the elimination of measures with $p > 0.05$ significance levels began, starting with the measure having the smallest F-ratio. This continued until only significant measures remained in the analysis. Afterward, each measure which had been removed was substituted back into the set to determine if it substantially improved the regression.

Several sets of algorithms intended to detect the drowsy status of a driver in an on-board detection system implementation were developed. Algorithms in each set were developed to estimate PERCLOS, EYEMEAS, DRVDROW, SLEEPER1, SLEEPER2, and SLEEPER3. Each set of algorithms used a slightly different set of independent measures so that the loss of certain measures for which data collection problems might arise in an actual vehicle on actual roadways will not cause the failure of the entire detection system. Specifically, it is anticipated that lane-related measures would be collectable for a majority of the time that a detection system is in operation, but would not be collectable for certain intervals. Previous studies have shown that the best driver status algorithms usually contain lane-related measures, but alternative algorithms that do not contain lane-related measures are desirable for use during intervals when the lane boundaries are not detectable. This concept has been referred to as the "step up, step down" approach. Table 2 shows the different sets of measures used in the regression analyses. (In Table 2, "accelerometer" refers to lateral accelerometer.) Following development of the algorithms, classification analyses were performed. For all algorithms with correlation coefficients higher than 0.4, scatterplots were generated with algorithm output values on one axis and the measured values the algorithms were designed to predict on the other. Thresholds were set based on examination of the scatterplots, and classification matrices were subsequently constructed for each

Independent Measures		Dependent Measures					
		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer						
E	Steering, Accelerometer, & HPHDGDEV/VAR						
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ						
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)						

Table 2: Sets of Measures Used In Multiple Regression Analyses for Each Dependent (Definitional) Variable.

algorithm. The classification matrices examined the predictability of awake and drowsy categories of wakefulness at the threshold value.

Following development and classification of the driver status algorithms, the effect of combining driver status and driver performance on the classification matrices was examined. The arrangement was similar to the "or" criterion used previously in the test and evaluation experiment. In this arrangement, the driver was classified as impaired if the drowsiness level (status algorithm output) exceeded its threshold, if the performance level (measured by LANEX or LNMNSQ) exceeded a threshold, or if both measures exceeded their threshold values. For those independent measure groups where lane-related measures were not included, new algorithms were developed using the independent measure groups to predict LANEX and LNMNSQ, and the status algorithm outputs were "ored" with the resulting eLANEX (estimated LANEX) and eLNMNSQ (estimated LNMNSQ) outputs.

RESULTS AND DISCUSSION

Correlation Analyses

Tables 3a, 3b, 3c, and 3d show the Pearson product-moment correlation results for EYEMEAS, PERCLOS, DRVDROW, LANDEV, and LANEX for the 1, 2, 3, and 6-minute interval data sets, respectively. As in previous studies, it was found that a trend existed toward increasing correlations with longer averages. However, there were two noteworthy differences between the correlations for the current data set and previous correlation results: the correlation values were generally much lower, and the incremental correlation values between time intervals (that is, between the 1-minute interval data set and the 2-minute interval data set, between the 2-minute interval data set and the 3-minute data set, and between the 3-minute interval data set and the 6-minute interval data set) were lower.

It was hypothesized that the differences in properties of the correlation coefficients between the current study and previous studies were a result of the lane enforcement procedures. Large lane excursions that took place in the previous studies did not occur in this study due to the controls placed upon lane keeping. These large, uncontrolled lane excursions corresponded with drowsy periods of driving, and resulted in high correlations between lane-related measures and definitional drowsiness measures. Control of large lane excursions resulted in substantially lower correlations. Also, it is likely that lower incremental differences between correlations for the 1, 2, 3, and 6-minute interval data sets are a result of the lower magnitudes of the correlations.

It was also noted that incremental differences between correlations tended to become smaller as the time interval over which data were averaged increased. In some cases, the correlation coefficients for the 3-minute interval data set were actually higher than those for the 6-minute interval data set. However, both the three-minute and six-

R Values	EYEMEAS	PERCLOS	DRVDROW	LANDEV	LANEX
EYEMEAS		0.445	0.503	0.234	0.237
PERCLOS	0.445		0.177	0.230	0.224
DRVDROW	0.503	0.177		0.236	0.127
STVELV	-0.039	0.024	0.373	0.316	0.050
LGREV	-0.016	0.015	0.214	0.370	0.115
MDREV	-0.077	-0.010	0.395	0.410	0.113
SMREV	-0.108	-0.065	0.149	-0.102	-0.045
STEXED	0.009	-0.012	0.024	0.100	0.013
NMRHOLD	0.085	0.019	-0.321	-0.217	-0.077
THRSHLD	0.100	0.080	-0.212	-0.096	-0.046
LANDEV	0.234	0.230	0.236		0.513
LANVAR	0.230	0.253	0.217	0.961	0.544
LNMNSQ	0.294	0.249	0.188	0.663	0.873
LANEX	0.237	0.224	0.127	0.513	
LNERRSQ	0.143	0.186	0.089	0.372	0.451
LNRTDEV	0.109	0.145	0.298	0.760	0.334
LNRTVAR	0.092	0.151	0.279	0.711	0.322
ACCDEV	-0.004	0.000	0.045	0.507	0.333
ACCVAR	-0.006	-0.012	0.017	0.453	0.330
INTACDEV	-0.016	-0.020	-0.020	0.373	0.332
INTACVAR	-0.010	-0.020	-0.013	0.342	0.355
ACEXEED	-0.034	-0.027	0.019	0.242	0.261
HPHDGDEV	0.098	0.133	0.302	0.745	0.323
HPHDGVAR	0.081	0.138	0.284	0.699	0.310
VIBPROP	0.103	0.195	0.072	0.316	0.252
NUMVIB	0.094	0.169	0.075	0.318	0.267

Table 3a: Correlation Coefficients Between Measures for 1-Minute Interval Data Set.

R Values	EYEMEAS	PERCLOS	DRVDROW	LANDEV	LANEX
EYEMEAS		0.495	0.520	0.271	0.302
PERCLOS	0.495		0.228	0.308	0.332
DRVDROW	0.520	0.228		0.274	0.156
STVELV	-0.040	0.022	0.381	0.327	0.038
LGREV	-0.020	0.019	0.239	0.387	0.098
MDREV	-0.080	-0.005	0.416	0.435	0.113
SMREV	-0.120	-0.086	0.159	-0.126	-0.042
STEXED	0.011	-0.018	0.022	0.116	0.011
NMRHOLD	0.100	0.034	-0.343	-0.213	-0.085
THRSHLD	0.103	0.090	-0.230	-0.083	-0.037
LANDEV	0.271	0.308	0.274		0.543
LANVAR	0.281	0.359	0.261	0.968	0.571
LNMNSQ	0.373	0.371	0.231	0.704	0.888
LANEX	0.302	0.332	0.156	0.543	
LNERRSQ	0.223	0.343	0.125	0.401	0.488
LNRTDEV	0.126	0.198	0.328	0.798	0.349
LNRTVAR	0.111	0.210	0.314	0.749	0.332
ACCDEV	-0.009	0.013	0.052	0.524	0.344
ACCVAR	-0.011	-0.003	0.022	0.467	0.336
INTACDEV	-0.019	-0.013	-0.018	0.396	0.327
INTACVAR	-0.013	-0.014	-0.013	0.370	0.332
ACEXEED	-0.026	-0.002	0.026	0.282	0.262
HPHDGDEV	0.112	0.180	0.331	0.783	0.338
HPHDGVAR	0.098	0.192	0.318	0.736	0.318
VIBPROP	0.164	0.322	0.104	0.348	0.287
NUMVIB	0.135	0.257	0.099	0.351	0.286

Table 3b: Correlation Coefficients Between Measures for 2-Minute Interval Data Set.

R Values	EYEMEAS	PERCLOS	DRVDROW	LANDEV	LANEX
EYEMEAS		0.530	0.530	0.287	0.346
PERCLOS	0.530		0.248	0.314	0.360
DRVDROW	0.530	0.248		0.291	0.176
STVELV	-0.034	0.026	0.392	0.340	0.034
LGREV	-0.005	0.020	0.255	0.410	0.111
MDREV	-0.078	-0.001	0.429	0.447	0.111
SMREV	-0.122	-0.082	0.175	-0.171	-0.057
STEXED	0.035	-0.023	0.035	0.128	0.000
NMRHOLD	0.098	0.023	-0.367	-0.197	-0.066
THRSHLD	0.101	0.068	-0.253	-0.054	-0.028
LANDEV	0.287	0.314	0.291		0.562
LANVAR	0.298	0.359	0.277	0.972	0.601
LNMNSQ	0.405	0.391	0.248	0.718	0.903
LANEX	0.346	0.360	0.176	0.562	
LNERRSQ	0.244	0.334	0.140	0.413	0.564
LNRTDEV	0.128	0.198	0.341	0.811	0.368
LNRTVAR	0.113	0.208	0.328	0.763	0.351
ACCDEV	-0.002	0.012	0.057	0.505	0.347
ACCVAR	-0.007	0.000	0.020	0.452	0.334
INTACDEV	-0.020	-0.029	-0.024	0.364	0.326
INTACVAR	-0.018	-0.028	-0.021	0.339	0.322
ACEXEED	-0.040	-0.017	0.019	0.293	0.249
HPHDGDEV	0.115	0.182	0.344	0.796	0.353
HPHDGVAR	0.099	0.190	0.332	0.750	0.337
VIBPROP	0.177	0.330	0.127	0.359	0.365
NUMVIB	0.164	0.287	0.130	0.369	0.312

Table 3c: Correlation Coefficients Between Measures for 3-Minute Interval Data Set.

R Values	EYEMEAS	PERCLOS	DRVDROW	LANDEV	LANEX
EYEMEAS		0.561	0.545	0.308	0.423
PERCLOS	0.561		0.279	0.363	0.464
DRVDROW	0.545	0.279		0.326	0.212
STVELV	-0.028	0.022	0.408	0.350	0.013
LGREV	0.002	0.032	0.293	0.418	0.072
MDREV	-0.078	-0.006	0.453	0.450	0.085
SMREV	-0.139	-0.112	0.188	-0.259	-0.079
STEXED	0.060	-0.028	0.074	0.207	0.035
NMRHOLD	0.113	0.046	-0.405	-0.145	-0.027
THRSHLD	0.118	0.091	-0.282	0.012	0.001
LANDEV	0.308	0.363	0.326		0.561
LANVAR	0.323	0.410	0.316	0.978	0.596
LNMNSQ	0.467	0.472	0.290	0.716	0.927
LANEX	0.423	0.464	0.212	0.561	
LNERRSQ	0.312	0.401	0.184	0.447	0.619
LNRTDEV	0.134	0.206	0.370	0.830	0.360
LNRTVAR	0.116	0.205	0.359	0.784	0.336
ACCDEV	-0.021	0.000	0.092	0.456	0.313
ACCVAR	-0.028	-0.018	0.046	0.390	0.302
INTACDEV	-0.035	-0.054	-0.016	0.273	0.270
INTACVAR	-0.027	-0.049	-0.011	0.256	0.255
ACEXEED	-0.040	-0.029	0.041	0.277	0.202
HPHDGDEV	0.120	0.189	0.373	0.814	0.343
HPHDGVAR	0.102	0.188	0.363	0.769	0.320
VIBPROP	0.225	0.380	0.190	0.400	0.405
NUMVIB	0.202	0.347	0.193	0.438	0.349

Table 3d: Correlation Coefficients Between Measures for 6-Minute Interval Data Set.

R Values	SLEEPER1	SLEEPER2	SLEEPER3
EYEMEAS	0.863	0.918	0.646
PERCLOSE	0.438	0.471	0.927
DRVDROW	0.886	0.822	0.594
STVELV	0.216	0.160	0.174
LGREV	0.149	0.116	0.115
MDREV	0.213	0.148	0.165
SMREV	0.038	0.000	-0.001
STEXED	0.040	0.040	-0.006
NMRHOLD	-0.165	-0.105	-0.123
THRSHLD	-0.096	-0.050	-0.041
LANDEV	0.331	0.329	0.374
LANVAR	0.328	0.329	0.405
LNMNSQ	0.370	0.388	0.421
LANEX	0.294	0.314	0.367
LNERRSQ	0.217	0.229	0.332
LNRTDEV	0.274	0.246	0.297
LNRTVAR	0.257	0.229	0.299
ACCDEV	0.033	0.025	0.032
ACCVAR	0.008	0.005	0.008
INTACDEV	-0.025	-0.024	-0.033
INTACVAR	-0.022	-0.022	-0.031
ACEXEED	-0.010	-0.018	-0.006
HPHDGDEV	0.268	0.238	0.284
HPHDGVAR	0.252	0.222	0.287
VIBPROP	0.173	0.178	0.323
NUMVIB	0.167	0.171	0.288

Table 4a: Correlation Coefficients Between SLEEPER1, SLEEPER2, and SLEEPER3, and All Other Measures for 3-Minute Interval Data Set.

R Values	SLEEPER1	SLEEPER2	SLEEPER3
EYEMEAS	0.865	0.920	0.677
PERCLOSE	0.470	0.504	0.914
DRVDROW	0.892	0.830	0.645
STVELV	0.228	0.172	0.190
LGREV	0.176	0.139	0.149
MDREV	0.229	0.160	0.187
SMREV	0.038	-0.004	-0.009
STEXED	0.077	0.075	0.009
NMRHOLD	-0.181	-0.115	-0.135
THRSHLD	-0.105	-0.054	-0.047
LANDEV	0.361	0.358	0.427
LANVAR	0.363	0.362	0.460
LNMNSQ	0.425	0.446	0.498
LANEX	0.355	0.381	0.459
LNERRSQ	0.279	0.294	0.397
LNRTDEV	0.293	0.262	0.321
LNRTVAR	0.277	0.245	0.315
ACCDEV	0.044	0.030	0.039
ACCVAR	0.012	0.003	0.006
INTACDEV	-0.028	-0.031	-0.049
INTACVAR	-0.021	-0.023	-0.043
ACEXEED	0.003	-0.007	-0.005
HPHDGDEV	0.288	0.255	0.308
HPHDGVAR	0.272	0.238	0.303
VIBPROP	0.235	0.238	0.383
NUMVIB	0.225	0.225	0.358

Table 4b: Correlation Coefficients Between SLEEPER1, SLEEPER2, and SLEEPER3, and All Other Measures for 6-Minute Interval Data Set.

minute interval data sets consistently yielded higher correlation coefficients than either the one-minute interval data set or the two-minute interval data set. For this reason, it was decided to remove the one-minute and two-minute interval data sets from further consideration in multiple regression and classification analyses, since the three-minute and six-minute interval data sets were considered likely to yield algorithms with more predictive power.

A final observation made from the correlation results shown in Tables 3a, 3b, 3c, and 3d was that DRVDROW, for which data were collected for the first time in this study, showed promise as a reliable definitional measure of drowsiness on a level comparable to that of PERCLOS and EYEMEAS. DRVDROW correlated relatively well with EYEMEAS in the three-minute and six-minute interval data sets ($R = 0.530$ and $R = 0.545$, respectively). Also, DRVDROW correlations with some of the independent measures, particularly steering-reversal measures and heading-related measures, were much higher than correlations between either PERCLOS or EYEMEAS and the same measures. This pointed to the possibility that DRVDROW might be able to predict some aspects of driver drowsiness better than PERCLOS or EYEMEAS. Furthermore, it suggested that it might be advantageous to try developing new variables that combine DRVDROW and either PERCLOS and EYEMEAS so that the aspects of drowsiness that are represented well by eye closure and the aspects of drowsiness that are represented well by driver subjective opinion are combined into a single measure.

Therefore, the measures SLEEPER1, SLEEPER2, and SLEEPER3 (described previously) were developed. SLEEPER1 and SLEEPER2 combine DRVDROW and EYEMEAS, while SLEEPER3 combines DRVDROW and PERCLOS. Tables 4a and 4b show the Pearson product-moment correlation results between the new SLEEPER1, SLEEPER2, and SLEEPER3 variables and all other variables in the data set. All three SLEEPER variables had correlation results comparable to those of PERCLOS, EYEMEAS, and DRVDROW, signifying that they should be retained for further analysis.

Distribution Analyses

Because the correlation analyses produced lower R values than those observed in previous studies, it was decided to investigate an alternate approach to algorithm development concurrently with algorithm development through the previously used multiple regression analyses. It was desired to determine if characteristics of data taken for intervals immediately prior to an activation of the seat vibration system were substantially different than characteristics of data taken during "non-drowsy" periods. This led to the distribution analyses, which have been described previously.

The resulting histograms for the one-minute interval data set are shown in Appendix C, and those for the three-minute interval data set are shown in Appendix D. The number under each column in each histogram represents the upper limit of the bin range for that column, while the number under the column immediately to the left of each column represents the lower limit of the bin range for that column.

It was hoped that the results of the distribution analyses would show a clear separation between the distributions for "drowsy" data taken immediately before activations of the seat vibration system and "non-drowsy" data taken at other times during the experimental sessions. Unfortunately, an examination of Appendices C and D reveals that this is not the case. For all six measures and both time intervals, the two distributions essentially completely overlap one another.

The results demonstrate that it is not possible to accurately predict when a driver will experience extreme lane exceedances using eye-closure-related measures, conventional lane-related measures, or the subjective opinion of the driver as to his or her level of drowsiness. Therefore, it is not possible to develop any type of driver drowsiness detection algorithm based on differing characteristics between data taken near occurrences of extreme lane deviation and data taken at other times. As a result, further efforts toward algorithm development were concentrated on using the multiple regression approach with whole data sets that has been used in previous studies.

Multiple Regression

Driver Status (Drowsiness) Algorithms

Tables 5a and 5b are summaries of results that were obtained from the multiple regression analyses performed on three-minute and six-minute interval data sets, respectively. No baselining techniques were used. More complete results of the regression analyses for three-minute data can be found in Appendix E, and more complete results for six-minute data can be found in Appendix F.

An examination of the R values in Tables 5a and 5b shows a substantial difference between the algorithms developed from data collected in the original algorithm development experiment (Wierwille et al., 1994) and algorithms developed from data collected in the current experiment. The R values for the six dependent variables collected in the current 3-minute data set ranged from 0.140 to 0.539, and the R values for the same variables collected in the current six-minute data set ranged from 0.133 to 0.614. In contrast, the R values for the five dependent variables collected in the original algorithm development experiment for independent variable groups D through G ranged from 0.677 to 0.886. Clearly, the previously developed algorithms were able to predict drowsiness levels more accurately than the new algorithms developed from lane-enforced data. Also, there appeared to be no appreciable difference in the ability to predict drowsiness levels between the three-minute algorithms and the six-minute algorithms developed from the lane-enforced data.

	Independent Measures	Dependent Measures					
		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer	0.140	0.152	0.467	0.216	0.160	0.186
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.386	0.315	0.512	0.351	0.303	0.428
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.482	0.493	0.554	0.481	0.475	0.534
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	0.491	0.505	▲	▲	▲	0.539

NOTE: ▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same R and fewer terms.

Table 5a: Summary Table of Multiple Regression Analyses Showing R Values for 3-Minute Interval Data Set and Dependent Driver Status Measures.

	Independent Measures	Dependent Measures					
		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer	0.214	0.178	0.499	0.223	0.133	0.214
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.404	0.340	0.538	0.326	0.325	0.422
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.575	0.569	0.583	0.547	0.532	0.614
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	▲	▲	▲	▲	0.544	▲

NOTE: ▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same R and fewer terms.

Table 5b: Summary Table of Multiple Regression Analyses Showing R Values for 6-Minute Interval Data Set and Dependent Driver Status Measures.

As in previous studies, it is apparent that algorithms that include lane-related measures (using regressor groups F and G) predict drowsiness better than algorithms that do not include lane-related measures (regressor groups D and E). However, it was also found that the inclusion of the heading-related measures HPHDGDEV and HPHDGVAR (regressor group E) yielded algorithms with higher R values than those developed with only steering and accelerometer-related measures (regressor group D).

Though the relatively low R values of the new set of algorithms are disappointing results, they are not surprising. The set of drowsiness algorithms developed from the data collected in the original algorithm development experiment performed poorly in the test and evaluation experiment. It was hypothesized that the reason for this poor performance was the enforcement of the lane positioning of the vehicle in that experiment, and it was recommended that new algorithms be developed under lane-enforced conditions. The current results show that algorithms developed under lane-enforced conditions do not provide R values as high in estimating drowsiness as those developed under conditions where large lane excursions were not tightly controlled. Therefore, it can be concluded that when lane deviations are controlled in such a manner as to reflect actual driving, the R values of the algorithms will inevitably be lower.

Driver Performance Algorithms

Tables 6a and 6b are summaries of results obtained from multiple regression analyses on three-minute and six-minute data sets, respectively, using the performance measures LANEX and LNMNSQ as dependent variables. These variables can be measured directly when lane-related information is available, but it is desirable to have algorithms to predict them for situations where lane information is not available. Such algorithms yield performance measures which can used in "OR" classification analyses.

	Independent Measures	Dependent Measures	
		LANEX	LNMNSQ
D	Steering and Accelerometer	0.367	0.493
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.497	0.664

Table 6a: Summary Table of Multiple Regression Analyses Showing R Values for 3-Minute Interval Data Set and Dependent Driver Performance Measures.

Independent Measures		Dependent Measures	
		LANEX	LNMNSQ
D	Steering and Accelerometer	0.348	0.485
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.514	0.680

Table 6b: Summary Table of Multiple Regression Analyses Showing R Values for 6-Minute Interval Data Set and Dependent Driver Performance Measures.

As can be seen in Tables 6a and 6b, the R values for the eight algorithms developed range from 0.348 to 0.680. Again, these R values are somewhat low, but they are in the same general range as the R-values for the new driver status algorithms, and most have R values high enough to be used in further "OR" classification matrix analyses.

Classification Matrices

Driver Status (Drowsiness)

Unconditional classification matrix analyses were performed for all driver status algorithms that had correlation coefficients of 0.4 or above. (The word "unconditional" is used here to describe classifications in which there is no "or"ing with performance.) An examination of algorithms with R values below 0.4 showed that the algorithms did not merit further analysis; often, the backwards stepwise regression analyses only left a single independent variable in the regression equation.

Threshold values for each of the six measures were based on examination of scatterplots constructed with the algorithm output on one axis and the measured variable on the other. The thresholds were set as follows:

PERCLOS	0.012
EYEMEAS	2000
DRVDROW	70

SLEEPER1	1.7
SLEEPER2	3
SLEEPER3	1.4

Each algorithm output data point and each measured data point was classified as "drowsy" if it was greater than or equal to the threshold value and as "awake" if it was less than the threshold value. Points were then paired on a casewise basis and grouped into categories of correct detections, correct rejections, false alarms, and missed detections. Apparent accuracy rates (APARs) were determined by dividing the number of correct classifications (correct detections and rejections) by the total number of paired data points.

The unconditional classification matrices for the drowsiness measures appear directly beneath the regression summaries for their respective algorithms in Appendices E and F. Summaries of the apparent accuracy rates obtained for the classification analyses appear in Tables 7a and 7b for three-minute average data and six-minute average data, respectively.

	Independent Measures	Dependent Measures					
		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer			0.692			
E	Steering, Accelerometer, & HPHDGDEV/VAR			0.703			0.854
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.928	0.857	0.719	0.785	0.852	0.850
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	0.928	0.863	▲	▲	▲	0.854

KEY:

▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same APAR and fewer terms.

Blank cells indicate that no classification matrices were generated for the algorithm because its R value was less than 0.4.

Table 7a: Summary Table of Unconditional Classification Matrix Analyses Showing Apparent Accuracy Rates for Driver Status Algorithms developed from 3-Minute Interval Data Set.

	Independent Measures	Dependent Measures: PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer			0.702			
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.916		0.714			0.853
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.937	0.861	0.735	0.782	0.840	0.840
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	▲	▲	▲	▲	0.832	▲

KEY:

▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same APAR and fewer terms.

Blank cells indicate that no classification matrices were generated for the algorithm because its R value was less than 0.4.

Table 7b: Summary Table of Unconditional Classification Matrix Analyses Showing Apparent Accuracy Rates for Driver Status Algorithms developed from 6-Minute Interval Data Set.

The APAR values obtained here are surprisingly high. Even though the R values for the algorithms developed in the current experiment are much lower than those developed previously, the APAR values are in a similar range to those obtained from previously developed algorithms. PERCLOS algorithms yielded some of the highest APAR values when classified. As was the case with the R values, there appears to be no appreciable difference between the performance of three-minute algorithms and six-minute algorithms in the ability to classify driver status correctly based on unconditional APARs.

An examination of the unconditional classification matrices in Appendices E and F reveals that false alarm rates (where the algorithm classified the driver as drowsy but the measured variable classified the driver as awake) were much lower than missed detection rates (where the algorithm classified the driver as awake but the measured variable classified the driver as drowsy). Though it is not desirable to have a system that misses detections, it is less desirable to have a system that produces a large number of false alarms. In an actual system, a high false alarm rate will likely translate to a low acceptance rate of the system by the driving population.

Driver Status <u>*or*</u> *Performance*

Because there were missed detections in the unconditional classification matrices, a process in which two criteria could be used in detection instead of one was implemented in new sets of classification matrices, called "conditional" classification matrices. In these matrices, each algorithm output data point and each measured data point were classified as before. However, data for LANEX and LNMNSQ were also classified as "awake" or "drowsy". For independent measure sets F and G, LANEX and LNMNSQ were directly measurable. Therefore, all LANEX and LNMNSQ data points were classified as either correct detections or correct rejections; since no algorithm needed to be used, there were no missed detections or false alarms. Thresholds were set at 0.066667 for LANEX and at 3 for LNMNSQ. The effect of combining a drowsiness algorithm and measured LANEX or LNMNSQ was to move data points from the drowsiness algorithm classification matrices from classification as missed detections, false alarms, or correct rejections to classification as correct detections if the LANEX or LNMNSQ data point for that minute was above threshold. The result of this was more correct classifications than the unconditional classification matrices, resulting in higher APARs. These results can be seen in Tables 8a, 8b, 8c, and 8d.

In independent measure sets D and E, LANEX and LNMNSQ were not available; therefore, in the conditional classification matrices the eLANEX and eLNMNSQ algorithms that appear in Appendix G were used. The same threshold values as before were used. The disadvantage in using these algorithms was that they contained incorrect

Independent Measures		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer			✦			
E	Steering, Accelerometer, & HPHDGDEV/VAR			0.650*			0.802*
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.966	0.890	0.757	0.823	0.882	0.899
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	0.966	0.897	▲	▲	▲	0.903

(Dependent Measures: PERCLOS through SLEEPER3)

KEY:

▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same APAR and fewer terms.

✦ denotes that the classification matrix was not generated because the R value of the eLANEX algorithm was less than 0.4.

* indicates that an eLANEX algorithm was used in the OR classification matrix. For all other values, measured LANEX was used.

Blank cells indicate that no classification matrices were generated for the algorithm because its R value was less than 0.4

Table 8a: Summary Table of Conditional Classification Matrix Analyses Showing Apparent Accuracy Rates for Driver Status Algorithms developed from 3-Minute Interval Data Set -OR- LANEX/eLANEX.

Independent Measures		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer			0.654*			
E	Steering, Accelerometer, & HPHDGDEV/VAR			0.667*			0.808*
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.966	0.890	0.764	0.829	0.884	0.899
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	0.964	0.897	▲	▲	▲	0.903

(Dependent Measures: PERCLOS through SLEEPER3)

KEY:

▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same APAR and fewer terms.

* indicates that an eLNMNSQ algorithm was used in the OR classification matrix. For all other values, measured LNMNSQ was used.

Blank cells indicate that no classification matrices were generated for the algorithm because its R value was less than 0.4

Table 8b: Summary Table of Conditional Classification Matrix Analyses Showing Apparent Accuracy Rates for Driver Status Algorithms developed from 3-Minute Interval Data Set -OR- LNMNSQ/eLNMNSQ.

Independent Measures		Dependent Measures					
		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer			✦			
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.853*		0.681*			0.815*
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.962	0.891	0.769	0.828	0.878	0.887
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	▲	▲	▲	▲	0.874	▲

KEY:

▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same APAR and fewer terms.

✦ denotes that the classification matrix was not generated because the R value of the eLANEX algorithm was less than 0.4.

* indicates that an eLANEX algorithm was used in the OR classification matrix. For all other values, measured LANEX was used.

Blank cells indicate that no classification matrices were generated for the algorithm because its R value was less than 0.4

Table 8c: Summary Table of Conditional Classification Matrix Analyses Showing Apparent Accuracy Rates for Driver Status Algorithms developed from 6-Minute Interval Data Set -OR- LANEX/eLANEX.

Independent Measures		Dependent Measures					
		PERCLOS	EYEMEAS	DRVDROW	SLEEPER1	SLEEPER2	SLEEPER3
D	Steering and Accelerometer			0.672*			
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.857*		0.689*			0.824*
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.966	0.891	0.769	0.824	0.874	0.891
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	▲	▲	▲	▲	0.870	▲

KEY:

▲ denotes that introduction of the variable did not improve the R value. See entry directly above for model with same APAR and fewer terms.

* indicates that an eLNMNSQ algorithm was used in the OR classification matrix. For all other values, measured LNMNSQ was used.

Blank cells indicate that no classification matrices were generated for the algorithm because its R value was less than 0.4

Table 8d: Summary Table of Conditional Classification Matrix Analyses Showing Apparent Accuracy Rates for Driver Status Algorithms developed from 6-Minute Interval Data Set -OR- LNMNSQ/eLNMNSQ.

classifications; they introduced additional missed detections and false alarms when the matrices were "or"ed. The result of this, which can be seen by comparing Tables 8a, 8b, 8c, and 8d with Tables 7a and 7b, was that the apparent accuracy rates were lower for the composite "or"ed matrices than for the unconditional classification matrices in every case where eLANEX or eLNMNSQ algorithms were used. In contrast, introducing measured LANEX or measured LNMNSQ resulted in a higher apparent accuracy rate in each case.

A comparison of Tables 8a, 8b, 8c, and 8d reveals that the performance of LANEX is roughly equivalent to the performance of LNMNSQ in raising the APAR values from the unconditional APAR values. Also, the performance of three-minute interval data is roughly equivalent to the performance of six-minute interval data.

Conclusions

The primary focus of this experiment was to collect a new set of data from sleep-deprived subjects, using lane enforcement procedures, and develop new algorithms from that data for the detection of driver drowsiness. The restrictions placed on lane-keeping behavior and the truncation of the resulting data produced a data set with characteristics believed to be much closer to those of actual, on-the-road driving than data sets that were collected in previous experiments. However, the lack of large lane deviations resulted in much lower correlations between individual measures, specifically between drowsiness measures (PERCLOS, EYEMEAS, and DRVDROW) and performance-related measures, than had been observed previously. Based on the outcome of the test and evaluation experiment, this result was expected.

The distribution analyses demonstrated that "lane busts", or exceedances of the lane boundaries by three feet or more on either side, could not be predicted reliably by measures such as PERCLOS, EYEMEAS, DRVDROW, or LANDEV. Some missed detections and/or false alarms will be unavoidable, even if PERCLOS, EYEMEAS, or DRVDROW can be detected with perfect accuracy. Therefore, to avoid run-off-road accidents in a drowsy driver detection system, an auxiliary system that can measure lane position directly and nearly instantaneously must be used.

The new algorithms developed in this experiment all had lower multiple-R values than the algorithms developed in previous experiments. Again, this was not surprising given the results of the test and evaluation experiment. Multiple-R values for most algorithms developed without lane-related variables in the set of regressors were so low that the algorithms have fundamentally no predictive ability. However, the classification accuracy of the new algorithms was much higher than expected and in a comparable range to that of the algorithms developed previously. In addition, it was shown that three-minute average algorithms perform nearly as well as six-minute average algorithms;

there is fundamentally no difference between the accuracy levels for the two time intervals.

Though constructing composite, conditional "OR" classification matrices with algorithm estimates of LANEX or LNMNSQ (that is, eLANEX or eLNMNSQ) did not improve classification accuracy, such matrices constructed with measured LANEX or LNMNSQ did improve classification accuracy levels.

Recommendations

The results of this experiment combined with the results of previous experiments, are sufficient to specify the design of a drowsy driver detection/alarm/countermeasures system (DDDACS) for use in full-scale testing in an actual vehicle. The system should be a three-stage system, similar to those proposed previously. It should have a detection phase, an alarm phase, and a countermeasure phase. The detection phase should be based on either driver status (drowsiness) exceeding a threshold, driver performance (LANEX) exceeding a threshold, or both. Using the algorithms developed in the current experiment, the simultaneous monitoring of status and performance in this manner should produce reasonable detection accuracy when lane information is available. When lane information is not available, however, reasonable detection accuracy cannot be achieved and the system should not be active. A "step up, step down" system is not feasible due to the lack of detection accuracy in algorithms when lane-related measures are not included in the independent variable set.

"Lane busts" are prima facie evidence of driving performance that can result in accidents. However, it has been shown here that they cannot be reliably predicted using any of the dependent drowsiness variables. Therefore, an auxiliary lane departure warning system should be included in the detection phase. This system should use a seat vibration system similar to the one used in this experiment. The vibration should be activated when the vehicle exceeds either lane boundary by more than a specified amount and deactivated when the vehicle is brought back within the boundaries.

Because the differences in the results between three-minute averages and six-minute averages are so slight, three-minute averages should be used in the system because they allow for a faster-acting system. "Pipelining" of the averages should be accomplished in the same manner as in the test and evaluation experiment; each minute, new moving averages should be calculated from the three most recent one-minute averages for each measure.

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APPENDIX A

Potential Subject Screening Questionnaire

Subject Screening Questionnaire

1) Name ______________________________

2) Telephone Number ___________________

3) Do you have a valid driver's license? YES NO

4) Are you a student? YES NO Major? _____________

5) Age _________

6) Gender: M F

7) Do you ordinarily wear glasses or contact lenses?

Glasses YES NO

Contacts YES NO

8) Do you have any problems with your hearing?

Explain: ____

9) What are your usual sleeping hours?

Retire ____ : ____ AM PM Awake ____ : ____ AM PM

10) Have you ever had any trouble staying awake while driving? YES NO

If YES, how often.........

never	almost never	occasionally	moderately often	often

11) Have you ever had an automobile accident or "near miss" due to drowsiness behind the wheel?

YES NO

12) On the average, how many cups of coffee do you drink per day? ______

13) On average, how many caffeinated soft drinks do you drink per day? ______

14) How often do you take naps during the day?

never	almost never	occasionally	moderately often	often

15) Do you smoke cigarettes? YES NO

If YES, how many per day... _____ cigarettes OR _____ packs

16) Do you use other types of smoking materials such as a pipe or cigar?

YES NO

If YES...... Type: _________________ How often: _______________

17) When do you ordinarily eat supper? ____ : ____ PM

18) If you snack at night, please describe what you eat and when.

Snack: ___________________________ Time: ____ : ____ PM

19) What is your height and weight? HT: ___ ft ___ in WT: ______ lbs

APPENDIX B

Information Sheet Regarding Procedures for Experiment and Participant Informed Consent Form

Introduction to the Study

The purpose of this research is to test and evaluate a drowsy driver detection system for possible future use in an automobile and to determine an appropriate configuration for drowsiness alarms and countermeasures. The study is being conducted in the Vehicle Analysis and Simulation Laboratory, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg. The research team consists of Mark Lewin and Terry Fairbanks. The two researchers are graduate students in the Department of Industrial and Systems Engineering. Dr. Walter W. Wierwille is the principal investigator and Paul T. Norton Professor in the Department.

Your task will be to sit in an automobile simulator and drive as you would normally. The simulator will move so as to mimic the motions of an actual automobile. The screen in front of you will show a roadway on which you must drive.

If you decide to participate in this study, you must awake at 7:00 AM or before and go through your normal daytime activities without resting or napping. Then, at about 6:00 PM, a member of the experimental team will pick you up at your residence. This team member will buy you dinner at a fast-food restaurant. You may eat whatever you like, but you will not be permitted to drink caffeinated or sugared beverages, such as coffee or cola. If you are a smoker, you will be permitted to smoke right after dinner, but not thereafter. You will then be taken to the laboratory where you will be allowed to read, study, watch TV (which will be provided), or listen to your own personal headset stereo. You will not be permitted to eat, smoke, drink caffeinated coffee, or drink caffeinated soft drinks, since these may effect the outcome of the experiment. However, you will be permitted to drink water or non-caffeinated, diet soft drinks. A member of the research team will remain with you during all of this time and will prevent you from napping.

Shortly after midnight the experimental session will begin. You will have a period of time (10 to 15 minutes) to get used to the simulator. After that, you will have a short break while the experimenters make final preparations. Then, the data gathering session will begin.

Once you are seated in the simulator, you must not attempt to leave the simulator until you have given the experimenters a chance to stop the simulator and guide you in exiting.

You will be asked to drive the simulator in the same way as you would drive an actual automobile. Once the data run has begun you must remain in the right lane. Your cruise control will be set at 60 mph.

If possible, we would like you to complete the entire data gathering experiment, which will take a little less than 3 hours. You may, however, withdraw from the experiment at any time if you do not wish to continue for any reason.

After the completion of the experiment, you will be paid and any remaining questions will be answered. If you participate in this experiment you must agree to let one of the experimenters drive you home, since they will be on a different schedule and will not be drowsy at this time.

Payment for the experiment will be $5 per hour between 6:00 PM and midnight, and $8 per hour from midnight until approximately 3:00 A.M. If you complete the experiment you will receive approximately $54. If you decide to withdraw during the experiment or simply cannot continue for whatever reason, you will be paid for the time actually spent. Since the simulator is a complex system, equipment failures do occasionally occur. If this happens it may be necessary for the experimenters to terminate the experiment, in which case you will be paid for the time actually spent.

Initially, you will be asked to take a simple hearing test and a simple vision test. You will also be asked to fill out a brief questionnaire on your normal sleeping/waking patterns and your normal eating/drinking/smoking (if any) patterns. If you qualify, you will then be scheduled for the experiment.

There are some minor risks and discomforts to which you will be exposed in this experiment. They are outlined in the attached informed consent form, which you should read carefully.

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Simulator Test and Evaluation of a Drowsy Driver Detection/Alarm/Countermeasures System (DDDACS)

Investigators: Mark G. Lewin, Rollin J. Fairbanks, Dr. Walter W. Wierwille

I. The Purpose of this Research/Project

The nature of this study and the purpose for conducting the research are contained in the document Introduction to the Study, which you have already read.

II. Procedures

The research procedures with which you will be involved are detailed in the document Introduction to the Study, which you have already read. By now you should have a clear understanding of what will be expected of you.

III. Risks

There are some minor risks and discomforts to which you expose yourself in volunteering for this research. The risks are:

- The risk of possible interference with your next day's activities caused by less than a full night's sleep. This risk can be minimized by sleeping longer than usual the morning following your participation.

- The risk of injury if you attempt to leave the simulator without the help of the experimenters. Please inform one of the experimenters if you feel that you must leave the simulator. The simulator will be stopped, and you will then be guided out of the simulator.

The discomforts are:

- Possible discomfort associated with trying to drive while tired or drowsy.

- Possible discomfort associated with sitting in one seat for a long period of time.

- Possible minor motion sickness due to the movement of the simulator.

In order to minimize these risks to both yourself and the research team, you should not volunteer for participation in this experiment if you have known hearing impairment, are under 18 years old, if you are pregnant, if you are not in good health, or if you have any other condition which would adversely affect your being sleep deprived and staying up until approximately 3:00 AM.

IV. Benefits of this Project

There are no direct benefits to you from this research (other than payment). No promise or guarantee of any benefits to you (other than payment) have been made to encourage you to participate in this experiment. However, you may find the experiment interesting, and it may be beneficial to society. Your participation and that of other volunteers should aid in the implementation of an effective drowsiness detection and warning system in future automobiles.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with anonymity. Shortly after you have participated, your name will be separated from your data.

VI. Compensation

You will be paid at a rate of $5.00 per hour between 6 P.M. and midnight and $8.00 per hour after midnight. If you complete your participation you will be paid $54.00. Cash payment will be made shortly after you have finished your participation.

VII. Freedom to Withdraw

You should know that at any time you are free to withdraw from participation in this research program, for any reason, without penalty. If you choose to withdraw, you will be compensated for the portion of the time of the study completed. You are free not to answer any questions or respond to experimental situations that you choose without penalty.

There may be circumstances under which the investigators may determine that you should not continue as a subject. If this occurs, you will be compensated for the portion of the project completed.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

- I agree to awake at or before 7:00 AM on the day of the experiment.
- I agree not to take any naps after 7:00 AM on the day of the experiment.
- I agree not to drink caffeinated coffee, drink caffeinated soft drinks, or ingest any other type of stimulant between 6:00 PM on the day of the experiment and the conclusion of the experiment.
- Once seated in the simulator, I agree not to attempt to leave the simulator until I have allowed the investigators to stop the simulator and guide me in exiting.
- I agree to allow one of the investigators to drive me home following the experiment.

X. Subject's Permission

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

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

____________________________ ____________________

Signature Date

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

Mark G. Lewin Investigator	(540) 231-9084 Phone
Rollin J. Fairbanks Investigator	(540) 231-9084 Phone
Walter W. Wierwille Principal Investigator Faculty Advisor	(540) 231-7952 Phone
E. R. Stout Chair, Institutional Review Board Research Division	(540) 231-9359 Phone

(A copy of this signed Informed Consent form is to be given to the research participant.)

APPENDIX C

Distribution Analyses for EYEMEAS, PERCLOS, DRVDROW, LANDEV, LANEX, and LNMNSQ in One-Minute Interval Data Set

Figure C1a: Histogram of EYEMEAS 1-Minute Averages Immediately Before Vibrations.

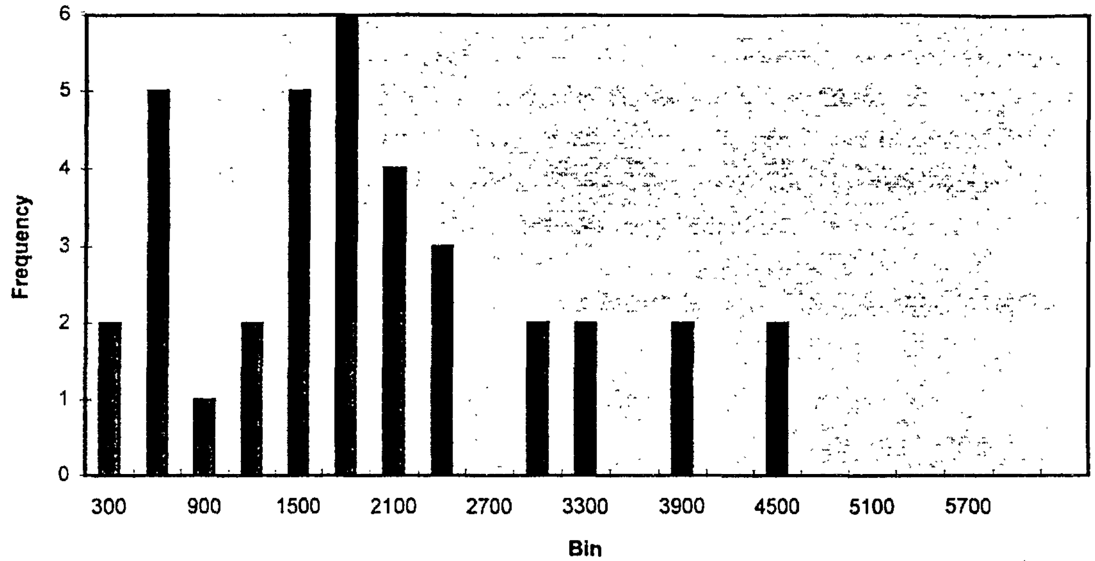


Figure C1b: Histogram of EYEMEAS 1-Minute Data with 10 Minutes Before Vibrations Deleted and 5 Minutes After Vibrations Deleted.

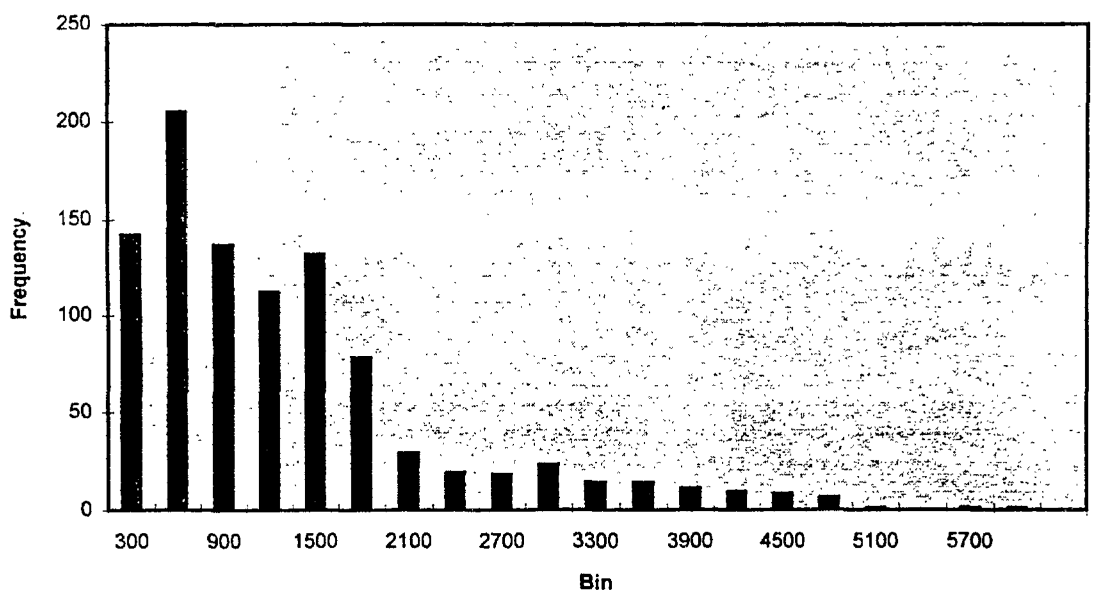


Figure C1: EYEMEAS 1-minute histograms.

Figure C2a: Histogram of PERCLOS 1-Minute Averages Immediately Before Vibrations.

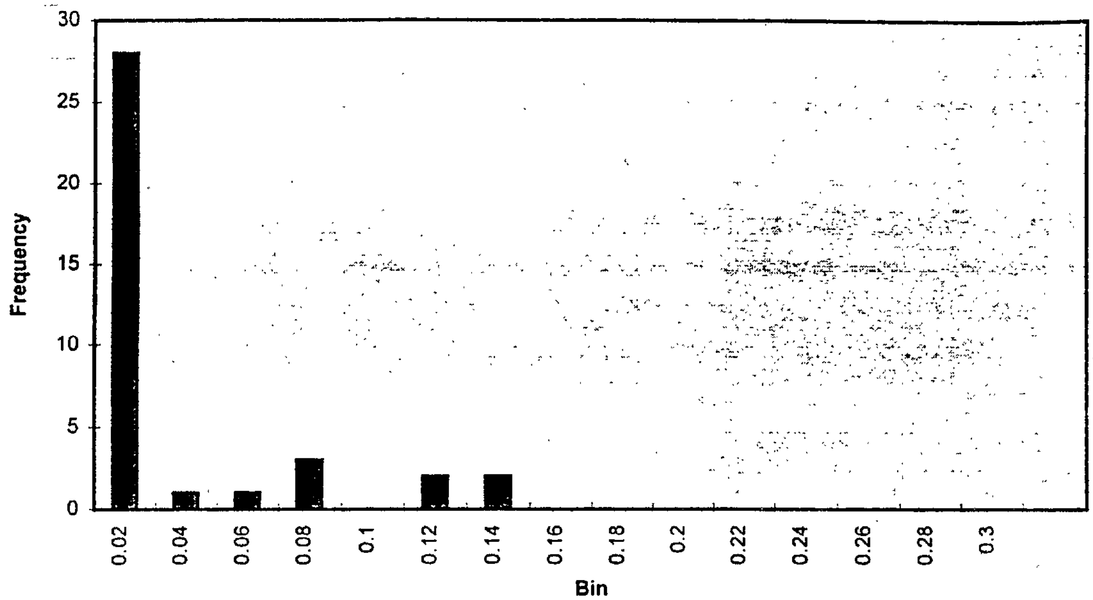


Figure C2b: Histogram of PERCLOS 1-Minute Data with 10 Minutes Before Vibrations Deleted and 5 Minutes After Vibrations Deleted.

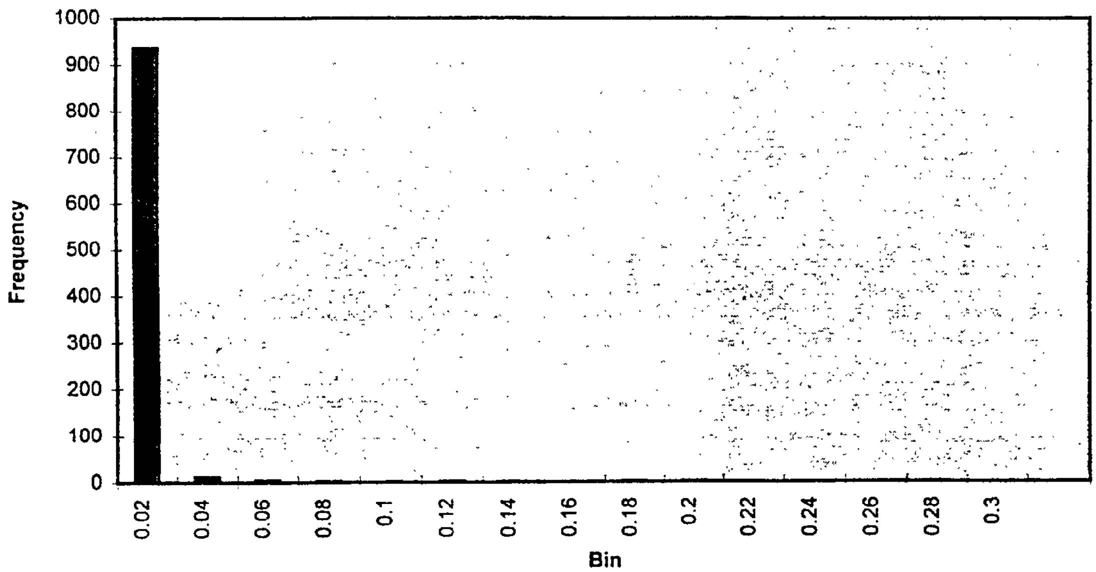


Figure C2: PERCLOS 1-minute histograms.

Figure C3a: Histogram of DRVDROW 1-Minute Averages Immediately Before Vibrations.

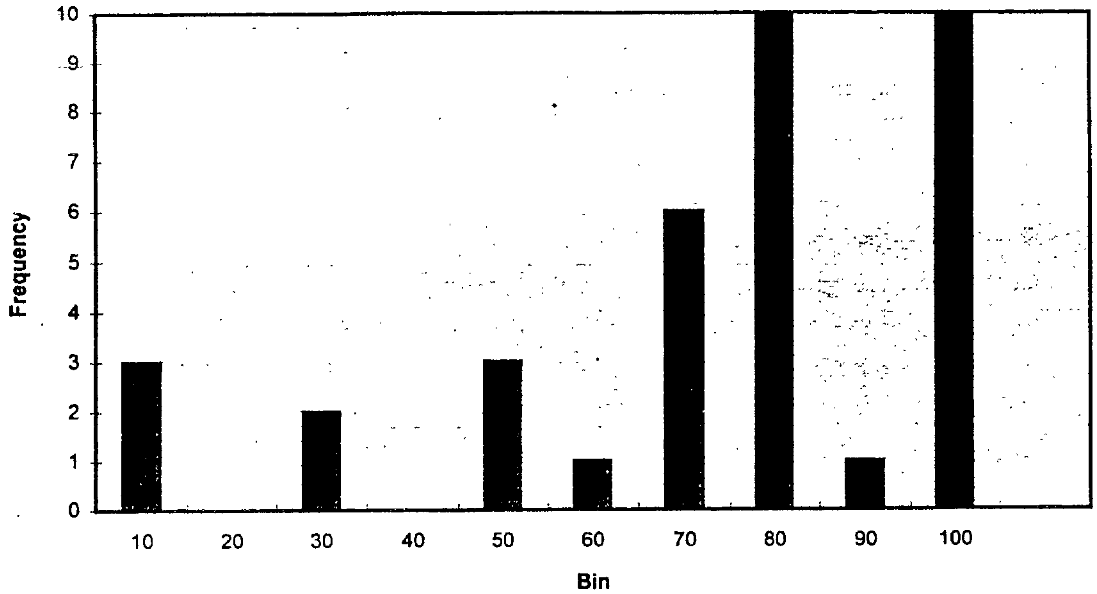


Figure C3b: Histogram of DRVDROW 1-Minute Data with 10 Minutes Before Vibrations Deleted and 5 Minutes After Vibrations Deleted.

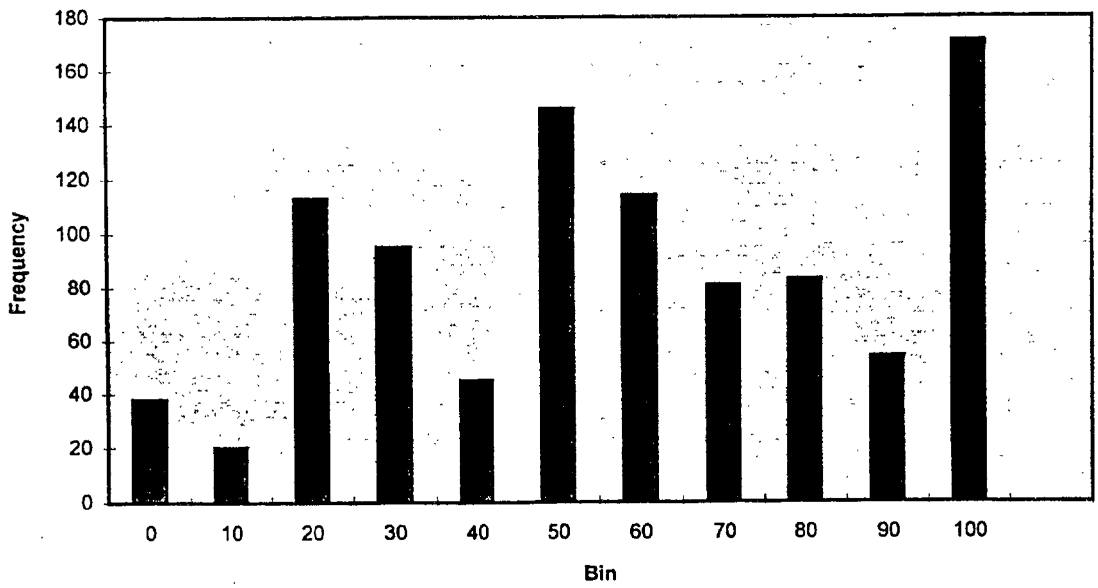


Figure C3: DRVDROW 1-minute histograms.

Figure C4a: Histogram of LANDEV 1-Minute Averages Immediately Before Vibrations.

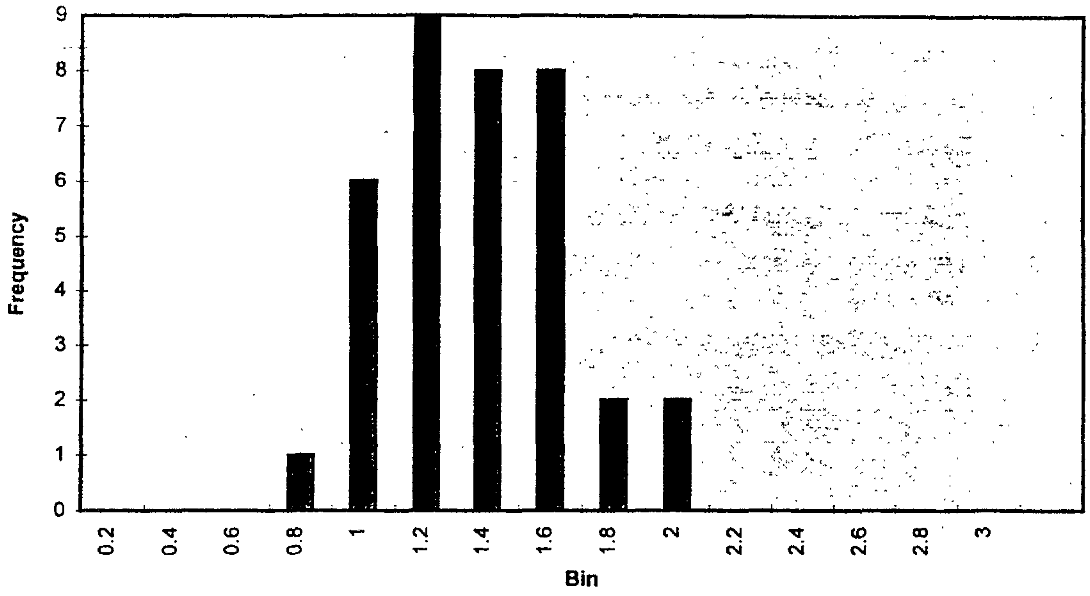


Figure C4b: Histogram of LANDEV 1-Minute Data with 10 Minutes Before Vibrations Deleted and 5 Minutes After Vibrations Deleted.

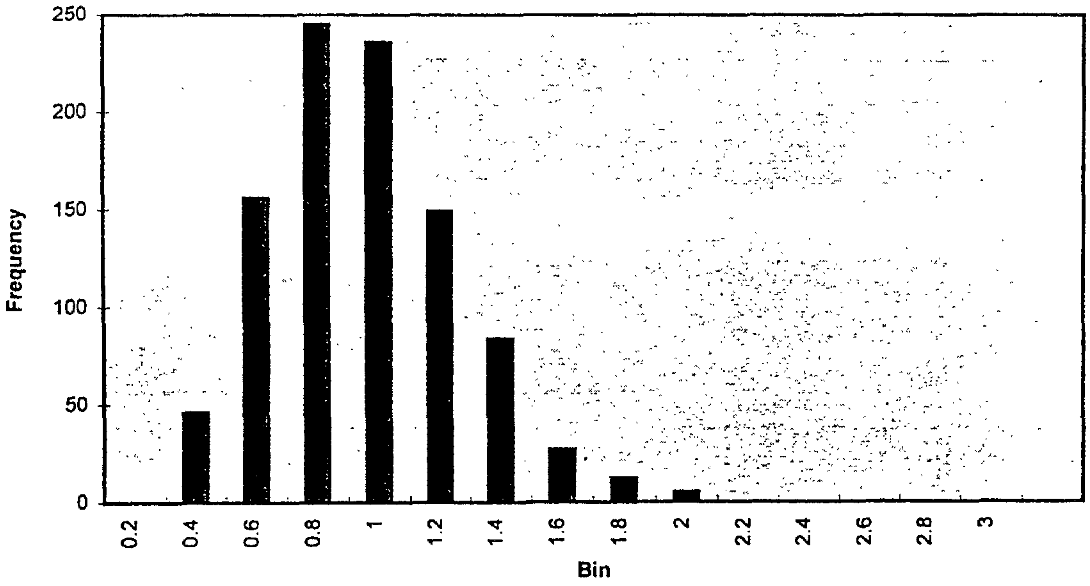


Figure C4: LANDEV 1-minute histograms.

Figure C5a: Histogram of LANEX 1-Minute Averages Immediately Before Vibrations.

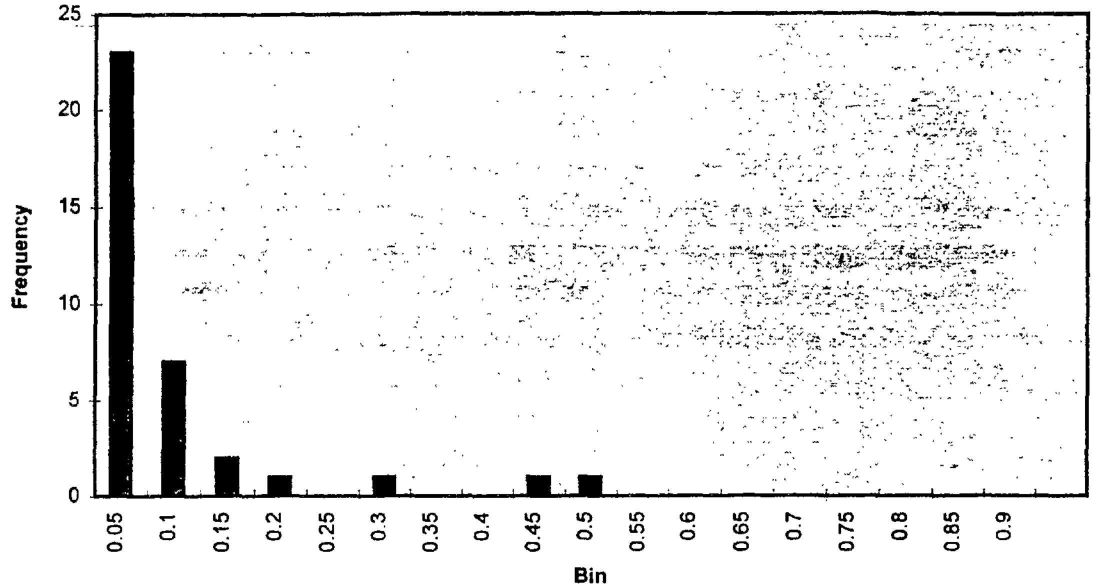


Figure C5b: Histogram of LANEX 1-Minute Data with 10 Minutes Before Vibrations Deleted and 5 Minutes After Vibrations Deleted.

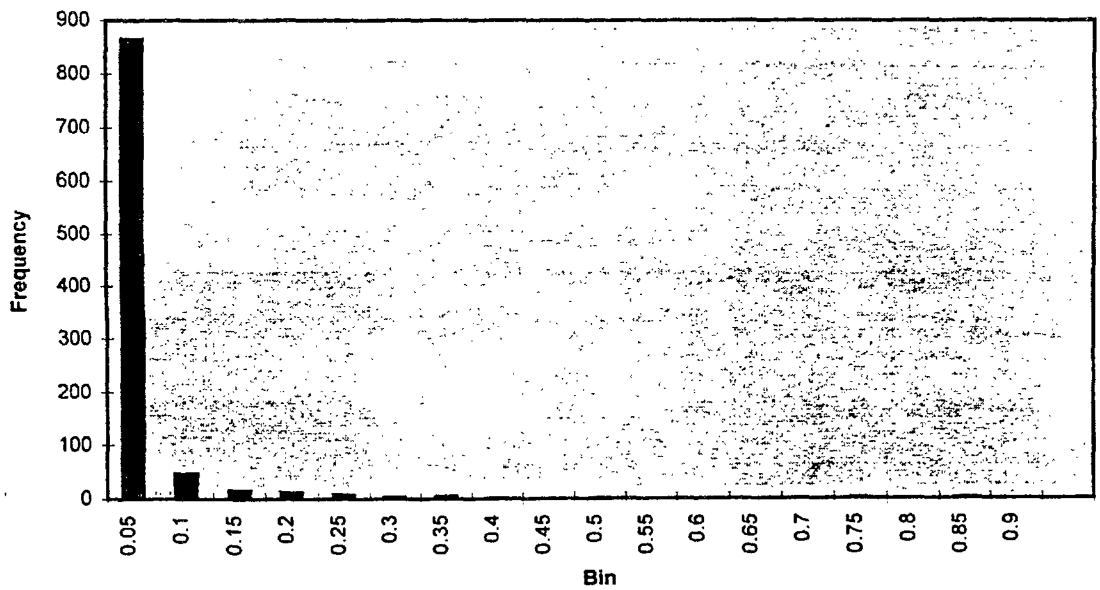


Figure C5: LANEX 1-minute histograms.

Figure C6a: Histogram of LNMNSQ 1-Minute Averages Immediately Before Vibrations.

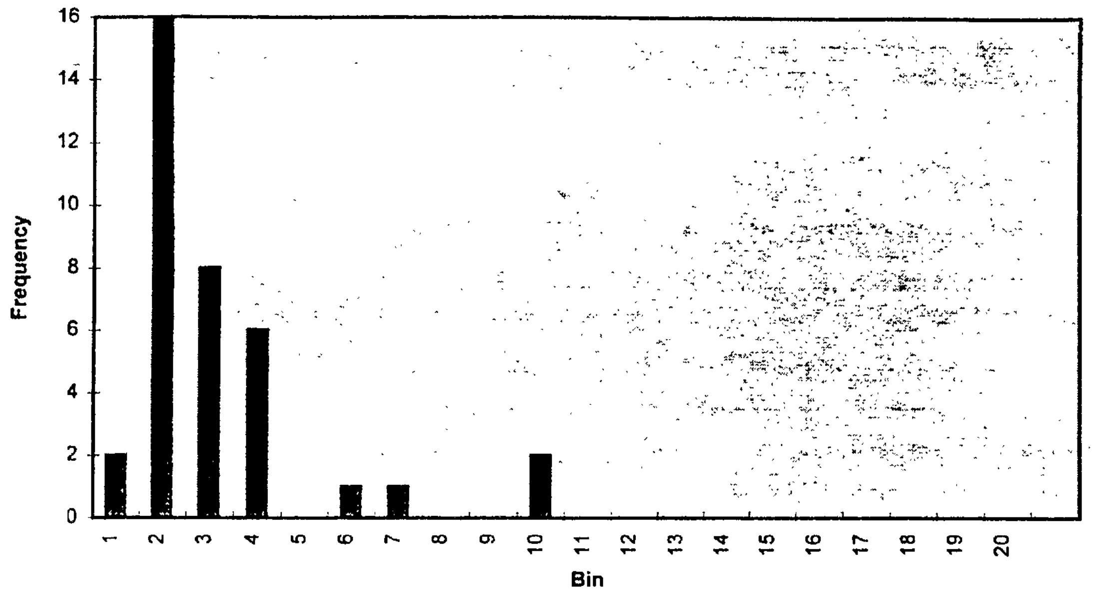


Figure C6b: Histogram of LNMNSQ 1-Minute Data with 10 Minutes Before Vibrations Deleted and 5 Minutes After Vibrations Deleted.

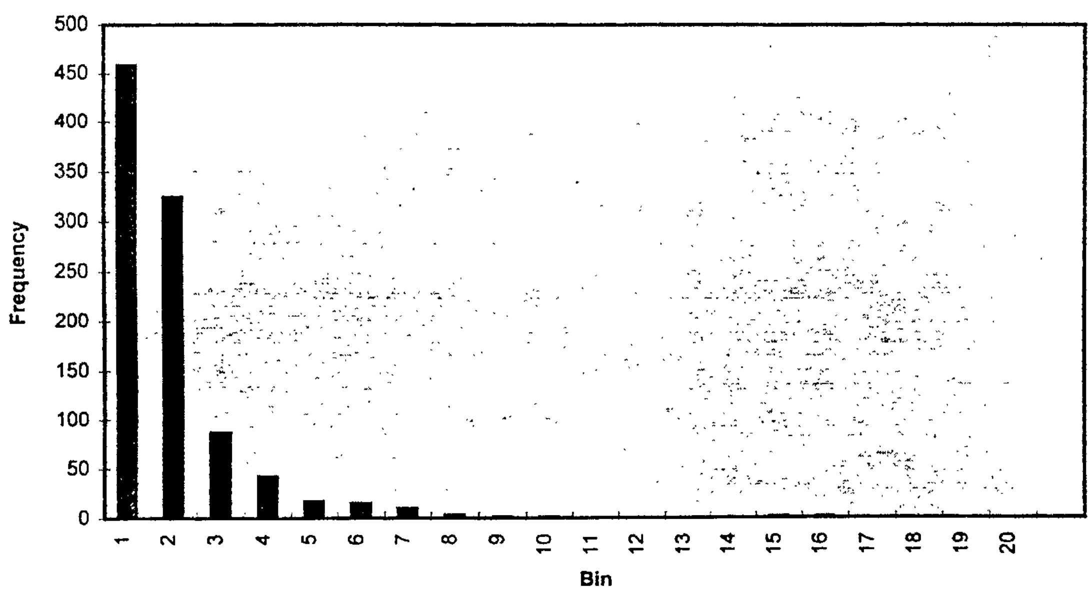
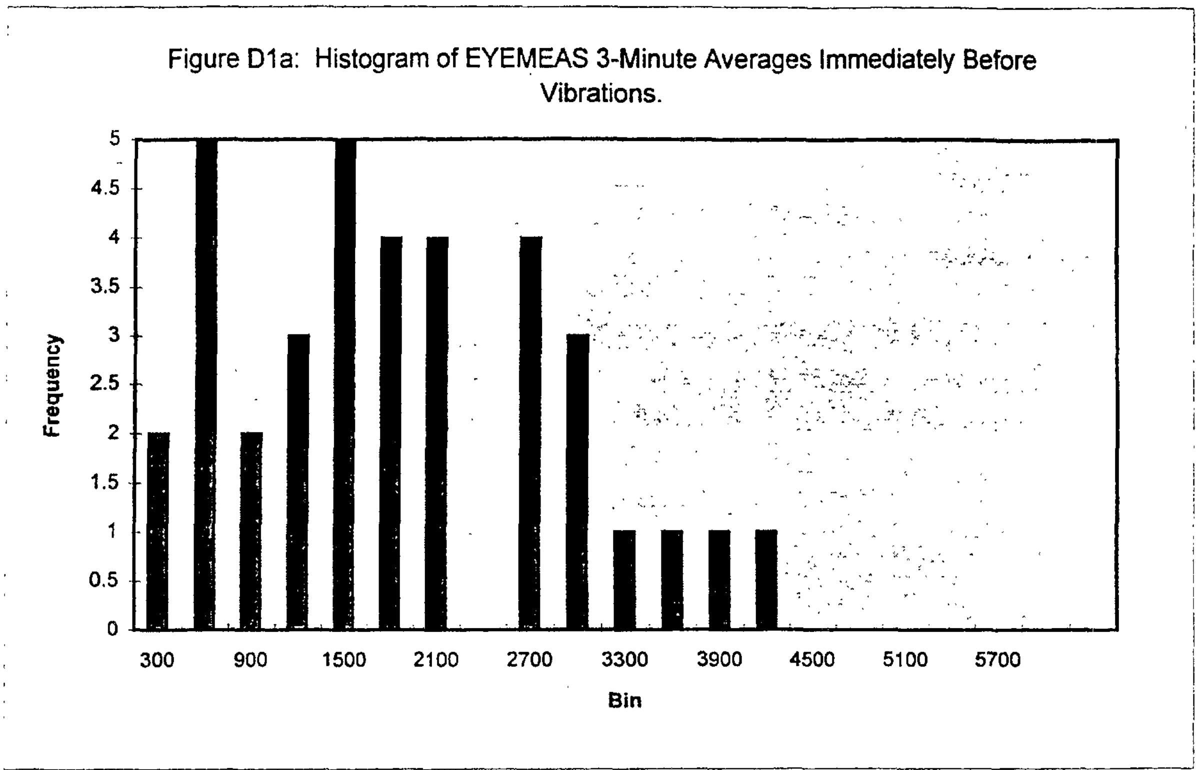


Figure C6: LNMNSQ 1-minute histograms.

APPENDIX D

Distribution Analyses for EYEMEAS, PERCLOS, DRVDROW, LANDEV, LANEX, and LNMNSQ in Three-Minute Interval Data Set



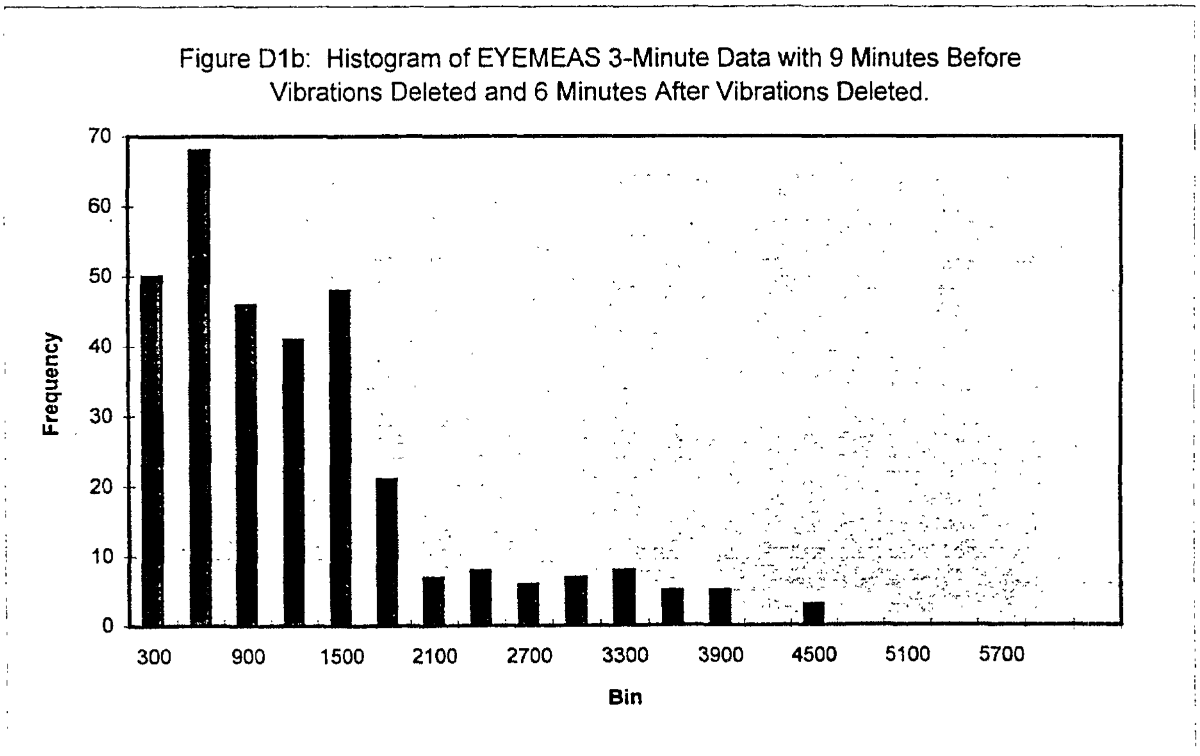
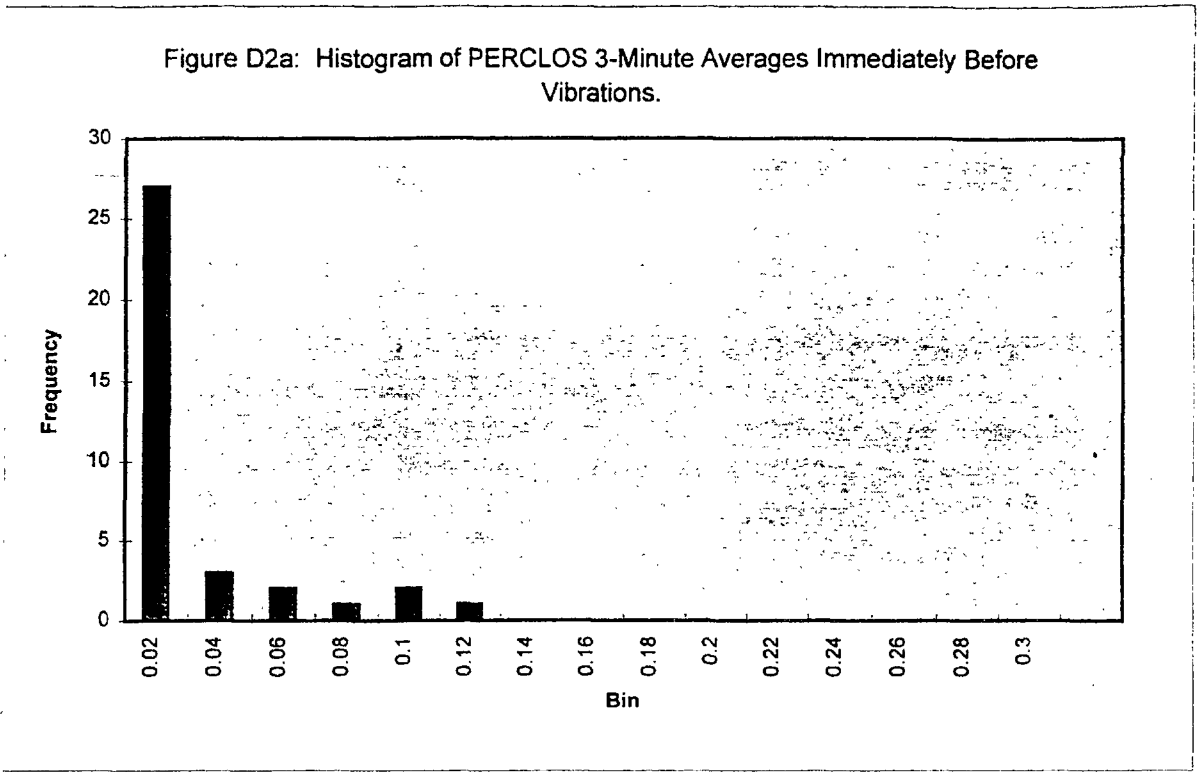


Figure D1: EYEMEAS 3-minute histograms.



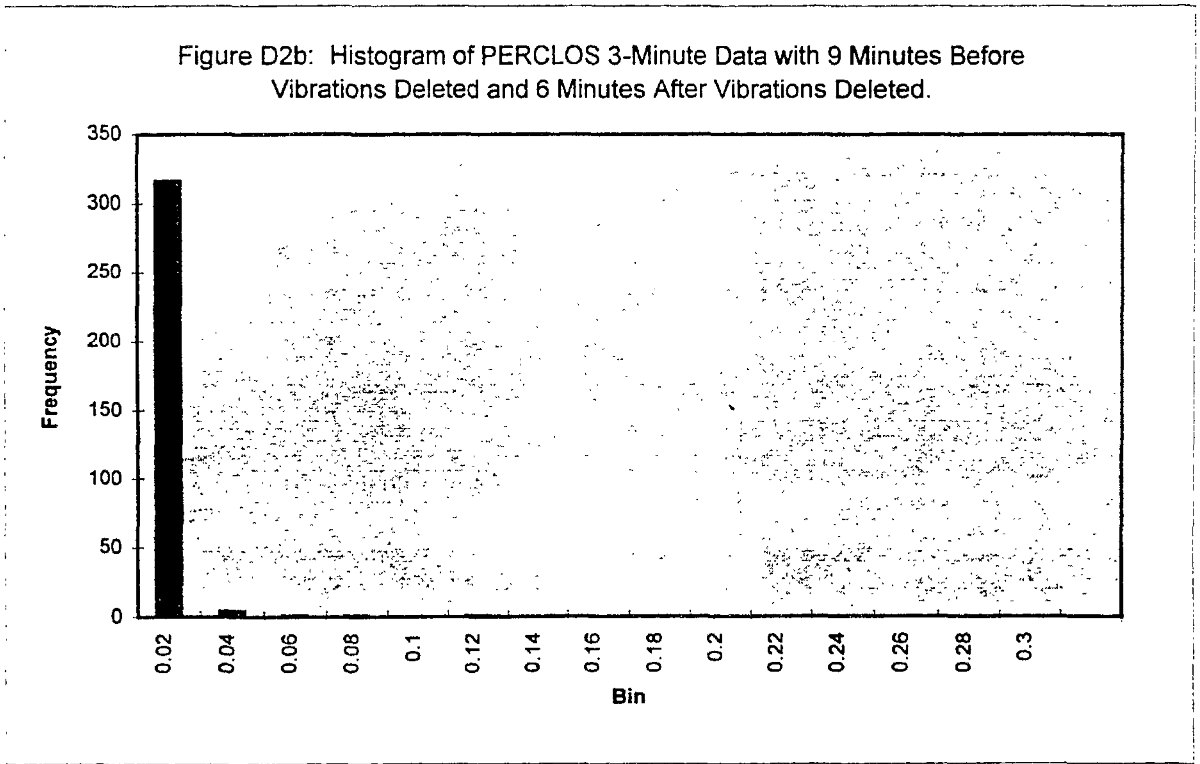


Figure D2: PERCLOS 3-minute histograms.

Figure D3a: Histogram of DRVDROW 3-Minute Averages Immediately Before Vibrations.

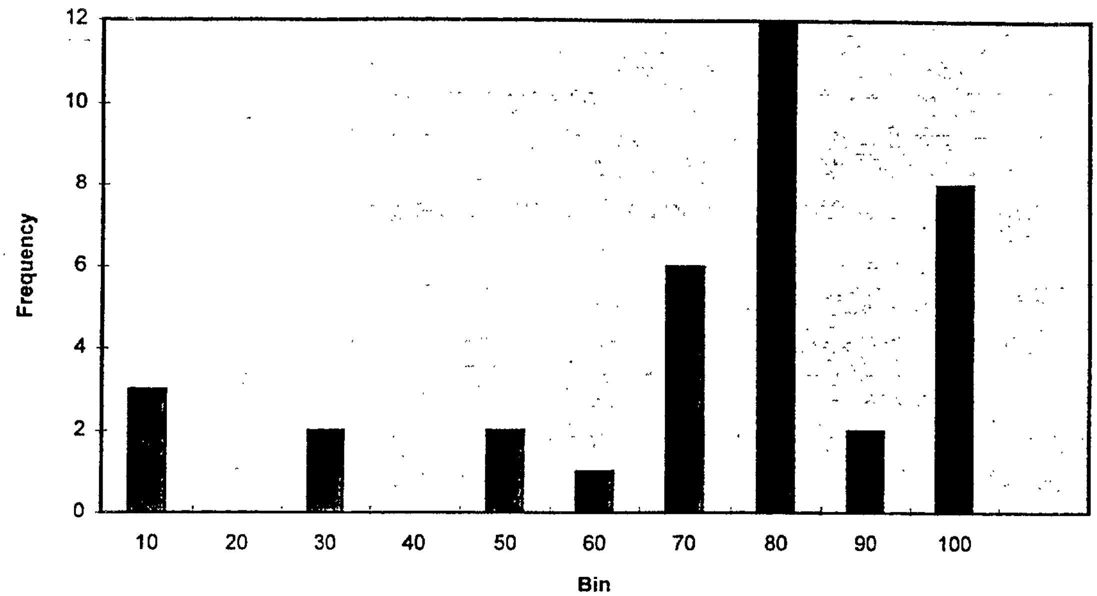


Figure D3b: Histogram of DRVDROW 3-Minute Data with 9 Minutes Before Vibrations Deleted and 6 Minutes After Vibrations Deleted.

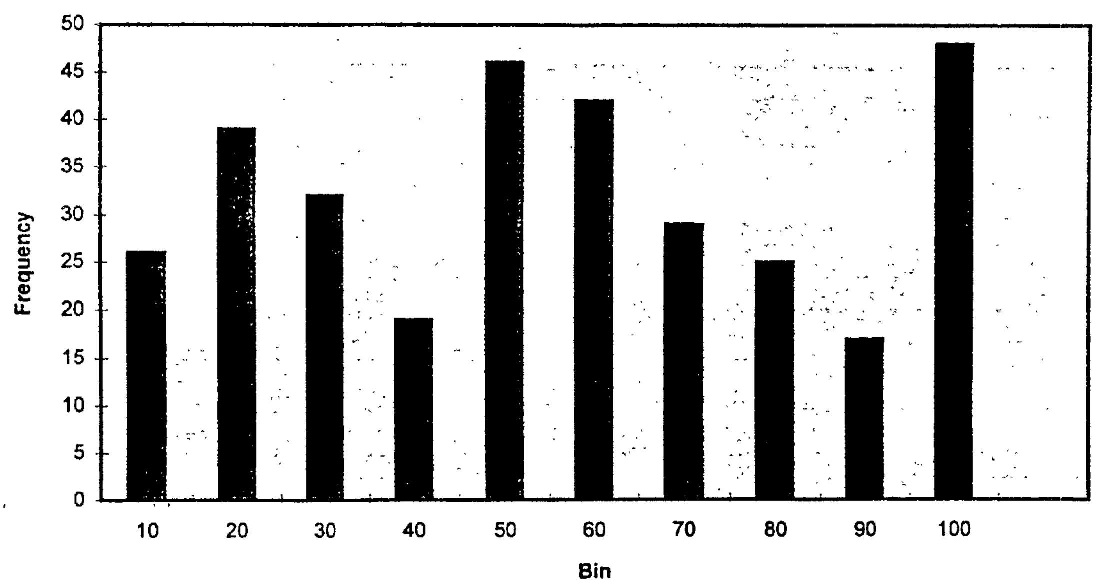
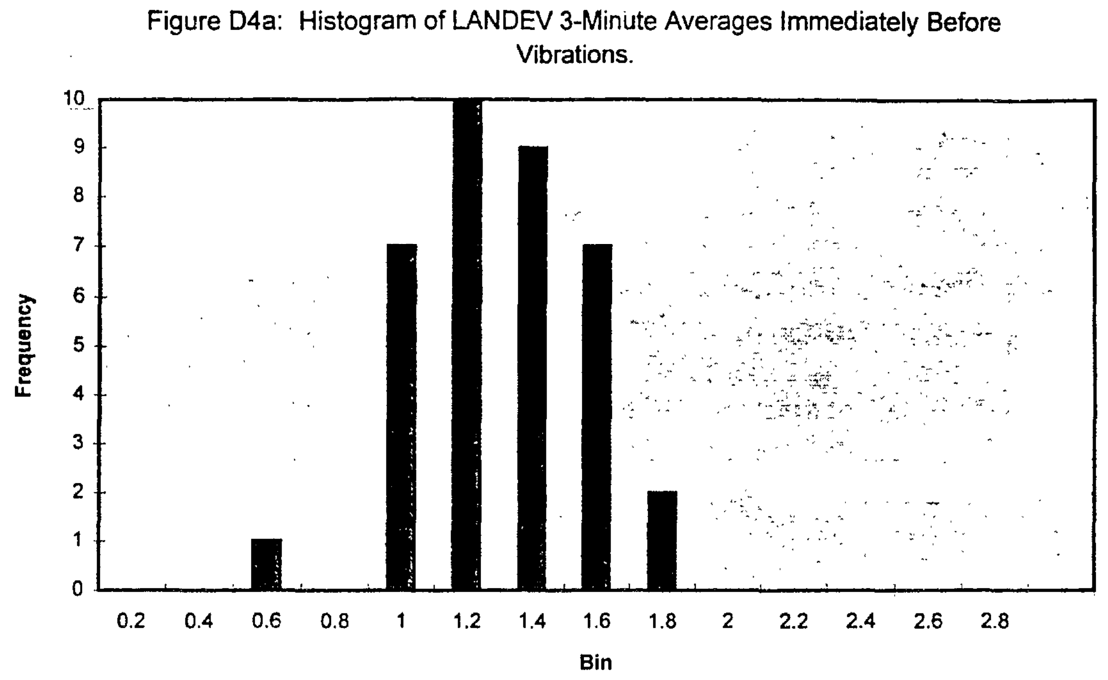


Figure D3: DRVDROW 3-minute histograms.



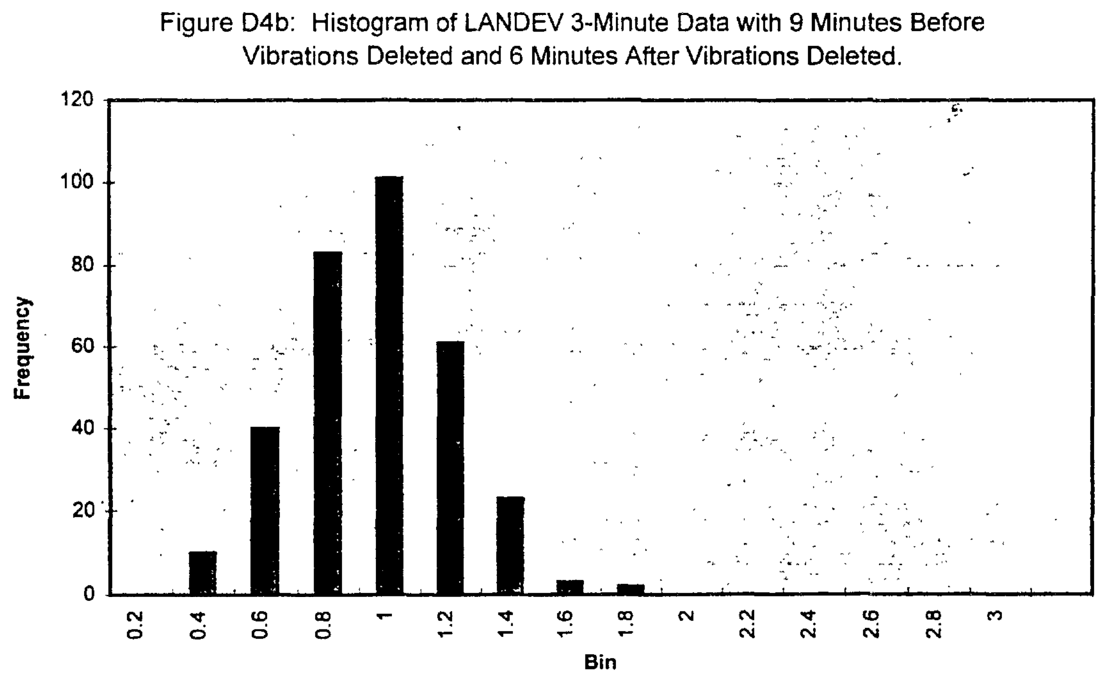


Figure D4: LANDEV 3-minute histograms.

Figure D5a: Histogram of LANEX 3-Minute Averages Immediately Before Vibrations.

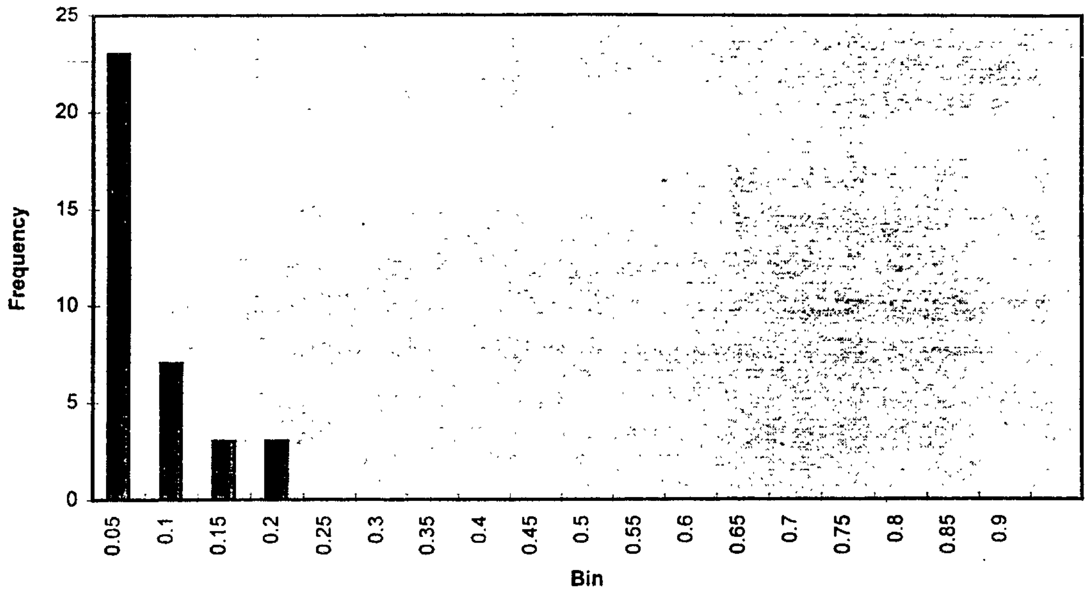


Figure D5b: Histogram of LANEX 3-Minute Data with 9 Minutes Before Vibrations Deleted and 6 Minutes After Vibrations Deleted.

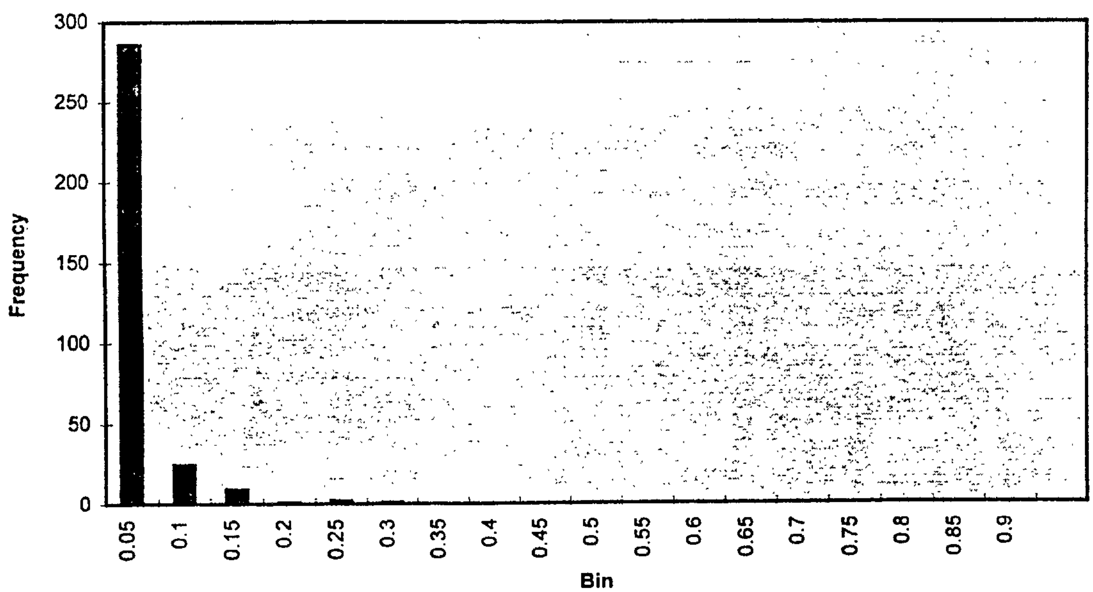
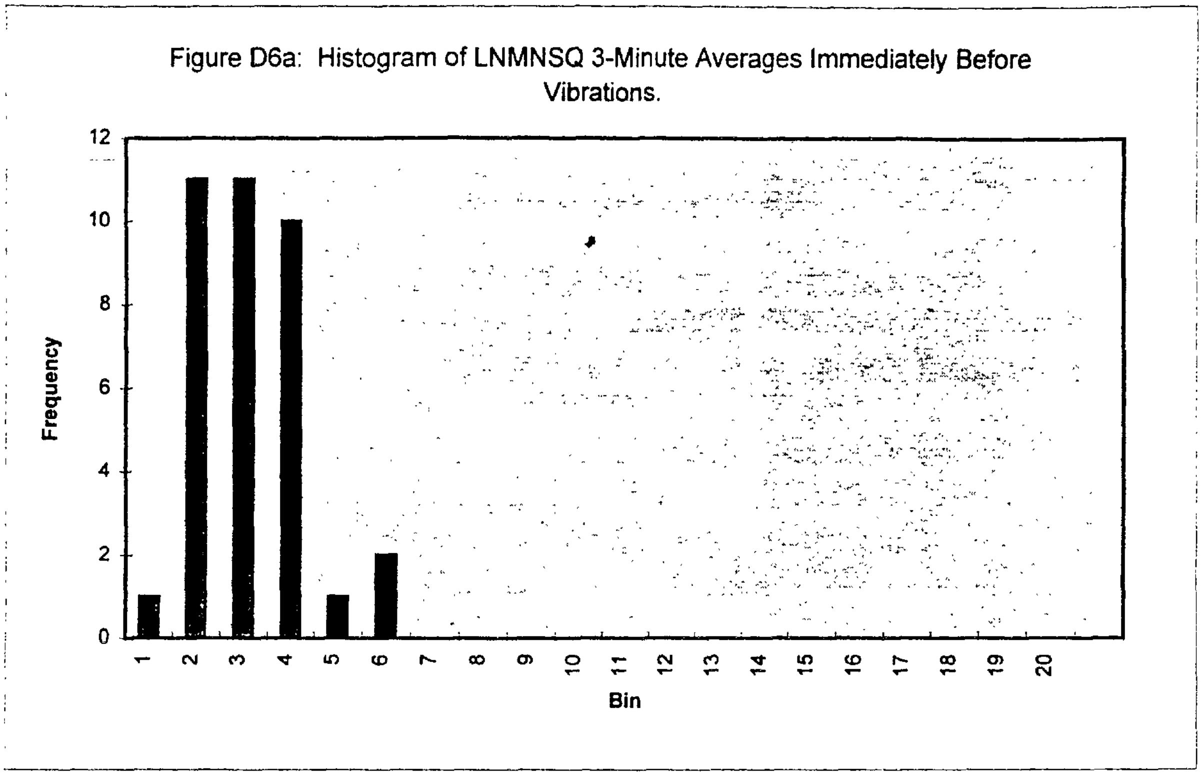


Figure D5: LANEX 3-minute histograms.



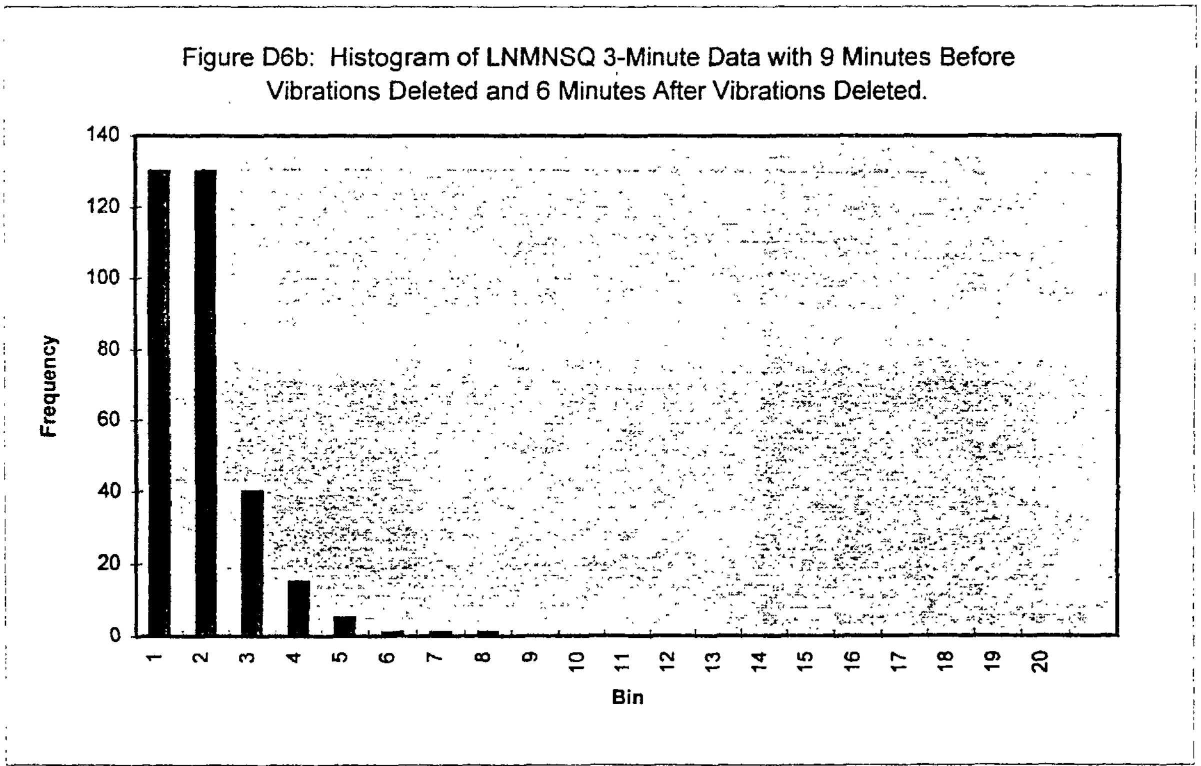


Figure D6: LNMNSQ 3-minute histograms.

APPENDIX E

Regression Summaries, Unconditional Classification Matrices, and Conditional "OR" Classification Matrices for Driver Status Algorithms Developed Using Three-Minute Interval Data Set

Regression Summary for Dependent Variable: PERCLOS
$R = 0.13988993$ $R^2 = 0.01956919$ Adjusted $R^2 = 0.00909450$
$F(5,468) = 1.8682$ $p < 0.09845$ Std. Error of estimate: 0.01213

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			0.019718	0.009782	2.01572	0.0444
MDREV	-0.16564	0.103934	-0.00019	0.000119	-1.59374	0.11167
SMREV	-0.2	0.095133	-0.00018	0.000085	-2.10231	0.03606
NMRHOLDS	-0.21795	0.144721	-0.00033	0.000216	-1.506	0.132742
ACCDEV	0.191304	0.118654	0.002625	0.001628	1.61228	0.107575
INTACDEV	-0.19115	0.109916	-0.0097	0.005579	-1.73907	0.08268

Note: Classification matrices not developed for this algorithm.

Figure E1: Regression Summary for Algorithm D4e-3.

Regression Summary for Dependent Variable: EYEMEAS
$R = 0.15229754$ $R^2 = 0.02319454$ Adjusted $R^2 = 0.01695961$
$F(3,470) = 3.7201$ $p < 0.01150$ Std. Error of estimate: 922.18

	BETA	St. Err. of BETA	B	St. Err. of B	t(470)	p-level
Intercept			2708.663	708.4829	3.82319	0.000149
MDREV	-0.19993	0.102887	-17.486	8.9981	-1.94324	0.052584
SMREV	-0.23685	0.092914	-16.167	6.3424	-2.54911	0.011116
NMRHOLDS	-0.21657	0.140019	-24.654	15.9394	-1.54674	0.122599

Note: Classification matrices not developed for this algorithm.

Figure E2: Regression Summary for Algorithm D2e-3.

Regression Summary for Dependent Variable: DRVDROW
$R = 0.46730576$ $R^2 = 0.21837467$ Adjusted $R^2 = 0.21338557$
$F(3,470) = 43.770$ $p < 0.00000$ Std. Error of estimate: 27.018

	BETA	St. Err. of BETA	B	St. Err. of B	t(470)	p-level
Intercept			31.8411	5.065182	6.28626	0
MDREV	0.448109	0.042569	1.2836	0.121936	10.52666	0
SMREV	0.128083	0.041936	0.2864	0.093756	3.05428	0.002384
INTACDEV	-0.16325	0.042715	-20.7222	5.421954	-3.82191	0.00015

		Observed		
		Low	High	Total
Predicted	High	15	47	62
Algorithm	Low	281	131	412
Output	Total	296	178	**474**
	% Correct	94.93	26.40	69.20

DRVDROW R Value = 0.46731
Apparent Accuracy Rate: 0.692
Threshold: 70

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm D6e-3. (Independent variables employed included Steering and Accelerometer.)

		Observed		
		Low	High	Total
Predicted	High	19	55	74
Algorithm	Low	255	145	400
Output	Total	274	200	**474**
	% Correct	93.07	27.50	65.40

Algorithm D6e (Threshold = 70) - OR - eLNMNSQ-D (Threshold = 3.00000)
Apparent Accuracy Rate: 0.654

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm D6e-3 -OR- Algorithm eLNMNSQ-D-3 Data.

Figure E3: Regression Summary and Classification Matrices for Algorithm D6e-3.

Regression Summary for Dependent Variable: SLEEPER1
$R = 0.21560006$ $R^2 = 0.04648338$ Adjusted $R^2 = 0.04446322$
$F(1,472) = 23.010$ $p < 0.00000$ Std. Error of estimate: 0.66552

	BETA	St. Err. of BETA	B	St. Err. of B	t(472)	p-level
Intercept			1.116913	0.036689	30.4428	0
STVELV	0.2156	0.044946	0.001708	0.000356	4.79685	0.000002

Note: Classification matrices not developed for this algorithm.

Figure E4: Regression Summary for Algorithm SLEEPER1-D-3.

Regression Summary for Dependent Variable: SLEEPER2
$R = 0.16040012$ $R^2 = 0.02572820$ Adjusted $R^2 = 0.02366406$
$F(1,472) = 12.464$ $p < 0.00046$ Std. Error of estimate: 1.1605

	BETA	St. Err. of BETA	B	St. Err. of B	t(472)	p-level
Intercept			1.876437	0.063977	29.33004	0
STVELV	0.1604	0.045433	0.002192	0.000621	3.5305	0.000455

Note: Classification matrices not developed for this algorithm.

Figure E5: Regression Summary for Algorithm SLEEPER2-D-3.

Regression Summary for Dependent Variable: SLEEPER3
$R = 0.18592858$ $R^2 = 0.03456944$ Adjusted $R^2 = 0.03046995$
$F(2,471) = 8.4326$ $p < 0.00025$ Std. Error of estimate: 1.0315

	BETA	St. Err. of BETA	B	St. Err. of B	t(471)	p-level
Intercept			1.41847	0.130668	10.85556	0
NMRHOLDS	-0.37762	0.094318	-0.04842	0.012093	-4.00369	0.000072
THRSHLDS	0.289884	0.094318	3.777037	1.228919	3.07346	0.002239

Note: Classification matrices not developed for this algorithm.

Figure E6: Regression Summary for Algorithm SLEEPER3-D-3.

Regression Summary for Dependent Variable: PERCLOS
$R = 0.38622797$ $R^2 = 0.14917204$ Adjusted $R^2 = 0.14008200$
$F(5,468) = 16.410$ $p < 0.00000$ Std. Error of estimate: 0.01130

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			-0.0024	0.001042	-2.26722	0.023832
STVELV	0.572219	0.123366	0.0001	0.000017	4.6384	0.000005
LGREV	-0.56672	0.099348	-0.0043	0.000753	-5.70439	0
MDREV	-0.63109	0.106843	-0.0007	0.000122	-5.90672	0
STEXED'	-0.13252	0.047687	-10.549	3.796015	-2.77898	0.005672
HPHDGVAR	0.742369	0.083434	0.0753	0.008465	8.89767	0

Note: Classification matrices not developed for this algorithm.

Figure E7: Regression Summary for Algorithm E4e-3.

Regression Summary for Dependent Variable: EYEMEAS
$R = 0.31524564$ $R^2 = 0.09937982$ Adjusted $R^2 = 0.09169862$
$F(4,469) = 12.938$ $p < 0.00000$ Std. Error of estimate: 886.43

	BETA	St. Err. of BETA	B	St. Err. of B	t(469)	p-level
Intercept			251.823	165.5025	1.52157	0.128791
STVELV	0.452565	0.126812	4.898	1.3725	3.56877	0.000396
LGREV	-0.34083	0.095935	-197.227	55.5141	-3.55273	0.00042
MDREV	-0.64568	0.112268	-56.468	9.8186	-5.75118	0
HPHDGDEV	0.548294	0.081092	3802.328	562.3579	6.7614	0

Note: Classification matrices not developed for this algorithm.

Figure E8: Regression Summary for Algorithm E2e-3.

Regression Summary for Dependent Variable: DRVDROW

R = 0.51213868 R^2 = 0.26228602 Adjusted R^2 = 0.25440446

F(5,468) = 33.278 p < 0.00000 Std. Error of estimate: 26.304

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			-25.3836	15.387	-1.64968	0.099679
MDREV	0.411958	0.070696	1.18	0.2025	5.8272	0
SMREV	0.433871	0.081249	0.97	0.18165	5.34001	0
THRSHLDS	0.310563	0.093526	117.671	35.43647	3.32062	0.000968
ACCDEV	-0.21968	0.048847	-7.5392	1.67644	-4.49717	0.000009
HPHDGVAR	0.303346	0.068175	76.9715	17.29883	4.44952	0.000011

		Observed		
		Low	High	Total
Predicted	High	18	55	73
Algorithm	Low	278	123	401
Output	Total	296	178	**474**
	% Correct	93.92	30.90	70.25

DRVDROW R Value = 0.51214

Apparent Accuracy Rate: 0.703

Threshold: 70

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm E6e-3. (Independent variables employed included Steering, Accelerometer, and HPHDGDEV/VAR.)

		Observed		
		Low	High	Total
Predicted	High	24	61	85
Algorithm	Low	247	142	389
Output	Total	271	203	**474**
	% Correct	91.14	30.05	64.98

Algorithm E6e (Threshold = 70) - OR - eLANEX-E (Threshold = 0.06667)

Apparent Accuracy Rate: 0.650

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm E6e-3 -OR- Algorithm eLANEX-E-3 Data.

		Observed		
		Low	High	Total
Predicted	High	25	67	92
Algorithm	Low	249	133	382
Output	Total	274	200	**474**
	% Correct	90.88	33.50	66.67

Algorithm E6e (Threshold = 70) - OR - eLNMNSQ-E (Threshold = 3.00000)

Apparent Accuracy Rate: 0.667

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm E6e-3 -OR- Algorithm eLNMNSQ-E-3 Data.

Figure E9: Regression Summary and Classification Matrices for Algorithm E6e-3.

Regression Summary for Dependent Variable: SLEEPER1
$R = 0.35060881$ $R^2 = 0.12292654$ Adjusted $R^2 = 0.11165793$
$F(6,467) = 10.909$ $p < 0.00000$ Std. Error of estimate: 0.64169

	BETA	St. Err. of BETA	B	St. Err. of B	t(467)	p-level
Intercept			0.177286	0.197792	0.89632	0.370541
STVELV	0.412909	0.130455	0.003271	0.001033	3.16515	0.001651
LGREV	-0.301	0.098328	-0.1275	0.041649	-3.0612	0.002332
MDREV	-0.28887	0.121945	-0.01849	0.007807	-2.36881	0.018251
SMREV	0.117505	0.052283	0.005871	0.002612	2.24746	0.025077
ACCDEV	-0.14109	0.055113	-0.10821	0.042273	-2.5599	0.010784
HPHDGDEV	0.524602	0.086037	2.663005	0.436742	6.09744	0

Note: Classification matrices not developed for this algorithm.

Figure E10: Regression Summary for Algorithm SLEEPER1-E-3.

Regression Summary for Dependent Variable: SLEEPER2
$R = 0.30313550$ $R^2 = 0.09189113$ Adjusted $R^2 = 0.08414607$
$F(4,469) = 11.864$ $p < 0.00000$ Std. Error of estimate: 1.1240

	BETA	St. Err. of BETA	B	St. Err. of B	t(469)	p-level
Intercept			0.732611	0.209855	3.49104	0.000527
STVELV	0.479586	0.127339	0.006554	0.00174	3.76623	0.000187
LGREV	-0.37941	0.096333	-0.27723	0.070391	-3.93848	0.000094
MDREV	-0.36181	0.112734	-0.03996	0.01245	-3.2094	0.001421
HPHDGDEV	0.472684	0.081428	4.139266	0.713061	5.80492	0

Note: Classification matrices not developed for this algorithm.

Figure E11: Regression Summary for Algorithm SLEEPER2-E-3.

Regression Summary for Dependent Variable: SLEEPER3
R = 0.42763183 R^2 = 0.18286899 Adjusted R^2 = 0.17059449
F(7,466) = 14.898 p < 0.00000 Std. Error of estimate: 0.95404

	BETA	St. Err. of BETA	B	St. Err. of B	t(466)	p-level
Intercept			-0.05873	0.2196	-0.26745	0.78924
STVELV	0.547861	0.128913	0.006678	0.0016	4.24985	0.000026
LGREV	-0.5313	0.101234	-0.34628	0.066	-5.24823	0
MDREV	-0.48592	0.115719	-0.04787	0.0114	-4.19919	0.000032
SMREV	0.115847	0.050402	0.008907	0.0039	2.29846	0.021978
STEXED	-0.13603	0.047085	-931.284	322.3619	-2.88894	0.004046
INTACDEV	-0.1159	0.049048	-0.50592	0.2141	-2.36304	0.018535
HPHDGVAR	0.782086	0.08595	6.824233	0.75	9.09927	0

		Observed		
		Low	High	Total
Predicted	High	39	18	57
Algorithm	Low	387	30	417
Output	Total	426	48	**474**
	% Correct	90.85	37.50	85.44

SLEEPER3 R Value = 0.42763
Apparent Accuracy Rate: 0.854
Threshold: 1.4

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-E-3. (Independent variables employed included Steering, Accelerometer, and HPHDGDEV/VAR.)

		Observed		
		Low	High	Total
Predicted	High	34	23	57
Algorithm	Low	357	60	417
Output	Total	391	83	**474**
	% Correct	91.30	27.71	80.17

Algorithm SLEEPER3-E (Threshold = 1.4) - OR - eLANEX-E (Threshold = 0.06667)
Apparent Accuracy Rate: 0.802

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-E-3 -OR- Algorithm eLANEX-E-3 Data.

		Observed		
		Low	High	Total
Predicted	High	36	28	64
Algorithm	Low	355	55	410
Output	Total	391	83	**474**
	% Correct	90.79	33.73	80.80

Algorithm SLEEPER3-E (Threshold = 1.4) - OR - eLNMNSQ-E (Threshold = 3.00000)
Apparent Accuracy Rate: 0.808

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-E-3 -OR- Algorithm eLNMNSQ-E-3 Data.

Figure E12: Regression Summary and Classification Matrices for Algorithm SLEEPER3-E-3.

Regression Summary for Dependent Variable: PERCLOS
$R = 0.48232223$ $R^2 = 0.23263473$ Adjusted $R^2 = 0.22277565$
$F(6,467) = 23.596$ $p < 0.00000$ Std. Error of estimate: 0.01074

	BETA	St. Err. of BETA	B	St. Err. of B	t(467)	p-level
Intercept			-0.00304	0.001063	-2.85703	0.004467
STVELV	0.387123	0.118343	0.000055	0.000017	3.27121	0.00115
LGREV	-0.20208	0.077889	-0.00153	0.00059	-2.5945	0.009771
MDREV	-0.33165	0.0933	-0.00038	0.000107	-3.55464	0.000417
LNMNSQ	0.333604	0.064803	0.003326	0.000646	5.14795	0
LANVAR	0.253799	0.06782	0.00524	0.0014	3.74227	0.000205
INTACDEV	-0.15691	0.047731	-0.00796	0.002423	-3.28727	0.001088

Observed

		Low	High	Total
Predicted	High	17	16	33
Algorithm	Low	424	17	441
Output	Total	441	33	**474**
	% Correct	96.15	48.48	92.83

PERCLOS R Value = 0.48232
Apparent Accuracy Rate: 0.928
Threshold: 0.012

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

Observed

		Low	High	Total
Predicted	High	1	56	57
Algorithm	Low	402	15	417
Output	Total	403	71	**474**
	% Correct	99.75	78.87	96.62

Algorithm F4e (Threshold = 0.012) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.966

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-3 -OR- Measured LANEX Data.

Observed

		Low	High	Total
Predicted	High	2	57	59
Algorithm	Low	401	14	415
Output	Total	403	71	**474**
	% Correct	99.50	80.28	96.62

Algorithm F4e (Threshold = 0.012) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.966

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-3 -OR- Measured LNMNSQ Data.

Figure E13: Regression Summary and Classification Matrices for Algorithm F4e-3.

Regression Summary for Dependent Variable: EYEMEAS
$R = 0.49305382$ $R^2 = 0.24310207$ Adjusted $R^2 = 0.23501556$
$F(5,468) = 30.063$ $p < 0.00000$ Std. Error of estimate: 813.50

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			658.4794	91.138	7.22505	0
STVELV	0.309549	0.083595	3.350214	0.905	3.70295	0.000239
MDREV	-0.43026	0.086316	-37.6294	7.549	-4.98478	0.000001
LNMNSQ	0.719422	0.098876	547.73	75.279	7.27602	0
LANEX	-0.22521	0.095389	-4799.08	2032.675	-2.36097	0.018636
ACEXEED	-0.16174	0.043547	-12313.3	3315.304	-3.71406	0.000229

		Observed Low	Observed High	Total
Predicted	High	7	16	23
Algorithm	Low	390	61	451
Output	Total	397	77	**474**
	% Correct	98.24	20.78	85.65

EYEMEAS R Value = 0.49303
Apparent Accuracy Rate: 0.857
Threshold: 2000

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm F2e-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed Low	Observed High	Total
Predicted	High	2	53	55
Algorithm	Low	369	50	419
Output	Total	371	103	**474**
	% Correct	99.46	51.46	89.03

Algorithm F2e (Threshold = 2000) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.890

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm F2e-3 -OR- Measured LANEX Data.

		Observed Low	Observed High	Total
Predicted	High	2	54	56
Algorithm	Low	368	50	418
Output	Total	370	104	**474**
	% Correct	99.46	51.92	89.03

Algorithm F2e (Threshold = 2000) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.890

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm F2e-3 -OR- Measured LNMNSQ Data.

Figure E14: Regression Summary and Classification Matrices for Algorithm F2e-3.

Regression Summary for Dependent Variable: DRVDROW

$R = 0.55351317$ $R^2 = 0.30637683$ Adjusted $R^2 = 0.29746518$

$F(6,467) = 34.379$ $p < 0.00000$ Std. Error of estimate: 25.534

	BETA	St. Err. of BETA	B	St. Err. of B	t(467)	p-level
Intercept			-19.0802	14.84457	-1.28533	0.199314
STVELV	0.248908	0.086348	0.0882	0.03061	2.88261	0.004126
MDREV	0.351189	0.091147	1.006	0.26108	3.853	0.000133
SMREV	0.385826	0.078104	0.8626	0.17462	4.93992	0.000001
THRSHLDS	0.275862	0.093295	104.5228	35.3491	2.95687	0.003265
LNMNSQ	0.302007	0.044025	7.5309	1.0978	6.85996	0
ACCDEV	-0.25487	0.049259	-8.747	1.69055	-5.17404	0

Predicted Algorithm Output		Observed Low	Observed High	Total
	High	20	65	85
	Low	276	113	389
	Total	296	178	**474**
	% Correct	93.24	36.52	71.94

DRVDROW R Value = 0.55351

Apparent Accuracy Rate: 0.719

Threshold: 70

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm F6e-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

Predicted Algorithm Output		Observed Low	Observed High	Total
	High	15	103	118
	Low	256	100	356
	Total	271	203	**474**
	% Correct	94.46	50.74	75.74

Algorithm F6e (Threshold = 70) - OR - LANEX (Threshold = 0.06667)

Apparent Accuracy Rate: 0.757

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm F6e-3 -OR- Measured LANEX Data.

Predicted Algorithm Output		Observed Low	Observed High	Total
	High	15	103	118
	Low	259	97	356
	Total	274	200	**474**
	% Correct	94.53	51.50	76.37

Algorithm F6e (Threshold = 70) - OR - LNMNSQ (Threshold = 3.00000)

Apparent Accuracy Rate: 0.764

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm F6e-3 -OR- Measured LNMNSQ Data.

Figure E15: Regression Summary and Classification Matrices for Algorithm F6e-3.

Regression Summary for Dependent Variable: SLEEPER1
$R = 0.48144126$ $R^2 = 0.23178568$ Adjusted $R^2 = 0.22357827$
$F(5,468) = 28.241$ $p < 0.00000$ Std. Error of estimate: 0.59991

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			0.357781	0.172959	2.06859	0.039133
STVELV	0.206212	0.045059	0.001634	0.000357	4.57644	0.000006
SMREV	0.138629	0.043307	0.006927	0.002164	3.2011	0.001462
LNMNSQ	0.361975	0.06053	0.201728	0.033734	5.98004	0
LANDEV	0.175862	0.067209	0.42942	0.164111	2.61665	0.009167
ACCDEV	-0.29967	0.050265	-0.22986	0.038554	-5.96191	0

		Observed Low	Observed High	Total
Predicted	High	15	24	39
Algorithm	Low	348	87	435
Output	Total	363	111	**474**
	% Correct	95.87	21.62	78.48

SLEEPER1 R Value = 0.48144
Apparent Accuracy Rate: 0.785
Threshold: 1.7

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER1 Data Resulting in Algorithm SLEEPER1-F-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed Low	Observed High	Total
Predicted	High	8	60	68
Algorithm	Low	330	76	406
Output	Total	338	136	**474**
	% Correct	97.63	44.12	82.28

Algorithm SLEEPER1-F (Threshold = 1.7) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.823

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER1 Data Resulting in Algorithm SLEEPER1-F-3 -OR- Measured LANEX Data.

		Observed Low	Observed High	Total
Predicted	High	7	62	69
Algorithm	Low	331	74	405
Output	Total	338	136	**474**
	% Correct	97.93	45.59	82.91

Algorithm SLEEPER1-F (Threshold = 1.7) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.829

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER1 Data Resulting in Algorithm SLEEPER1-F-3 -OR- Measured LNMNSQ Data.

Figure E16: Regression Summary and Classification Matrices for Algorithm SLEEPER1-F-3.

Regression Summary for Dependent Variable: SLEEPER2

$R = 0.47484712$ $R^2 = 0.22547978$ Adjusted $R^2 = 0.21720499$

$F(5,468) = 27.249$ $p < 0.00000$ Std. Error of estimate: 1.0391

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			1.325161	0.127258	10.41318	0
STVELV	0.182294	0.043048	0.002491	0.000588	4.23462	0.000028
LNMNSQ	0.681952	0.099898	0.655621	0.096041	6.82651	0
LANEX	-0.2091	0.095768	-5.62658	2.57695	-2.18343	0.0295
ACCDEV	-0.19145	0.051094	-0.25332	0.067606	-3.74695	0.000201
ACEXEED	-0.12712	0.047267	-12.2209	4.544002	-2.68945	0.007413

		Observed		
		Low	High	Total
Predicted	High	7	21	28
Algorithm	Low	383	63	446
Output	Total	390	84	**474**
	% Correct	98.21	25.00	85.23

SLEEPER2 R Value = 0.47485

Apparent Accuracy Rate: 0.852

Threshold: 3

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-F-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed		
		Low	High	Total
Predicted	High	4	58	62
Algorithm	Low	360	52	412
Output	Total	364	110	**474**
	% Correct	98.90	52.73	88.19

Algorithm SLEEPER2-F (Threshold = 3) - OR - LANEX (Threshold = 0.06667)

Apparent Accuracy Rate: 0.882

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-F-3 -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	3	58	61
Algorithm	Low	361	52	413
Output	Total	364	110	**474**
	% Correct	99.18	52.73	88.40

Algorithm SLEEPER2-F (Threshold = 3) - OR - LNMNSQ (Threshold = 3.00000)

Apparent Accuracy Rate: 0.884

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-F-3 -OR- Measured LNMNSQ Data.

Figure E17: Regression Summary and Classification Matrices for Algorithm SLEEPER2-F-3.

Regression Summary for Dependent Variable: SLEEPER3
$R = 0.53394126$ $R^2 = 0.28509327$ Adjusted $R^2 = 0.27435433$
$F(7,466) = 26.548$ $p < 0.00000$ Std. Error of estimate: 0.89238

	BETA	St. Err. of BETA	B	St. Err. of B	t(466)	p-level
Intercept			0.868176	0.232043	3.74145	0.000206
STVELV	0.393598	0.114568	0.004798	0.001397	3.43549	0.000644
LGREV	-0.20171	0.0763	-0.13147	0.049729	-2.64363	0.008479
MDREV	-0.2913	0.105169	-0.02869	0.010359	-2.7698	0.005833
NMRHOLDS	-0.1756	0.065891	-0.02252	0.008448	-2.66502	0.007965
LNMNSQ	0.357999	0.062946	0.306987	0.053977	5.68737	0
LANVAR	0.265219	0.067738	0.470883	0.120265	3.91538	0.000104
INTACDEV	-0.24404	0.04804	-1.06524	0.209694	-5.07998	0.000001

Observed

		Low	High	Total
Predicted	High	51	28	79
Algorithm	Low	375	20	395
Output	Total	426	48	**474**
	% Correct	88.03	58.33	85.02

SLEEPER3 R Value = 0.53394
Apparent Accuracy Rate: 0.850
Threshold: 1.4

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-3. (Independent variables employed included Steeri:.g, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

Observed

		Low	High	Total
Predicted	High	31	66	97
Algorithm	Low	360	17	377
Output	Total	391	83	**474**
	% Correct	92.07	79.52	89.87

Algorithm SLEEPER3-F (Threshold = 1.4) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.899

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-3 -OR- Measured LANEX Data.

Observed

		Low	High	Total
Predicted	High	31	66	97
Algorithm	Low	360	17	377
Output	Total	391	83	**474**
	% Correct	92.07	79.52	89.87

Algorithm SLEEPER3-F (Threshold = 1.4) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.899

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-3 -OR- Measured LNMNSQ Data.

Figure E18: Regression Summary and Classification Matrices for Algorithm SLEEPER3-F-3.

Regression Summary for Dependent Variable: PERCLOS

$R = 0.49073253$ $R^2 = 0.24081841$ Adjusted $R^2 = 0.22941440$

$F(7,466) = 21.117$ $p < 0.00000$ Std. Error of estimate: 0.01069

	BETA	St. Err. of BETA	B	St. Err. of B	t(466)	p-level
Intercept			-0.00299	0.001052	-2.83806	0.004737
STVELV	0.519969	0.124176	0.00007	0.000018	4.18737	0.000034
LGREV	-0.36289	0.09742	-0.00275	0.000738	-3.72499	0.000219
MDREV	-0.49255	0.104825	-0.00056	0.00012	-4.6988	0.000003
STEXED	-0.10572	0.045236	-8.41549	3.60093	-2.33703	0.01986
LNMNSQ	0.386739	0.054188	0.00386	0.00054	7.13703	0
LNRTVAR	0.365293	0.089166	0.0183	0.004468	4.09675	0.000049
INTACDEV	-0.14288	0.047827	-0,00725	0.002428	-2.98742	0.002962

		Observed		
		Low	High	Total
Predicted	High	18	17	35
Algorithm	Low	423	16	439
Output	Total	441	33	**474**
	% Correct	95.92	51.52	92.83

PERCLOS R Value = 0.49073

Apparent Accuracy Rate: 0.928

Threshold: 0.012

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm G4e-3. (Independent variables employed included Steering, Accelerometer, and all lane measures including LNRTDEV/VAR.)

		Observed		
		Low	High	Total
Predicted	High	2	57	59
Algorithm	Low	401	14	415
Output	Total	403	71	**474**
	% Correct	99.50	80.28	96.62

Algorithm G4e (Threshold = 0.012) - OR - LANEX (Threshold = 0.06667)

Apparent Accuracy Rate: 0.966

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm G4e-3 -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	3	57	60
Algorithm	Low	400	14	414
Output	Total	403	71	**474**
	% Correct	99.26	80.28	96.41

Algorithm G4e (Threshold = 0.012) - OR - LNMNSQ (Threshold = 3.00000)

Apparent Accuracy Rate: 0.964

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm G4e-3 -OR- Measured LNMNSQ Data.

Figure E19: Regression Summary and Classification Matrices for Algorithm G4e-3.

Regression Summary for Dependent Variable: EYEMEAS
R = 0.50518315 R^2 = 0.25521001 Adjusted R^2 = 0.24402218
F(7,466) = 22.811 p < 0.00000 Std. Error of estimate: 808.70

	BETA	St. Err. of BETA	B	St. Err. of B	t(466)	p-level
Intercept			402.0784	164.862	2.43888	0.015105
STVELV	0.355826	0.089313	3.85107	0.967	3.98405	0.000079
MDREV	-0.38587	0.090308	-33.7468	7.898	-4.27282	0.000023
LNMNSQ	0.672622	0.119174	512.0988	90.733	5.64403	0
LANDEV	0.236721	0.078085	789.6631	260.478	3.03159	0.002568
LANEX	-0.22762	0.099335	-4850.4	2116.771	-2.29141	0.022385
LNRTVAR	-0.22138	0.083261	-846.976	318.549	-2.65886	0.00811
ACCDEV	-0.1658	0.049411	-173.733	51.776	-3.35549	0.000857

Observed

Predicted Algorithm Output		Low	High	Total
	High	7	19	26
	Low	390	58	448
	Total	397	77	**474**
	% Correct	98.24	24.68	86.29

EYEMEAS R Value = 0.50518
Apparent Accuracy Rate: 0.863
Threshold: 2000

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm G2e-3. (Independent variables employed included Steering, Accelerometer, and all lane measures including LNRTDEV/VAR.)

Observed

Predicted Algorithm Output		Low	High	Total
	High	1	55	56
	Low	370	48	418
	Total	371	103	**474**
	% Correct	99.73	53.40	89.66

Algorithm G2e (Threshold = 2000) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.897

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm G2e-3 -OR- Measured LANEX Data.

Observed

Predicted Algorithm Output		Low	High	Total
	High	1	56	57
	Low	369	48	417
	Total	370	104	**474**
	% Correct	99.73	53.85	89.66

Algorithm G2e (Threshold = 2000) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.897

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm G2e-3 -OR- Measured LNMNSQ Data.

Figure E20: Regression Summary and Classification Matrices for Algorithm G2e-3.

Regression Summary for Dependent Variable: SLEEPER3

$R = 0.53863418$ $R^2 = 0.29012678$ Adjusted $R^2 = 0.27791391$

$F(8,465) = 23.756$ $p < 0.00000$ Std. Error of estimate: 0.89018

	BETA	St. Err. of BETA	B	St. Err. of B	t(465)	p-level
Intercept			-0.16549	0.2039	-0.81147	0.417512
STVELV	0.534174	0.120231	0.006512	0.0015	4.44291	0.000011
LGREV	-0.32983	0.095654	-0.21497	0.0623	-3.44812	0.000616
MDREV	-0.37012	0.106709	-0.03646	0.0105	-3.46854	0.000572
SMREV	0.119326	0.047014	0.009174	0.0036	2.53808	0.011471
STEXED	-0.10653	0.044009	-729.345	301.3027	-2.42064	0.015875
LNMNSQ	0.422557	0.052455	0.362346	0.045	8.05565	0
LNRTVAR	0.368618	0.089118	1.588412	0.384	4.1363	0.000042
INTACDEV	-0.22641	0.047786	-0.98827	0.2086	-4.73796	0.000003

		Observed		
		Low	High	Total
Predicted	High	48	27	75
Algorithm	Low	378	21	399
Output	Total	426	48	**474**
	% Correct	88.73	56.25	85.44

SLEEPER3 R Value = 0.53863

Apparent Accuracy Rate: 0.854

Threshold: 1.4

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-G-3. (Independent variables employed included Steering, Accelerometer, and all lane measures including LNRTDEV/VAR.)

		Observed		
		Low	High	Total
Predicted	High	27	64	91
Algorithm	Low	364	19	383
Output	Total	391	83	**474**
	% Correct	93.09	77.11	90.30

Algorithm SLEEPER3-G (Threshold = 1.4) - OR - LANEX (Threshold = 0.06667)

Apparent Accuracy Rate: 0.903

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-G-3 -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	27	64	91
Algorithm	Low	364	19	383
Output	Total	391	83	**474**
	% Correct	93.09	77.11	90.30

Algorithm SLEEPER3-G (Threshold = 1.4) - OR - LNMNSQ (Threshold = 3.00000)

Apparent Accuracy Rate: 0.903

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-G-3 -OR- Measured LNMNSQ Data.

Figure E21: Regression Summary and Classification Matrices for Algorithm SLEEPER3-G-3.

APPENDIX F

Regression Summaries, Unconditional Classification Matrices, and Conditional "OR" Classification Matrices for Driver Status Algorithms Developed Using Six-Minute Interval Data Set

Regression Summary for Dependent Variable: PERCLOS
$R = 0.21424527$ $R^2 = 0.04590104$ Adjusted $R^2 = 0.01686324$
$F(7,230) = 1.5807$ $p < 0.14198$ Std. Error of estimate: 0.01049

	BETA	St. Err. of BETA	B	St. Err. of B	t(230)	p-level
Intercept			0.01996	0.016102	1.2394	0.21646
MDREV	-0.27441	0.176541	-0.00028	0.000182	-1.55439	0.121467
SMREV	-0.2107	0.17219	-0.00018	0.000145	-1.22362	0.222347
STEXED	-0.09338	0.069111	-8.01949	5.935241	-1.35116	0.17797
NMRHOLDS	-0.38216	0.257809	-0.00053	0.00036	-1.48233	0.139622
THRSHLDS	0.15323	0.173096	0.02221	0.025087	0.88523	0.376958
ACCDEV	0.416782	0.204128	0.00668	0.00327	2.04177	0.042316
INTACDEV	-0.4071	0.185492	-0.02391	0.010892	-2.19471	0.029185

Note: Classification matrices not developed for this algorithm.

Figure F1: Regression Summary for Algorithm D4e-6.

Regression Summary for Dependent Variable: EYEMEAS
$R = 0.17804053$ $R^2 = 0.03169843$ Adjusted $R^2 = 0.01082986$
$F(5,232) = 1.5190$ $p < 0.18467$ Std. Error of estimate: 903.24

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			2893.097	1326.684	2.1807	0.030211
MDREV	-0.27291	0.175504	-24.202	15.563	-1.55503	0.121302
SMREV	-0.25922	0.155916	-18.779	11.295	-1.66253	0.097757
NMRHOLDS	-0.24626	0.241387	-29.523	28.938	-1.0202	0.308696
ACCDEV	0.176989	0.197067	243.28	270.877	0.89812	0.370053
INTACDEV	-0.17065	0.179363	-859.791	903.717	-0.95139	0.342395

Note: Classification matrices not developed for this algorithm.

Figure F2: Regression Summary for Algorithm D2e-6.

Regression Summary for Dependent Variable: DRVDROW

$R = 0.49927375$ $R^2 = 0.24927428$ Adjusted $R^2 = 0.23638628$

$F(4,233) = 19.342$ $p < 0.00000$ Std. Error of estimate: 26.352

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			-23.9242	23.69037	-1.00987	0.313605
MDREV	0.604658	0.08666	1.7805	0.25518	6.9774	0
SMREV	0.363384	0.113685	0.8741	0.27347	3.19641	0.001584
THRSHLDS	0.334322	0.140411	138.0536	57.98077	2.38102	0.018069
INTACDEV	-0.08356	0.059355	-13.9804	9.93038	-1.40784	0.16051

		Observed		
		Low	High	Total
Predicted	High	7	25	32
Algorithm	Low	142	64	206
Output	Total	149	89	**238**
	% Correct	95.30	28.09	70.17

DRVDROW R Value = 0.49927

Apparent Accuracy Rate: 0.702

Threshold: 70

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm D6e-6. (Independent variables employed included Steering and Accelerometer.)

		Observed		
		Low	High	Total
Predicted	High	6	26	32
Algorithm	Low	134	72	206
Output	Total	140	98	**238**
	% Correct	95.71	26.53	67.23

Algorithm D6e (Threshold = 70) - OR - eLNMNSQ-D (Threshold = 3.00000)

Apparent Accuracy Rate: 0.672

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm D6e-6 -OR- Algorithm eLNMNSQ-D-6 Data.

Figure F3: Regression Summary and Classification Matrices for Algorithm D6e-6.

Regression Summary for Dependent Variable: SLEEPER1
$R = 0.22283711$ $R^2 = 0.04965638$ Adjusted $R^2 = 0.04156835$
$F(2,235) = 6.1395$ $p < 0.00252$ Std. Error of estimate: 0.65875

	BETA	St. Err. of BETA	B	St. Err. of B	t(235)	p-level
Intercept			1.633673	0.127913	12.7718	0
NMRHOLDS	-0.44269	0.143256	-0.03932	0.012725	-3.09018	0.002241
THRSHLDS	0.29161	0.143256	2.686911	1.319966	2.03559	0.042913

Note: Classification matrices not developed for this algorithm.

Figure F4: Regression Summary for Algorithm SLEEPER1-D-6.

Regression Summary for Dependent Variable: SLEEPER2
$R = 0.13308084$ $R^2 = 0.01771051$ Adjusted $R^2 = 0.00935060$
$F(2,235) = 2.1185$ $p < 0.12250$ Std. Error of estimate: 1.1528

	BETA	St. Err. of BETA	B	St. Err. of B	t(235)	p-level
Intercept			1.76262	0.201936	8.72857	0
ACCDEV	0.294471	0.146985	0.51623	0.257677	2.00342	0.046281
INTACDEV	-0.29501	0.146985	-1.89574	0.944529	-2.00707	0.045888

Note: Classification matrices not developed for this algorithm.

Figure F5: Regression Summary for Algorithm SLEEPER2-D-6.

Regression Summary for Dependent Variable: SLEEPER3
$R = 0.21449643$ $R^2 = 0.04600872$ Adjusted $R^2 = 0.03788964$
$F(2,235) = 5.6667$ $p < 0.00395$ Std. Error of estimate: 0.93209

	BETA	St. Err. of BETA	B	St. Err. of B	t(235)	p-level
Intercept			1.483813	0.180988	8.19841	0
NMRHOLDS	-0.47164	0.14353	-0.05916	0.018004	-3.28598	0.001172
THRSHLDS	0.375983	0.14353	4.892417	1.867665	2.61954	0.009378

Note: Classification matrices not developed for this algorithm.

Figure F6: Regression Summary for Algorithm SLEEPER3-D-6.

Regression Summary for Dependent Variable: PERCLOS
$R = 0.40449755$ $R^2 = 0.16361826$ Adjusted $R^2 = 0.14559280$
$F(5,232) = 9.0771$ $p < 0.00000$ Std. Error of estimate: 0.00978

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			-0.0024	0.001377	-1.74202	0.08283
STVELV	0.72866	0.201384	0.0000903	0.000025	3.61825	0.000364
LGREV	-0.63537	0.162345	-0.00448	0.001144	-3.91371	0.000119
MDREV	-0.77627	0.166116	-0.0008	0.000172	-4.67304	0.000005
STEXED	-0.19915	0.069586	-17.1034	5.976072	-2.86197	0.004595
HPHDGVAR	0.839146	0.127311	0.079071	0.011996	6.59131	0

		Observed Low	Observed High	Total
Predicted	High	4	4	8
Algorithm	Low	214	16	230
Output	Total	218	20	**238**
	% Correct	98.17	20.00	91.60

PERCLOS R Value = 0.40450
Apparent Accuracy Rate: 0.916
Threshold: 0.012

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm E4e-6. (Independent variables employed included Steering, Accelerometer, and HPHDGDEV/VAR.)

		Observed Low	Observed High	Total
Predicted	High	4	4	8
Algorithm	Low	199	31	230
Output	Total	203	35	**238**
	% Correct	98.03	11.43	85.29

Algorithm E4e (Threshold = 0.012) - OR - eLANEX-E (Threshold = 0.06667)
Apparent Accuracy Rate: 0.853

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm E4e-6. -OR- Algorithm eLANEX-E-6 Data.

		Observed Low	Observed High	Total
Predicted	High	4	7	11
Algorithm	Low	197	30	227
Output	Total	201	37	**238**
	% Correct	98.01	18.92	85.71

Algorithm E4e (Threshold = 0.012) - OR - eLNMNSQ-E (Threshold = 3.00000)
Apparent Accuracy Rate: 0.857

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm E4e-6. -OR- Algorithm eLNMNSQ-E-6 Data.

Figure F7: Regression Summary and Classification Matrices for Algorithm E4e-6.

Regression Summary for Dependent Variable: EYEMEAS
R = 0.33980182 $R^2 = 0.11546528$ Adjusted $R^2 = 0.10028013$
$F(4,233) = 7.6038$ $p < 0.00001$ Std. Error of estimate: 861.43

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			116.517	248.6082	0.46868	0.639738
STVELV	0.642393	0.208251	6.831	2.2144	3.08471	0.002284
LGREV	-0.43904	0.156958	-265.414	94.887	-2.79716	0.005586
MDREV	-0.78589	0.1728	-69.691	15.3236	-4.54798	0.000009
HPHDGDEV	0.612748	0.119221	4406.414	857.3442	5.13961	0.000001

Figure F8: Regression Summary for Algorithm E2e-6.

Regression Summary for Dependent Variable: DRVDROW
$R = 0.53780402$ $R^2 = 0.28923316$ Adjusted $R^2 = 0.27391491$
$F(5,232) = 18.882$ $p < 0.00000$ Std. Error of estimate: 25.696

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			-47.3948	25.14356	-1.88497	0.060684
MDREV	0.403577	0.10556	1.1884	0.31083	3.82321	0.000169
SMREV	0.518145	0.121827	1.2464	0.29306	4.25312	0.000031
THRSHLDS	0.378751	0.139269	156.4	57.50906	2.71957	0.007031
ACCDEV	-0.18118	0.067888	-8.2695	3.09856	-2.66882	0.008149
HPHDGVAR	0.364848	0.10185	97.9508	27.3438	3.58219	0.000415

Observed

Predicted Algorithm Output		Low	High	Total
	High	10	31	41
	Low	139	58	197
	Total	149	89	**238**
	% Correct	93.29	34.83	71.43

DRVDROW R Value = 0.53780
Apparent Accuracy Rate: 0.714
Threshold: 70

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm E6e-6. (Independent variables employed included Steering, Accelerometer, and HPHDGDEV/VAR.)

Observed

Predicted Algorithm Output		Low	High	Total
	High	11	32	43
	Low	130	65	195
	Total	141	97	**238**
	% Correct	92.20	32.99	68.07

Algorithm E6e (Threshold = 70) - OR - eLANEX-E (Threshold = 0.06667)
Apparent Accuracy Rate: 0.681

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm E6e-6. -OR- Algorithm eLANEX-E-6 Data.

Observed

Predicted Algorithm Output		Low	High	Total
	High	11	35	46
	Low	129	63	192
	Total	140	98	**238**
	% Correct	92.14	35.71	68.91

Algorithm E6e (Threshold = 70) - OR - eLNMNSQ-E (Threshold = 3.00000)
Apparent Accuracy Rate: 0.689

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm E6e-6. -OR- Algorithm eLNMNSQ-E-6 Data.

Figure F9: Regression Summary and Classification Matrices for Algorithm E6e-6.

Regression Summary for Dependent Variable: SLEEPER1
$R = 0.32646937$ $R^2 = 0.10658225$ Adjusted $R^2 = 0.09512817$
$F(3,234) = 9.3052$ $p < 0.00001$ Std. Error of estimate: 0.64008

	BETA	St. Err. of BETA	B	St. Err. of B	t(234)	p-level
Intercept			0.50387	0.17067	2.95231	0.003475
STVELV	0.27526	0.120789	0.002169	0.000952	2.27884	0.023578
LGREV	-0.32437	0.137987	-0.14529	0.061807	-2.35074	0.019567
HPHDGDEV	0.350601	0.094117	1.868056	0.501469	3.72517	0.000245

Figure F10: Regression Summary for Algorithm SLEEPER1-E-6.

Regression Summary for Dependent Variable: SLEEPER2
$R = 0.32456540$ $R^2 = 0.10534270$ Adjusted $R^2 = 0.08998378$
$F(4,233) = 6.8587$ $p < 0.00003$ Std. Error of estimate: 1.1049

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			0.537309	0.318882	1.68498	0.093332
STVELV	0.620482	0.209439	0.008415	0.00284	2.96259	0.003367
LGREV	-0.4712	0.157853	-0.36331	0.121709	-2.98504	0.003138
MDREV	-0.44372	0.173786	-0.05018	0.019655	-2.55324	0.011311
HPHDGDEV	0.530773	0.119901	4.868061	1.09969	4.42676	0.000015

Figure F11: Regression Summary for Algorithm SLEEPER2-E-6.

Regression Summary for Dependent Variable: SLEEPER3
$R = 0.42229843$ $R^2 = 0.17833596$ Adjusted $R^2 = 0.16062769$
$F(5,232) = 10.071$ $p < 0.00000$ Std. Error of estimate: 0.87061

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			0.298972	0.1225	2.43984	0.015444
STVELV	0.748381	0.199605	0.008327	0.0022	3.74932	0.000224
LGREV	-0.68534	0.16091	-0.43352	0.1018	-4.25915	0.00003
MDREV	-0.53463	0.164648	-0.04961	0.0153	-3.24712	0.001338
STEXED	-0.16396	0.068971	-1264.18	531.8022	-2.37717	0.018258
HPHDGVAR	0.791618	0.126186	6.697056	1.0675	6.27343	0

		Observed		
		Low	High	Total
Predicted	High	17	11	28
Algorithm	Low	192	18	210
Output	Total	209	29	**238**
	% Correct	91.87	37.93	85.29

SLEEPER3 R Value = 0.42230
Apparent Accuracy Rate: 0.853
Threshold: 1.4

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-E-6. (Independent variables employed included Steering, Accelerometer, and HPHDGDEV/VAR.)

		Observed		
		Low	High	Total
Predicted	High	15	13	28
Algorithm	Low	181	29	210
Output	Total	196	42	**238**
	% Correct	92.35	30.95	81.51

Algorithm SLEEPER3-E (Threshold = 1.4) - OR - eLANEX-E (Threshold = 0.06667)
Apparent Accuracy Rate: 0.815

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-E-6. -OR- Algorithm eLANEX-E-6 Data.

		Observed		
		Low	High	Total
Predicted	High	14	16	30
Algorithm	Low	180	28	208
Output	Total	194	44	**238**
	% Correct	92.78	36.36	82.35

Algorithm SLEEPER3-E (Threshold = 1.4) - OR - eLNMNSQ-E (Threshold = 3.00000)
Apparent Accuracy Rate: 0.824

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-E-6. -OR- Algorithm eLNMNSQ-E-6 Data.

Figure F12: Regression Summary and Classification Matrices for Algorithm SLEEPER3-E-6.

Regression Summary for Dependent Variable: PERCLOS
$R = 0.57483855$ $R^2 = 0.33043936$ Adjusted $R^2 = 0.31304818$
$F(6,231) = 19.000$ $p < 0.00000$ Std. Error of estimate: 0.00877

	BETA	St. Err. of BETA	B	St. Err. of B	t(231)	p-level
Intercept			-0.0026	0.001378	-1.92078	0.05599
STVELV	0.357112	0.128601	0	0.000016	2.77689	0.005939
MDREV	-0.44237	0.129947	-0.0005	0.000134	-3.40422	0.000782
STEXED	-0.15776	0.059157	-13.5482	5.080455	-2.66674	0.008201
LNMNSQ	0.430096	0.085709	0.0043	0.000852	5.01808	0.000001
LANVAR	0.246026	0.089905	0.0049	0.001809	2.73651	0.006692
INTACDEV	-0.21847	0.058745	-0.0128	0.00345	-3.71897	0.000251

Observed

Predicted Algorithm Output		Low	High	Total
	High	8	13	21
	Low	210	7	217
	Total	218	20	**238**
	% Correct	96.33	65.00	93.70

PERCLOS R Value = 0.57484
Apparent Accuracy Rate: 0.937
Threshold: 0.012

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-6. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

Observed

Predicted Algorithm Output		Low	High	Total
	High	2	28	30
	Low	201	7	208
	Total	203	35	**238**
	% Correct	99.01	80.00	96.22

Algorithm F4e (Threshold = 0.012) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.962

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-6. -OR- Measured LANEX Data.

Observed

Predicted Algorithm Output		Low	High	Total
	High	1	30	31
	Low	200	7	207
	Total	201	37	**238**
	% Correct	99.50	81.08	96.64

Algorithm F4e (Threshold = 0.012) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.966

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-6. -OR- Measured LNMNSQ Data.

Figure F13: Regression Summary and Classification Matrices for Algorithm F4e-6.

Regression Summary for Dependent Variable: EYEMEAS
$R = 0.56911454$ $R^2 = 0.32389136$ Adjusted $R^2 = 0.30932005$
$F(5,232) = 22.228$ $p < 0.00000$ Std. Error of estimate: 754.76

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			758.79	154.212	4.9204	0.000002
STVELV	0.397864	0.120756	4.23	1.284	3.29477	0.001139
MDREV	-0.4763	0.127599	-42.24	11.315	-3.73278	0.000238
LNMNSQ	0.918816	0.158481	783.84	135.201	5.79763	0
LANEX	-0.32104	0.150682	-8038.92	3773.096	-2.13059	0.034175
ACCDEV	-0.23169	0.065894	-318.47	90.575	-3.51614	0.000527

Predicted Algorithm Output		Observed: Low	Observed: High	Observed: Total
	High	5	11	16
	Low	194	28	222
	Total	199	39	**238**
	% Correct	97.49	28.21	86.13

EYEMEAS R Value = 0.56911
Apparent Accuracy Rate: 0.861
Threshold: 2000

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm F2e-6. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

Predicted Algorithm Output		Observed: Low	Observed: High	Observed: Total
	High	2	25	27
	Low	187	24	211
	Total	189	49	**238**
	% Correct	98.94	51.02	89.08

Algorithm F2e (Threshold = 2000) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.891

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm F2e-6. -OR- Measured LANEX Data

Predicted Algorithm Output		Observed: Low	Observed: High	Observed: Total
	High	1	27	28
	Low	185	25	210
	Total	186	52	**238**
	% Correct	99.46	51.92	89.08

Algorithm F2e (Threshold = 2000) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.891

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced EYEMEAS Data Resulting in Algorithm F2e-6. -OR- Measured LNMNSQ Data.

Figure F14: Regression Summary and Classification Matrices for Algorithm F2e-6.

Regression Summary for Dependent Variable: DRVDROW

R = 0.58317659 R^2 = 0.34009494 Adjusted R^2 = 0.32587285

F(5,232) = 23.913 p < 0.00000 Std. Error of estimate: 24.760

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			3.14	8.7486	0.35896	0.719952
STVELV	0.436211	0.056924	0.154	0.0201	7.66299	0
SMREV	0.264105	0.054703	0.635	0.1316	4.828	0.000003
LNMNSQ	0.768212	0.155529	21.761	4.4057	4.93935	0.000001
LANEX	-0.39776	0.147715	-330.724	122.819	-2.69277	0.007603
ACCDEV	-0.27764	0.064418	-12.672	2.9402	-4.30996	0.000024

		Observed: Low	Observed: High	Total
Predicted	High	10	36	46
Algorithm	Low	139	53	192
Output	Total	149	89	**238**
	% Correct	93.29	40.45	73.53

DRVDROW R Value = 0.58318

Apparent Accuracy Rate: 0.735

Threshold: 70

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm F6e-6. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed: Low	Observed: High	Total
Predicted	High	7	49	56
Algorithm	Low	134	48	182
Output	Total	141	97	**238**
	% Correct	95.04	50.52	76.89

Algorithm F6e (Threshold = 70) - OR - LANEX (Threshold = 0.06667)

Apparent Accuracy Rate: 0.769

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm F6e-6. -OR- Measured LANEX Data.

		Observed: Low	Observed: High	Total
Predicted	High	7	50	57
Algorithm	Low	133	48	181
Output	Total	140	98	**238**
	% Correct	95.00	51.02	76.89

Algorithm F6e (Threshold = 70) - OR - LNMNSQ (Threshold = 3.00000)

Apparent Accuracy Rate: 0.769

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced DRVDROW Data Resulting in Algorithm F6e-6. -OR- Measured LNMNSQ Data.

Figure F15: Regression Summary and Classification Matrices for Algorithm F6e-6.

Regression Summary for Dependent Variable: SLEEPER1
$R = 0.54728563$ $R^2 = 0.29952156$ Adjusted $R^2 = 0.28442505$
$F(5,232) = 19.840$ $p < 0.00000$ Std. Error of estimate: 0.56921

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			0.410343	0.201123	2.04025	0.042458
STVELV	0.261044	0.058648	0.002057	0.000462	4.45101	0.000013
SMREV	0.135384	0.056359	0.007267	0.003025	2.40216	0.017086
LNMNSQ	0.882456	0.160239	0.557785	0.101284	5.50713	0
LANEX	-0.35631	0.152188	-6.61056	2.823517	-2.34125	0.020067
ACCDEV	-0.3168	0.066369	-0.32264	0.067592	-4.77329	0.000003

		Observed		
		Low	High	Total
Predicted	High	11	14	25
Algorithm	Low	172	41	213
Output	Total	183	55	**238**
	% Correct	93.99	25.45	78.15

SLEEPER1 R Value = 0.54729
Apparent Accuracy Rate: 0.782
Threshold: 1.7

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER1 Data Resulting in Algorithm SLEEPER1-F-6. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed		
		Low	High	Total
Predicted	High	7	29	36
Algorithm	Low	168	34	202
Output	Total	175	63	**238**
	% Correct	96.00	46.03	82.77

Algorithm SLEEPER1-F (Threshold = 1.7) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.828

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER1 Data Resulting in Algorithm SLEEPER1-F-6 -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	7	31	38
Algorithm	Low	165	35	200
Output	Total	172	**66**	**238**
	% Correct	95.93	46.97	82.35

Algorithm SLEEPER1-F (Threshold = 1.7) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.824

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER1 Data Resulting in Algorithm SLEEPER1-F-6 -OR- Measured LNMNSQ Data.

Figure F16: Regression Summary and Classification Matrices for Algorithm SLEEPER1-F-6.

Regression Summary for Dependent Variable: SLEEPER2
R = 0.53228675 R^2 = 0.28332919 Adjusted R^2 = 0.27102583
F(4,233) = 23.029 p < 0.00000 Std. Error of estimate: 0.98894

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			1.318681	0.20206	6.52619	0
STVELV	0.202467	0.059179	0.002746	0.000803	3.42123	0.000736
LNMNSQ	0.837479	0.15967	0.911209	0.173727	5.24505	0
LANEX	-0.30595	0.152812	-9.7709	4.880212	-2.00215	0.046428
ACCDEV	-0.29521	0.065873	-0.51753	0.115481	-4.48156	0.000012

		Observed		
		Low	High	Total
Predicted	High	5	11	16
Algorithm	Low	189	33	222
Output	Total	194	44	**238**
	% Correct	97.42	25.00	84.03

SLEEPER2 R Value = 0.53229
Apparent Accuracy Rate: 0.840
Threshold: 3

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-F-6. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed		
		Low	High	Total
Predicted	High	2	27	29
Algorithm	Low	182	27	209
Output	Total	184	54	**238**
	% Correct	98.91	50.00	87.82

Algorithm SLEEPER2-F (Threshold = 3) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.878

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-F-6. -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	2	29	31
Algorithm	Low	179	28	207
Output	Total	181	57	**238**
	% Correct	98.90	50.88	87.39

Algorithm SLEEPER2-F (Threshold = 3) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.874

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-F-6. -OR- Measured LNMNSQ Data.

Figure F17: Regression Summary and Classification Matrices for Algorithm SLEEPER2-F-6.

Regression Summary for Dependent Variable: SLEEPER3
R = 0.61440949 R^2 = 0.37749902 Adjusted R^2 = 0.35855334
F(7,230) = 19.925 p < 0.00000 Std. Error of estimate: 0.76107

	BETA	St. Err. of BETA	B	St. Err. of B	t(230)	p-level
Intercept			-0.44069	0.2793	-1.57794	0.115953
STVELV	0.430433	0.130391	0.004789	0.0015	3.30108	0.001116
MDREV	-0.35583	0.137299	-0.03302	0.0127	-2.59166	0.010163
SMREV	0.183382	0.061201	0.013901	0.0046	2.99641	0.003031
STEXED	-0.14003	0.057201	-1079.68	441.0498	-2.44798	0.015115
LNMNSQ	0.440137	0.083353	0.392885	0.0744	5.2804	0
LANVAR	0.288321	0.093517	0.520719	0.1689	3.08309	0.002299
INTACDEV	-0.27275	0.057169	-1.43796	0.3014	-4.77096	0.000003

		Observed		
		Low	High	Total
Predicted	High	25	16	41
Algorithm	Low	184	13	197
Output	Total	209	29	**238**
	% Correct	88.04	55.17	84.03

SLEEPER3 R Value = 0.61441
Apparent Accuracy Rate: 0.840
Threshold: 1.4

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-6. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Observed		
		Low	High	Total
Predicted	High	14	29	43
Algorithm	Low	182	13	195
Output	Total	196	42	**238**
	% Correct	92.86	69.05	88.66

Algorithm SLEEPER3-F (Threshold = 1.4) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.887

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-6. -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	13	31	44
Algorithm	Low	181	13	194
Output	Total	194	44	**238**
	% Correct	93.30	70.45	89.08

Algorithm SLEEPER3-F (Threshold = 1.4) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.891

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-6. -OR- Measured LNMNSQ Data.

Figure F18: Regression Summary and Classification Matrices for Algorithm SLEEPER3-F-6.

Regression Summary for Dependent Variable: SLEEPER2
R = 0.54417179 R^2 = 0.29612294 Adjusted R^2 = 0.28095318
F(5,232) = 19.521 p < 0.00000 Std. Error of estimate: 0.98218

	BETA	St. Err. of BETA	B	St. Err. of B	t(232)	p-level
Intercept			1.251024	0.203366	6.15159	0
STVELV	0.320097	0.082072	0.004341	0.001113	3.90019	0.000126
LNMNSQ	1.046861	0.188531	1.139025	0.205129	5.55273	0
LANEX	-0.43715	0.164669	-13.961	5.258858	-2.65475	0.008486
LNRTVAR	-0.21054	0.102525	-1.07512	0.523553	-2.0535	0.041146
ACCDEV	-0.27532	0.066136	-0.48266	0.115943	-4.16289	0.000044

		Observed		
		Low	High	Total
Predicted	High	7	11	**18**
Algorithm	Low	187	33	220
Output	Total	194	44	**238**
	% Correct	96.39	25.00	83.19

SLEEPER2 R Value = 0.54417
Apparent Accuracy Rate: 0.832
Threshold: 3

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-G-6. (Independent variables employed included Steering, Accelerometer, and all lane measures including LNRTDEV/VAR.)

		Observed		
		Low	High	Total
Predicted	High	3	27	30
Algorithm	Low	181	27	208
Output	Total	184	54	**238**
	% Correct	98.37	50.00	87.39

Algorithm SLEEPER2-G (Threshold = 3) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.874

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-G-6. -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	3	29	32
Algorithm	Low	178	28	206
Output	Total	181	57	**238**
	% Correct	98.34	50.88	86.97

Algorithm SLEEPER2-G (Threshold = 3) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.870

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER2 Data Resulting in Algorithm SLEEPER2-G-6. -OR- Measured LNMNSQ Data.

Figure F19: Regression Summary and Classification Matrices for Algorithm SLEEPER2-G-6.

APPENDIX G

Regression Summaries and Classification Matrices for Driver Performance Algorithms Developed Using Three-Minute and Six-Minute Interval Data Sets.

Regression Summary for Dependent Variable: LANEX
R = 0.36680870 $R^2 = 0.13454862$ Adjusted $R^2 = 0.13087367$
F(2,471) = 36.612 $p < 0.00000$ Std. Error of estimate: 0.04069

	BETA	St. Err. of BETA	B	St. Err. of B	t(471)	p-level
Intercept			0.017	0.00781	2.17756	0.02993
SMREV	-0.1208	0.04352	-0.0004	0.00014	-2.7748	0.00574
ACCDEV	0.36788	0.04352	0.01809	0.00214	8.45273	0

Figure G1: Regression Summary for Algorithm eLANEX-D-3.

Regression Summary for Dependent Variable: LNMNSQ
R = 0.49339638 $R^2 = 0.24343999$ Adjusted $R^2 = 0.23535709$
F(5,468) = 30.118 $p < 0.00000$ Std. Error of estimate: 1.0683

	BETA	St. Err. of BETA	B	St. Err. of B	t(468)	p-level
Intercept			0.18557	0.1819	1.02018	0.30817
STVELV	-0.2436	0.08376	-0.0035	0.00119	-2.9085	0.00381
MDREV	0.34451	0.09374	0.03957	0.01077	3.67517	0.00027
THRSHLDS	0.21393	0.0508	3.25059	0.77181	4.21162	0.00003
ACCDEV	0.38236	0.05129	0.52625	0.07059	7.45543	0
ACEXEED	0.1318	0.04628	13.1793	4.62794	2.84776	0.0046

Figure G2: Regression Summary for Algorithm eLNMNSQ-D-3.

Regression Summary for Dependent Variable: LANEX
R = 0.49743012 R^2 = 0.24743672 Adjusted R^2 = 0.24101827
F(4,469) = 38.551 p < 0.00000 Std. Error of estimate: 0.03803

	BETA	St. Err. of BETA	B	St. Err. of B	t(469)	p-level
Intercept			-0.0174	0.00401	-4.346	0.000017
LGREV	-0.3661	0.06863	-0.0099	0.00186	-5.3348	0
MDREV	-0.2228	0.05969	-0.0009	0.00025	-3.7324	0.00021
ACCDEV	0.26421	0.04661	0.01299	0.00229	5.66828	0
HPHDGVAR	0.6558	0.07429	0.23842	0.02701	8.82751	0

Figure G3: Regression Summary for Algorithm eLANEX-E-3.

Regression Summary for Dependent Variable: LNMNSQ
R = 0.66422380 R^2 = 0.44119326 Adjusted R^2 = 0.43642731
F(4,469) = 92.572 p<0.0000 Std. Error of estimate: 0.91711

	BETA	St. Err. of BETA	B	St. Err. of B	t(469)	p-level
Intercept			0.3326	0.08695	3.82541	0.00015
LGREV	-0.481	0.05912	-0.3656	0.04493	-8.1367	0
MDREV	-0.2007	0.05097	-0.0231	0.00586	-3.9366	0.000095
INTACVAR	0.26525	0.03616	1.76064	0.24001	7.33582	0
HPHDGVAR	0.94975	0.06273	9.66436	0.6383	15.1408	0

Figure G4: Regression Summary for Algorithm eLNMNSQ-E-3.

Regression Summary for Dependent Variable: LANEX
$R = 0.34844513$ $R^2 = 0.12141401$ Adjusted $R^2 = 0.11015009$
$F(3,234) = 10.779$ $p < 0.00000$ Std. Error of estimate: 0.03421

	BETA	St. Err. of BETA	B	St. Err. of B	t(234)	p-level
Intercept			0.01677	0.01066	1.57303	0.11706
LGREV	-0.1228	0.07092	-0.003	0.00171	-1.7323	0.08454
SMREV	-0.143	0.06425	-0.0004	0.00019	-2.2258	0.02698
ACCDEV	0.38046	0.06966	0.02089	0.00382	5.46158	0

Figure G5: Regression Summary for Algorithm eLANEX-D-6.

Regression Summary for Dependent Variable: LNMNSQ
$R = 0.48548148$ $R^2 = 0.23569226$ Adjusted $R^2 = 0.22257110$
$F(4,233) = 17.963$ $p < 0.00000$ Std. Error of estimate: 0.93864

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			1.4963	0.29476	5.07626	0.000001
STVELV	-0.4181	0.13195	-0.0052	0.00165	-3.1689	0.00174
MDREV	0.42108	0.13966	0.04377	0.01452	3.0151	0.00285
SMREV	-0.2131	0.06067	-0.0181	0.00515	-3.5124	0.00053
ACCDEV	0.3979	0.0643	0.64111	0.10361	6.18801	0

Figure G6: Regression Summary for Algorithm eLNMNSQ-D-6.

Regression Summary for Dependent Variable: LANEX
$R = 0.51371514$ $R^2 = 0.26390325$ Adjusted $R^2 = 0.25126639$
$F(4,233) = 20.884$ $p < 0.00000$ Std. Error of estimate: 0.03138

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			-0.0485	0.00855	-5.672	0
LGREV	-0.3617	0.09286	-0.0087	0.00224	-3.8956	0.00013
MDREV	-0.2607	0.09117	-0.0009	0.00032	-2.8595	0.00463
ACCVAR	0.22062	0.06269	0.00337	0.00096	3.51901	0.00052
HPHDGDEV	0.71473	0.0974	0.20526	0.02797	7.33813	0

Figure G7: Regression Summary for Algorithm eLANEX-E-6.

Regression Summary for Dependent Variable: LNMNSQ
$R = 0.68032280$ $R^2 = 0.46283912$ Adjusted $R^2 = 0.45361747$
$F(4,233) = 50.191$ $p < 0.00000$ Std. Error of estimate: 0.78689

	BETA	St. Err. of BETA	B	St. Err. of B	t(233)	p-level
Intercept			-1.1584	0.21443	-5.402	0
LGREV	-0.4376	0.07932	-0.3101	0.05621	-5.5164	0
MDREV	-0.2882	0.07788	-0.03	0.0081	-3.7007	0.00027
ACCVAR	0.25283	0.05356	0.11347	0.02404	4.72084	0.000004
HPHDGDEV	0.95003	0.0832	8.00829	0.70137	11.4181	0

Figure G8: Regression Summary for Algorithm eLNMNSQ-E-6.