

**ALGORITHMS REFINEMENT AND THRESHOLD  
DETERMINATION FOR A DROWSY DRIVER  
DETECTION SYSTEM**

by

Rollin J. Fairbanks, III

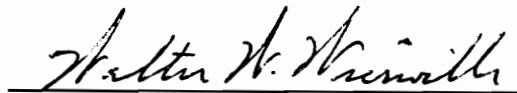
Thesis submitted to the faculty  
of the Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of

Master of Science

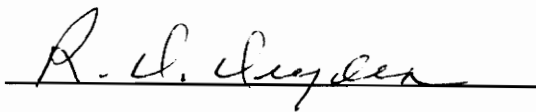
in

Industrial and Systems Engineering

APPROVED



Dr. Walter W. Wierwille, Chair



Dr. Robert D. Dryden



Dr. Dennis L. Price

December, 1995

Blacksburg, Virginia

C.2

LD  
5655  
V855  
1995  
F351  
C.2

# **ALGORITHM REFINEMENT AND THRESHOLD DETERMINATION FOR A DROWSY DRIVER DETECTION SYSTEM**

by

Rollin J. Fairbanks, III

Dr. Walter W. Wierwille, Committee Chair

Industrial and Systems Engineering

## **ABSTRACT**

Research conducted over the past three years in the Vehicle Analysis and Simulation Laboratory at Virginia Tech has resulted in the development and validation of algorithms for the detection of driver drowsiness. Specifically, the goal of the research has been to develop the best possible drowsiness-detection algorithms using measures that can be computed while a vehicle is in motion with minimal interference with the driver. The results of these studies, which have been previously reported, generally support the feasibility of drowsy-driver detection and indicate that further analysis and refinement of the algorithms is warranted. This thesis researches several methods of refining existing driver-status algorithms, the integration of driver-performance deterioration measures, and the selection of appropriate alarm thresholds to be used in test and evaluation study.

The results of five algorithm optimization refinements are described. Chapter 2 reports that the elimination of outlier dependent measure data prior to algorithm development was found not to improve algorithm accuracy. Chapter 3 describes that the addition of cross product and squared terms to the algorithms did not provide consistent improvement in algorithm accuracy. Chapter 4 reports that, although time-on-task variables were found to have some improved capability, they did not consistently add to the accuracy of the algorithms.

In Chapter 5, the predictive ability of the algorithms was tested and found to be good. This result is an important indication of the flexibility of previously developed algorithms. If the planned test and evaluation study shows that original algorithms do not detect drowsiness soon enough, algorithms with prediction capability can be substituted with no appreciable degradation in detection performance. Chapter 6 reports on a related study which investigated the benefit of integrating previous and current time segment data into the same algorithms. It was found that there was no notable improvement in algorithm accuracy.

The goal of the long term study has been to develop a system capable of monitoring driver status and driver performance. Additionally, preparation of the on-line test and evaluation study has lead to the conclusion that implementation would be more straightforward if unbaselined algorithms were used. Chapter 7 reports on the development and validation of unbaselined algorithms capable of monitoring both driver status and driver performance. The use of unbaselined data was found to produce no appreciable decrement in algorithm accuracy, and inclusion of a driver-performance monitoring component was found to improve system accuracy.

The final phase in the development of this drowsy driver detection alarm and countermeasure system will be testing and evaluation in a simulator environment. Although dual thresholds for dependent measures have previously been used for the purpose of classification matrix evaluation of algorithms, the on-line testing and evaluation of the final system requires the use of single thresholds for each dependent measure. Chapter 8 describes the development and validation of thresholds which should be used in the monitoring of driver-status only, as well as integrated driver status and driver performance monitoring.

## ACKNOWLEDGMENTS

This research is an extension of a series of studies which have been conducted during the past four years in the Vehicle Analysis and Simulation Laboratory (VASL) at Virginia Tech. Dr. Walter W. Wierwille, who is the director of the VASL and principle investigator for these studies, has served as my major advisor and committee chair. Thanks go to Dr. Wierwille for his guidance, flexibility, and support. His influence has gone beyond the lab. I would also like to recognize the other members of my committee, Dr. Dennis Price and Dr. Robert Dryden.

Additionally, I would like to recognize Dr. Stephen Wreggit and Chris Kirn who provided my orientation to the research project and to the operations of the VASL, and who collected the data my research is based on. Thanks are extended to my colleagues Mark Lewin and Vicki Lewis for their assistance during the final months of my thesis. A significant amount of credit is due to Sarah Fahey, a VASL colleague and friend, for her support and friendship during my time in the VASL.

This work was sponsored under a cooperative agreement funded by the National Highway Traffic Safety Administration's Office of Crash Avoidance Research. Dr. Ronald R. Knipling served as contract technical representative.

## TABLE OF CONTENTS

|                                                                       |           |
|-----------------------------------------------------------------------|-----------|
| ABSTRACT .....                                                        | i         |
| ACKNOWLEDGMENTS .....                                                 | iii       |
| TABLE OF CONTENTS .....                                               | iv        |
| LIST OF FIGURES .....                                                 | vii       |
| LIST OF TABLES .....                                                  | ix        |
| <b>Chapter 1: REVIEW OF THE LITERATURE AND CURRENT RESEARCH .....</b> | <b>1</b>  |
| Background .....                                                      | 2         |
| Current Research .....                                                | 4         |
| Data Collection .....                                                 | 4         |
| Data Preparation .....                                                | 5         |
| Multiple Regression. ....                                             | 5         |
| R Values. ....                                                        | 6         |
| Classification Matrices. ....                                         | 6         |
| Algorithm Validation .....                                            | 7         |
| Explanation of Measures .....                                         | 7         |
| Glossary .....                                                        | 7         |
| Steering-related measures .....                                       | 7         |
| Lateral Accelerometer-related measures .....                          | 8         |
| Lane-related measures .....                                           | 9         |
| Subsidiary (A/O) Task -Related Measures .....                         | 9         |
| Dependent Measures .....                                              | 10        |
| Algorithm Output Measures .....                                       | 10        |
| <b>Chapter 2: THE ELIMINATION OF OUTLIERS FROM PERCLOS DATA .....</b> | <b>11</b> |
| Introduction .....                                                    | 12        |
| Method .....                                                          | 12        |
| Results and Discussion .....                                          | 13        |
| <b>Chapter 3: EFFECTS OF USING HIGHER-ORDER ALGORITHMS .....</b>      | <b>15</b> |
| Introduction .....                                                    | 16        |
| Method .....                                                          | 16        |
| Data .....                                                            | 16        |
| Data Analysis .....                                                   | 17        |
| "Clipped" R Values .....                                              | 17        |
| Results .....                                                         | 19        |
| Multiple Regression .....                                             | 19        |

|                                                                  |           |
|------------------------------------------------------------------|-----------|
| Pearson-Product-Moment Correlation (R) Values .....              | 19        |
| "Clipped" Algorithm Output PERCLOS Values .....                  | 21        |
| Classification Matrices .....                                    | 21        |
| Discussion .....                                                 | 21        |
| Interpretation of Results.....                                   | 21        |
| Stability of algorithms when applied to new subject data .....   | 21        |
| Effect of higher order algorithms on accuracy of prediction..... | 31        |
| Outliers.....                                                    | 31        |
| Conclusions .....                                                | 31        |
| <b>Chapter 4: EFFECTS OF TIME-ON-TASK VARIABLES.....</b>         | <b>33</b> |
| Introduction.....                                                | 34        |
| Procedure .....                                                  | 34        |
| Results .....                                                    | 34        |
| Conclusions and Discussion.....                                  | 38        |
| <b>Chapter 5: THE PREDICTIVE POWER OF DRIVER DETECTION</b>       |           |
| <b>ALGORITHMS.....</b>                                           | <b>40</b> |
| Introduction.....                                                | 41        |
| Method .....                                                     | 41        |
| Baselining of Raw Data. ....                                     | 41        |
| Preparation of Advance Data. ....                                | 42        |
| Multiple Regression. ....                                        | 42        |
| Validation of Resulting Algorithms.....                          | 42        |
| Results .....                                                    | 43        |
| Discussion .....                                                 | 50        |
| <b>Chapter 6: TIME TREND ANALYSIS .....</b>                      | <b>53</b> |
| Introduction.....                                                | 54        |
| Method .....                                                     | 54        |
| Results .....                                                    | 55        |
| Discussion and Conclusion.....                                   | 55        |
| <b>Chapter 7: DEVELOPMENT OF UNBASELINED DRIVER STATUS AND</b>   |           |
| <b>DRIVER PERFORMANCE ALGORITHMS .....</b>                       | <b>59</b> |
| Unbaselined Driver Status (PERCLOS) Algorithms .....             | 60        |
| The Driver-Performance Monitoring Component.....                 | 61        |
| Introduction.....                                                | 61        |
| Method .....                                                     | 62        |
| Results .....                                                    | 64        |

|                                                                                       |     |
|---------------------------------------------------------------------------------------|-----|
| Case 1- Development/Validation Subjects .....                                         | 64  |
| Case 2- Odd/Even Subjects.....                                                        | 64  |
| Case 3- All Subjects .....                                                            | 69  |
| Discussion .....                                                                      | 69  |
| <b>Chapter 8: RECOMMENDATIONS FOR THE ON-LINE DETECTION</b>                           |     |
| SYSTEM STRUCTURE AND THRESHOLDS.....                                                  | 72  |
| The Estimation of Best Single-Threshold Levels .....                                  | 73  |
| Introduction.....                                                                     | 73  |
| Observed PERCLOS Single Threshold Level.....                                          | 73  |
| Estimated-PERCLOS (ePERCLOS) Single Threshold Level .....                             | 75  |
| Observed LANEX Single Threshold Level.....                                            | 76  |
| Estimated-LANEX (eLANEX) Single Threshold Level .....                                 | 78  |
| The Integration of Simultaneous Driver Performance and Driver Status Monitoring ..... | 79  |
| Introduction.....                                                                     | 79  |
| Lane Information Always Available .....                                               | 79  |
| Lane Information Never Available.....                                                 | 80  |
| Transitional Interval- Lane Information Sometimes Available.....                      | 81  |
| Transitional Interval Thresholds .....                                                | 84  |
| SUMMARY                                                                               |     |
| System Recommendations.....                                                           | 86  |
| REFERENCES .....                                                                      | 88  |
| APPENDIX A                                                                            |     |
| Summaries of the Multiple Regression Analyses for Higher Order                        |     |
| Algorithms Study .....                                                                | 92  |
| APPENDIX B                                                                            |     |
| Effects of the Removal of Baselining Techniques on the Accuracy of                    |     |
| Drowsy Driver Detection Algorithms.....                                               | 102 |
| VITA .....                                                                            | 120 |

## LIST OF FIGURES

|      |                                                                                                                                            |    |
|------|--------------------------------------------------------------------------------------------------------------------------------------------|----|
| 3.1: | Classification matrices showing accuracy of Algorithm 1-LIN when applied to development data (upper) and validation data (lower).....      | 22 |
| 3.2: | Classification matrices showing accuracy of Algorithm 1-LINCROSS when applied to development data (upper) and validation data (lower)..... | 23 |
| 3.3  | Classification matrices showing accuracy of Algorithm 1-FULL when applied to development data (upper) and validation data (lower).....     | 24 |
| 3.4: | Classification matrices showing accuracy of Algorithm 2-LIN when applied to development data (upper) and validation data (lower).....      | 25 |
| 3.5: | Classification matrices showing accuracy of Algorithm 2-LINCROSS when applied to development data (upper) and validation data (lower)..... | 26 |
| 3.6: | Classification matrices showing accuracy of Algorithm 2-FULL when applied to development data (upper) and validation data (lower).....     | 27 |
| 3.7: | Classification matrices showing accuracy of Algorithm 3-LIN when applied to development data (upper) and validation data (lower).....      | 28 |
| 3.8: | Classification matrices showing accuracy of Algorithm 3-LINCROSS when applied to development data (upper) and validation data (lower)..... | 29 |
| 3.9: | Classification matrices showing accuracy of Algorithm 3-FULL when applied to development data (upper) and validation data (lower).....     | 30 |
| 5.1: | Overall average accuracy of algorithms as a function of advance time .....                                                                 | 45 |
| 5.2: | Accuracy of the Group D algorithms for the development data set .....                                                                      | 46 |
| 5.3: | Accuracy of the Group F algorithms for the development data set.....                                                                       | 47 |
| 5.4: | Accuracy of the Group D algorithms applied to the validation data set.....                                                                 | 48 |
| 5.5: | Accuracy of the Group F algorithms applied to the validation data set .....                                                                | 49 |
| 6.1: | Graphical representations of the APAR and R values for development and validation data .....                                               | 57 |
| 7.1: | Unbaselined Development LANEX and PERCLOS Data.....                                                                                        | 63 |
| 7.2: | Regression Summary and Classification Matrix Showing Accuracy of Algorithm LDV-1 When Applied to Combined Data Set (24 Subjects) .....     | 70 |
| 7.3: | Regression Summary and Classification Matrix Showing Accuracy of Algorithm LDV-4 When Applied to Combined Data Set (24 Subjects) .....     | 71 |
| 8.1: | Trend Model of PERCLOS for Linearly Increasing Level of Drowsiness.....                                                                    | 74 |
| 8.2: | PERCLOS Data With Upper and Lower Threshold Lines for Three Categories and Single Threshold for Two Categories.....                        | 75 |

|      |                                                                                                                                                  |     |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 8.3: | Total Error, False Alarm, and Missed Detection Percentages as a Function of ePERCLOS Algorithm Output Threshold.....                             | 76  |
| 8.4: | Trend Model of LANEX for Linearly Increasing Level of Drowsiness.....                                                                            | 77  |
| 8.5: | Total Error, False Alarm, and Missed Detection Percentages as a Function of eLANEX Algorithm Output Threshold.....                               | 78  |
| B.1: | Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm D4a When Applied to Original Data and New Data .....      | 107 |
| B.2: | Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm F4a When Applied to Original Data and New Data .....      | 108 |
| B.3: | Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm J4a When Applied to Original Data and New Data.....       | 109 |
| B.4: | Baselined Regression Summary and Classification Matrix Showing Accuracy of Algorithm L3a When Applied to New Data.....                           | 110 |
| B.5: | Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm D4a-N When Applied to Original Data and New Data....  | 115 |
| B.6: | Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm F4a-N When Applied to Original Data and New Data....  | 116 |
| B.7: | Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm J4a-N When Applied to Original Data and New Data..... | 117 |
| B.8: | Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm L3a-N When Applied to Original Data and New Data....  | 118 |
| B.9: | Comparison of R Values and Apparent Accuracy Rates For Baselined and Non-Baselined Algorithms When Applied to Original Data and New Data.....    | 119 |

## LIST OF TABLES

|      |                                                                                                     |    |
|------|-----------------------------------------------------------------------------------------------------|----|
| 2.1: | A comparison of the regression and validation results using "clipped" PERCLOS and PERCLOS.....      | 13 |
| 2.2: | Regression Summary for Trial 1, "Clipped PERCLOS".....                                              | 14 |
| 2.3: | Regression Summary for Trial 2, Actual PERCLOS.....                                                 | 14 |
| 3.1: | Summary of variable groups used in algorithm development .....                                      | 18 |
| 3.2: | Summary of Results.....                                                                             | 20 |
| 4.1: | Explanation of Variable Groups.....                                                                 | 35 |
| 4.2: | Explanation of Time Variables .....                                                                 | 35 |
| 4.3: | Summary of regression and classification matrices results from inclusion of time variables.....     | 36 |
| 4.4: | Summary of regression and classification matrices results from inclusion of time variables.....     | 37 |
| 5.1: | Summary of prediction algorithm accuracy results compared with corresponding real-time results..... | 44 |
| 5.2: | Multiple Regression Summaries for Group D with 2, 4, 6, and 12-minute Advances.....                 | 51 |
| 5.3: | Multiple Regression Summaries for Group F with 2, 4, 6, and 12-minute Advances.....                 | 52 |
| 6.1: | A comparison of the original results with the results from studies 1A and 2A.....                   | 56 |
| 6.2: | Regression Summary for Algorithm 1A .....                                                           | 58 |
| 6.3: | Regression Summary for Algorithm 2A .....                                                           | 58 |
| 7.1: | Combinations of data sets and variable groups used in algorithm development and validation.....     | 62 |
| 7.2: | Case 1 Algorithm Development Results.....                                                           | 65 |
| 7.3: | Case 1 Validation Results.....                                                                      | 66 |
| 7.4: | Case 2 Algorithm Development Results (Odd-Numbered Subjects).....                                   | 67 |
| 7.5: | Case 2 Validation Results (Even-Numbered Subjects).....                                             | 68 |
| 8.1: | Classification Accuracy ePERCLOS (Alg F4a-N)-or-LANEX v. PERCLOS-or-LANEX.....                      | 80 |

|      |                                                                                            |     |
|------|--------------------------------------------------------------------------------------------|-----|
| 8.2: | Classification Accuracy: ePERCLOS (D4a-N) -or- eLANEX (LDV-1) v. PERCLOS-or-LANEX.....     | 80  |
| 8.3: | Linear Interpolation of Expected Classification Matrix Values For Transition Segments..... | 82  |
| 8.4: | Summary of transitional interval accuracy rates.....                                       | 83  |
| 8.5: | Explanation of Transitional Interval Threshold Levels .....                                | 84  |
| A.1: | Multiple Regression Summary for Algorithm 1-LIN.....                                       | 93  |
| A.2: | Multiple Regression Summary for Algorithm 1-LINCROSS .....                                 | 94  |
| A.3: | Multiple Regression Summary for Algorithm 1-FULL .....                                     | 95  |
| A.4: | Multiple Regression Summary for Algorithm 2-LIN.....                                       | 96  |
| A.5: | Multiple Regression Summary for Algorithm 2-LINCROSS .....                                 | 97  |
| A.6: | Multiple Regression Summary for Algorithm 2-FULL .....                                     | 98  |
| A.7: | Multiple Regression Summary for Algorithm 3-LIN.....                                       | 99  |
| A.8: | Multiple Regression Summary for Algorithm 3-LINCROSS .....                                 | 100 |
| A.9: | Multiple Regression Summary for Algorithm 3-FULL .....                                     | 101 |

## **Chapter 1**

### **REVIEW OF THE LITERATURE AND CURRENT RESEARCH**

## BACKGROUND

Today one of the largest hazards to highway safety is the drowsy driver. Over the last ten years, drowsiness related accidents accounted for at least 15,000 deaths. In 1991 the NHTSA Office of Crash Avoidance Research reported that driver drowsiness is one of the leading causes of motor vehicle accidents. The statistics are probably too low since official causes such as "failure to keep right," or "loss of control of vehicle," are often listed when driver fatigue is actually the underlying cause.

A recent NHTSA Research Note (Knipling and Wang, 1994) summarized available national statistics for the years 1989-93 based on General Estimates System (GES) data representative of all crashes and Fatal Accident Reporting System (FARS) statistics on fatal crashes. A summary of their findings is as follows:

- There were an average of 56,000 police-reported crashes in which driver drowsiness/fatigue was cited (0.9 percent of all crashes).
- An annual average of 1,542 fatalities were associated with these crashes (3.6 percent of all fatalities).
- These crashes resulted in an estimated 40,000 non-fatal injuries (all non-fatal severity levels).
- Due to under reporting, all of the above statistics are regarded as conservative.

Statistics on crash characteristics of "drowsiness-cited" cases indicated the following:

- Drowsy driver crashes peak in the early a.m. hours with a second smaller peak in the afternoon. Fifty five (55) percent occurred between midnight and 8:00 am, and another 18 percent occurred between 1:00 and 5:00 pm.
- Most occurred in non-urban areas, generally on roadways with 55-65 mph speed limits.
- Eighty (80) percent were single-vehicle crashes or collisions with parked vehicles. An additional 6.6 percent were subject vehicle-striking rear-end crashes.
- In 76 percent of crashes the driver was the only occupant of the subject vehicle.
- Fifteen (15) percent of drowsiness/fatigue crashes also involve alcohol.
- Involvement is strongly related to both driver sex and driver age. For the 1989-93 period, 76 percent of subject drivers were male, and 59 percent were under the age of 30. The higher-percentage male statistics are comparable to those of accidents in general, although this may somewhat affected by exposure.

- In addition to young male drivers, commercial (i.e. long-haul truck) drivers are at risk, primarily due to their high mileage exposure.

Clearly, there is a problem. Dingus, Hardee, and Wierwille (1987) reported that a relatively large percentage of accidents due to driver impairment occur when drivers are unaware of their level of impairment. Many devices exist which supposedly prevent the driver from becoming impaired due to drowsiness. However, none of the commercially available devices has been consistently supported by scientific research. Additionally, most of these devices are encumbering to the driver, and face limited acceptance in the driving public, particularly in the trucking industry, which is “less than enthusiastic” about such devices (Cross, 1995). For example, one reported device relies on the collection of brain wave activity to sense drowsiness (World Highways, 1981). It has even been suggested that candidates for driver-licenses should be tested for an ability to maintain alertness, just as they are tested for visual acuity and knowledge of rules of the road (Yoss, 1969).

It has been shown that correlations do exist between behavioral signals and driver drowsiness and that drowsiness can be detected with reasonable accuracy by monitoring driver performance measures (Wierwille et al, 1992; Dingus and Wierwille, 1995; Faidy et al, 1992). In a review of the current literature no research related to the determination and use of thresholds (specific to driver performance measures) was found.

In recognition of the lack of adequate detection devices, recent research has been conducted at Virginia Polytechnic Institute and State University, funded by the National Highway Traffic Safety Administration (NHTSA). The objective of this project has been to develop, validate, and refine elements of a driver-drowsiness detection and alerting system. The Three-Year Report of Research on Vehicle-Based Driver Status/Performance Monitoring (Wierwille, Wreggit, Kim, Ellsworth, and Fairbanks, 1994) presents initial detection algorithms based on simulator experiments using drowsy drivers.

## CURRENT RESEARCH

The research conducted at Virginia Tech thus far has consisted of three studies. The first involved obtaining an operational definition of drowsiness that reflected physiological changes normally associated with decrements in task performance and drowsiness. Prior to the algorithm development phase of the driver-drowsiness detection study, a review of the drowsiness literature was conducted. Physiological measures, driver-performance measures, and behavioral measures which are thought to have promise in the on-line detection of drowsiness were identified. The physiological components that were measured included eyelid closure, eye movement, muscle activity, brain wave activity, skin potential, and heart rate variability. Researchers were able to show that a good definition of drowsiness can be obtained using eyelid closure measures, simple EEG measures, and simple heart rate measures (Ellsworth, Wreggit, and Wierwille, 1993).

The second study examined the physiological measures using the operational definition from the first experiment as well as several driver-performance measures (Wreggit, Kirn, and Wierwille, 1993). The goal was to develop algorithms and procedures for the detection of driver impairment due to drowsiness.

The stability of these predictive algorithms was then examined using data collected during the third study, or validation phase. The algorithm outputs (predicted) PERCLOS were produced and compared to the actual (observed) PERCLOS. Algorithm accuracy was measured using multiple correlation Pearson-product-moment correlation (R) values and classification matrices.

### Data Collection (for second and third studies)

Sleep deprived subjects drove the computer-controlled, moving-base simulator for approximately 2 1/2 hours while data were collected. Five definitional dependent measures of drowsiness and several first order, independent measures including seat-movement, steering, lane, accelerometer, heading, and subsidiary task-related measures were collected.

Data were taken and recorded electronically every 15 seconds (Wreggit, Kirn, and Wierwille, 1993).

#### Data Preparation.

In each study, data were reduced into one-minute averages and baselined. Starting with one-minute average data for each subject, the first two minutes of data were deleted. The average of the first ten remaining minutes was calculated for each separate variable, and this average was then subtracted from every value for each measure, including the first ten.

#### Multiple Regression.

Backwards stepwise multiple regression and resubstitution were performed on the appropriate subgroups of collected data to find optimized combinations of variables that would best predict the values of dependent measures (PERCLOS is the dependent measure predominantly used in these studies).<sup>\*</sup> Multiple regression R values and classification matrices were used to analyze the results of these algorithms. Although the use of discriminate analysis was also used, it was found that this technique yielded negligible gain over the results of multiple regression (Wreggit, Kirn and Wierwille, 1993). As a result, discriminate analysis, which is more complex, was discontinued.

In each multiple regression analysis the beta weights of the various measures were first examined. Pairs of measures that were linearly related would exhibit large offsetting beta coefficients. One member of the pair was then removed. Thereafter, the elimination of non-significant measures ( $p > 0.05$ ) began, starting with the measure having the smallest magnitude of F-ratio. During each step of this process the beta weights continued to be examined and correction for linearly related measures was made. Once all remaining independent measures were found to be significant ( $p < 0.05$ ), various measures were substituted back into the set. This backward stepwise/resubstitution approach to multiple regression produced the final set of results for each subgroup of variables. Once these

---

<sup>\*</sup> PERCLOS is defined as the proportion of time that a driver-subject's eyes are closed 80% or more.

results were attained, B weights were used as coefficients for the corresponding independent variable to form predictive algorithms with respect to PERCLOS.

R Values.

The algorithms were then re-applied to the data which were used in their development, and the resulting predicted PERCLOS data were compared to the actual (observed) PERCLOS data. Algorithm accuracy was measured using Pearson-product-moment correlation (R) values.

Classification Matrices.

Algorithm accuracy was also examined using classification matrices. The threshold levels used were the same as used in the algorithm development phase of the main study (Wreggit, Kim, and Wierwille, 1993). The PERCLOS data were classified into three categories of drowsiness ("awake," "questionable," and "drowsy") according to the following criteria:

| <u>Classification</u> | <u>PERCLOS Value</u>   |
|-----------------------|------------------------|
| Awake.....            | PERCLOS < 0.075        |
| Questionable.....     | 0.075 < PERCLOS < 0.15 |
| Drowsy.....           | PERCLOS > 0.15         |

Observed (actual) PERCLOS classification data were compared with predicted (algorithm output) data, and the results were summarized in classification matrices. Misclassifications, or data sets in which the predicted category did not match the observed category, were examined and further divided into "large error" misclassifications and "all error" misclassifications. "Large error" misclassifications are defined as any misclassification in which the predicted classifications are two categories away from the observed (actual) classification. To summarize the results of these analyses, Apparent Accuracy Rates (APARs) were calculated for both "large error" misclassifications and "all" misclassifications. APAR for large misclassifications is the proportion of predicted

PERCLOS classifications which are not large errors, and APAR for all misclassifications is the proportion of predicted PERCLOS classifications which are correct.

### Algorithm Validation

The third study had several objectives, the most important of which was to validate the previously developed algorithms using a new group of subjects. A new group of sleep deprived subjects drove simulator for approximately 2 1/2 hours each while data were collected. The previously developed algorithms were then applied to these new data and found to remain stable between subjects with no degradation in algorithm accuracy. Additionally, the use of cruise control was examined and found to increase driver drowsiness (Kirn, Wreggit, and Wierwille, 1994).

The results of these studies generally support the feasibility of drowsy-driver detection and indicate that further analysis and refinement of the algorithms is warranted.

## EXPLANATION OF MEASURES (GLOSSARY)

### Selected Independent Measures

There were several categories of measures used in the development phase, including seat movement, steering, accelerometer, lane, heading, and subsidiary (A/O) task-related measures, as well as brain wave activity and heart rate measures. (The subsidiary task is defined on page 9). For the purpose of algorithm refinement studies, the most frequently appearing measures were selected from the previous development study. The names of these selected measures and their descriptions are as follow (Wreggit, Kim, and Wierwille, 1993):

#### Steering-related measures;

- NMRHOLD: The number of times the hold circuit output on the steering wheel exceeded a threshold value (corresponding to holding the steering wheel still for 0.4 second or longer).

- **THRSHLD:** The proportion of total time that the hold circuit on the steering wheel exceeded a threshold value.
- **STVELV:** The variance of steering velocity.
- **LGREV:** The number of times that steering excursions exceeded 15 degrees after steering velocity passed through zero.
- **MDREV:** The number of times that steering excursions exceeded 5 degrees (but less than 15 degrees) after steering velocity passed through zero.
- **SMREV:** The number of times that steering excursions exceeded 1 degree (but less than 5 degrees) after steering velocity passed through zero.
- **STEXED:** The proportion of time that steering velocity exceeded 150 degrees per second.

*Lateral Accelerometer-related measures:*

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

- ACXEED: The proportion of time that the magnitude of lateral acceleration exceeded a threshold of 0.3 g (9.66 ft/sec<sup>2</sup>)

Lane-related measures:

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

Subsidiary (A/O) Task -Related Measures:

Subsidiary task measures derive from an "A/O task" in which drivers are presented with words and must indicate whether or not the word contains the letters "A" or "O." Buttons on the steering wheel are used to input "yes" or "no" responses.

- AOTIME: Mean response time to a correct response. Incorrect responses and no-responses were specified as twelve seconds.
- NMWRONG: Mean number of incorrect responses.
- NMNR: Mean number of stimuli for which there was no response.

### Dependent Measures

- PERCLOS      The proportion of time that a driver-subject's eyes are closed 80% or more.
- EYEMEAS:      The mean square of the percentage of the subject's eye closure. (Eyes wide open represented zero percent and eyes closed represented 100 percent).
- AVEOBS:      The average drowsiness rating of three observers for each one-minute interval. (This measure was obtained after the experimental runs by viewing the videotapes of the subjects' faces. A rating was obtained for each minute.)
- LANEX:      The proportion of time that any part of the vehicle exceeded a lane boundary.

PERCLOS was chosen as the predominant dependent measure for this thesis. It is desirable to use only one definitional measure to ensure control across conditions, thus allowing reliable comparisons between the algorithms, and PERCLOS is typical of the definitional measures and is one of the most likely to be used in implementation. Additionally, PERCLOS was found to be one of the most reliable of the definitional measures between subjects (Wreggit, Kirn, and Wierwille, 1993).

### Algorithm Output Measures

Preliminary definitions are provided here. Detailed definitions are provided in the text as each measure is introduced.

- ePERCLOS      The algorithm output value (estimate of PERCLOS).
- eLANEX      The algorithm output value (estimate of LANEX).
- esLANEX      An average of the eLANEX and LANEX data within a six-minute interval (estimated special LANEX).

## **Chapter 2**

### **THE ELIMINATION OF OUTLIERS FROM PERCLOS DATA**

## INTRODUCTION

Multiple regression, which has been used to develop most of the driver drowsiness detection algorithms in this ongoing project, is a least-squares optimization technique. Consequently, dependent variable outliers can have a detrimental effect on regression results. PERCLOS, which has been selected as a typical dependent measure and subsequently used in many algorithm optimization attempts, does contain some apparent outliers among the development and validation data.

The dependent measure PERCLOS can be clipped in an attempt to improve the algorithm output predictability and thus use less of the optimization resource to absorb its effect. This study addressed the question of whether "clipping" PERCLOS to an operational range would reduce the effect of outliers.

## METHOD

A PERCLOS value greater than 0.15 is classified as "drowsy." In the examination of graphically represented PERCLOS data, values greater than 0.25 appear to be outliers. The value 0.25 was thus selected as the maximum value, and all PERCLOS values greater than 0.25 were changed to the value of 0.25, that is, "clipped."

The original set of baselined independent measure data from algorithm F4a were selected, and using "clipped" PERCLOS data as the dependent measure, multiple regression was performed in the same manner as previously reported. A second algorithm was developed using PERCLOS (unclipped) to allow for comparison. Although the F4a PERCLOS algorithm has been previously developed, the process was repeated for this study for consistency. (The process of backwards stepwise multiple regression and resubstitution involves a subjective component, and the possibility of variation is reduced if algorithms are developed by the same researcher at approximately the same time). Both algorithms were applied to validation data. R values and APAR values from classification matrices were calculated for both the validation and development data sets.

## RESULTS AND DISCUSSION

A summary of all results appears in Table 2.1. Multiple regression results are presented in Table 2.2 and 2.3. R values range from 0.817 to 0.868, and APAR values range from 0.787 to 0.983.

A reduction in R value occurred for the clipped PERCLOS data when applied to both the development and validation data sets. This indicates that no improvement in algorithm accuracy is obtained from the clipping of PERCLOS prior to regression. These findings support past research which has imposed no limitations on PERCLOS values prior to analysis. These results suggest that algorithms may not benefit from the use of "clipped" PERCLOS data. Future research is necessary to determine whether "clipped" data are beneficial for other independent measure groups and/or dependent measures.

Table 2.1. A comparison of the regression and validation results using "clipped" PERCLOS and PERCLOS.

| TRIAL                                               | DATA SET | ACCURACY MEASURE    | VALUE |
|-----------------------------------------------------|----------|---------------------|-------|
| Trial #1<br>Dependent Measure:<br>"clipped" PERCLOS | DEV      | R Value             | 0.864 |
|                                                     |          | APAR (large errors) | 0.983 |
|                                                     |          | APAR (all errors)   | 0.800 |
|                                                     | VAL      | R Value             | 0.817 |
|                                                     |          | APAR (large errors) | 0.986 |
|                                                     |          | APAR (all errors)   | 0.830 |
| Trial #2<br>Dependent Measure:<br>PERCLOS           | DEV      | R Value             | 0.868 |
|                                                     |          | APAR (large errors) | 0.983 |
|                                                     |          | APAR (all errors)   | 0.787 |
|                                                     | VAL      | R Value             | 0.856 |
|                                                     |          | APAR (large errors) | 0.983 |
|                                                     |          | APAR (all errors)   | 0.823 |

**Table 2.2. Regression Summary for Trial #1, “Clipped PERCLOS”**

Dependent Variable: CLIPPED PERCLOS

R= 0.86433999 R<sup>2</sup>= 0.74708361 Adjusted R<sup>2</sup>= 0.74278231

F(5,294)=173.69 p&lt;0.0000 Std.Error of estimate: 0.03987

|           | BETA   | St. Err.<br>of<br>BETA | B         | St. Err.<br>of B | t(294) | p-level |
|-----------|--------|------------------------|-----------|------------------|--------|---------|
| Intercept |        |                        | 0.002357  | 0.003            | 0.708  | 0.480   |
| INTACDE   | -0.125 | 0.031                  | -0.063314 | 0.016            | -4.029 | 0.000   |
| LANDEV    | 1.017  | 0.063                  | 0.061510  | 0.004            | 16.085 | 0.000   |
| LNERRSQ   | -0.447 | 0.055                  | -0.002746 | 0.000            | -8.160 | 0.000   |
| NMRHOLD   | -0.236 | 0.047                  | -0.003269 | 0.000            | -5.069 | 0.000   |
| THRSHLD   | 0.273  | 0.042                  | 0.202633  | 0.031            | 6.518  | 0.000   |

**Table 2.3. Regression Summary for Trial #2, Actual PERCLOS**

Dependent Variable: PERCLOS

R= 0.86810831 R<sup>2</sup>= 0.75361204 Adjusted R<sup>2</sup>= 0.74942176

F(5,294)=179.85 p&lt;0.0000 Std.Error of estimate: 0.04901

|           | BETA   | St. Err.<br>of<br>BETA | B         | St. Err.<br>of B | t(294) | p-level |
|-----------|--------|------------------------|-----------|------------------|--------|---------|
| Intercept |        |                        | -0.003090 | 0.004            | -0.755 | 0.451   |
| INTACDE   | -0.107 | 0.031                  | -0.067982 | 0.019            | -3.519 | 0.000   |
| LANDEV    | 0.910  | 0.062                  | 0.068508  | 0.005            | 14.572 | 0.000   |
| LNERRSQ   | -0.250 | 0.054                  | -0.001911 | 0.000            | -4.619 | 0.000   |
| NMRHOLD   | -0.205 | 0.046                  | -0.003536 | 0.000            | -4.459 | 0.000   |
| THRSHLD   | 0.242  | 0.041                  | 0.223915  | 0.038            | 5.859  | 0.000   |

### **Chapter 3**

#### **EFFECTS OF USING HIGHER-ORDER ALGORITHMS**

## INTRODUCTION

The purpose of this study was to investigate the effects of using higher-order algorithms on driver-drowsiness detection accuracy. During the algorithm development study, a wide variety of driver-drowsiness detection algorithms was developed using first-order independent measure terms (Wreggit, Kirn, and Wierwille, 1993). These algorithms were validated by applying them to data from a new driver-subject pool during the validation study (Wreggit, Kirn, and Wierwille, 1994). The effect of second order models was not investigated in these phases of the study. To examine potential improvement in algorithm accuracy resulting from the addition of second order terms to the algorithms, three groups of independent measures were selected from the development data and used to estimate the dependent measure PERCLOS. Multiple regression analyses were performed using linear (first order) terms only, linear and cross product (first order and partial second order) terms, and all first and second order (full second order) terms from each of the three groups of independent measures. The nine algorithms developed from this process were applied to the validation data and the accuracy of each type of algorithm (linear, cross product, or full second order) was determined by examining multiple regression Pearson-product-moment correlation (R) values as well as classification matrices.

## METHOD

### Data

Baselined data collected during the main study were selected to be re-analyzed. The selected data included independent and dependent measures from all subjects in both phases of the main study. Three groups of independent measures including variables most often appearing in the final algorithms were selected. They are: NMRHOLD, THRSHLD, STVELV, LGREV, MDREV, SMREV, STEXED, INTACDEV, LANDEV, LNRTDEV, LANEX, LNERRSQ.

The definitional measure of drowsiness PERCLOS was selected to be used as the dependent measure. The data representing the independent variables from the twelve subjects of the development phase were divided into three variable groups as illustrated in Table 3.1. Measures which were frequently found in previously developed algorithms were selected for these groups. The data from each group were then used to develop predictive algorithms using PERCLOS as the dependent variable.

Each group of variables was expanded to include linear terms (X, Y, Z, etc.), cross product terms (XY, XZ, YZ, etc.), and squared terms ( $X^2$ ,  $Y^2$ ,  $Z^2$ , etc.). These variables were divided into three subgroups with designations LIN, LINCROSS, and FULL, described as follow:

1. Subgroup LIN includes linear terms only,
2. Subgroup LINCROSS includes linear terms and cross product terms, and
3. Subgroup FULL includes linear terms, cross product terms, and squared terms.

### Data Analysis

Algorithms for each of the nine variable groups were developed and evaluated using the method described in Chapter 1. R values and classification matrix (large and all error) values were determined. In addition, "clipped" R values were calculated.

"Clipped" R Values. To minimize the detrimental effect of outliers within the algorithm output data sets, these values were "clipped" into a reasonable value. Specifically, output values greater than 0.45 were set equal to 0.45, and those with values less than zero (0.0) were set equal to zero (0.0). These values are based on the maximum and minimum values of the actual (observed) PERCLOS data. As was done previously, algorithm accuracy was measured using multiple correlation Pearson-product-moment correlation (R) values. Classification matrix analysis was not conducted using "clipped" predicted (algorithm output) PERCLOS data, because there would have been no differences when compared with unclipped data.

Table 3.1. Summary of variable groups used in algorithm development.

**VARIABLE GROUP 1**

(Used for regressions to develop algorithms: 1-LIN, 1-LINCROSS, and 1-FULL)

Dependent Variable: PERCLOS

|                        |            |                            |
|------------------------|------------|----------------------------|
| Independent Variables: | A- STVELV  | (steering-related measure) |
|                        | B- LGREV   | (steering-related measure) |
|                        | C- MDREV   | (steering-related measure) |
|                        | D- SMREV   | (steering-related measure) |
|                        | E- STEXED  | (steering-related measure) |
|                        | F- NMRHOLD | (steering-related measure) |
|                        | G- THRSHLD | (steering-related measure) |

**VARIABLE GROUP 2**

(Used for regressions to develop algorithms: 2-LIN, 2-LINCROSS, and 2-FULL)

Dependent Variable: PERCLOS

|                        |             |                                 |
|------------------------|-------------|---------------------------------|
| Independent Variables: | A- LGREV    | (steering-related measure)      |
|                        | B- STEXED   | (steering-related measure)      |
|                        | C- NMRHOLD  | (steering-related measure)      |
|                        | D- THRSHLD  | (steering-related measure)      |
|                        | E- INTACDEV | (accelerometer-related measure) |
|                        | F- LANDEV   | (lane-related measure)          |
|                        | G- LINERRSQ | (lane-related measure)          |

**VARIABLE GROUP 3**

(Used for regressions to develop algorithms: 3-LIN, 3-LINCROSS, and 3-FULL)

Dependent Variable: PERCLOS

|                        |             |                                 |
|------------------------|-------------|---------------------------------|
| Independent Variables: | A- LGREV    | (steering-related measure)      |
|                        | B- STEXED   | (steering-related measure)      |
|                        | C- NMRHOLD  | (steering-related measure)      |
|                        | D- THRSHLD  | (steering-related measure)      |
|                        | E- MDREV    | (steering-related measure)      |
|                        | F- INTACDEV | (accelerometer-related measure) |
|                        | G- LANDEV   | (lane-related measure)          |
|                        | H- LINERRSQ | (lane-related measure)          |
|                        | I- LINRTDEV | (lane-related measure)          |
|                        | J- LANEX    | (lane-related measure)          |

## RESULTS

In total, nine algorithms were developed in this study. These algorithms were derived from three separate groups of variables which were each expanded to subgroups of linear (LIN) terms only, linear and cross product (LINCROSS) terms, and all first and second order (FULL) terms from each of the three groups of independent measures. These algorithms were applied to the original (development) data set and to the new (validation) data set from the main study. The results from these data sets were analyzed using Pearson-product-moment correlation (R) values and classification matrices as described earlier.

### Multiple Regression

Appendix A contains the summaries for each of the multiple regression analyses. First order terms are labeled with the appropriate variable name, while second order terms are signified with letters which correspond to the letter designations noted in Table 3.1. R values are shown at the top. B weights (non-standardized) are listed in the fourth column and were used as coefficients for the corresponding variable for the purpose of algorithm development.

### Pearson-Product-Moment Correlation (R) Values

Correlation (R) values resulting from analysis of the output PERCLOS data (and "clipped" output PERCLOS data) versus actual PERCLOS values for each of the nine algorithms are summarized in Table 3.2. These results are presented for both the original data set and validation data to allow comparison. Average values for each type algorithm (linear, linear/cross product, and full second order) are presented in the lower section of the table.

Table 3.2. Summary of Results

| VARIABLE GROUP                                          | TERMS USED IN REGRESSION               | ACCURACY MEASURE TYPE | ORIGINAL DATA SET | VALIDATION DATA SET |
|---------------------------------------------------------|----------------------------------------|-----------------------|-------------------|---------------------|
| VARIABLE GROUP 1: Steering Measures Only                | Linear Only (1-LIN)                    | R Value               | 0.779             | 0.791               |
|                                                         |                                        | Clipped R Value       |                   | 0.829               |
|                                                         |                                        | APAR (large errors)   | 0.983             | 0.965               |
|                                                         |                                        | APAR (all errors)     | 0.760             | 0.747               |
|                                                         | Cross Products and Linear (1-LINCROSS) | R Value               | 0.835             | 0.141               |
|                                                         |                                        | Clipped R Value       |                   | 0.739               |
|                                                         |                                        | APAR (large errors)   | 0.980             | 0.955               |
|                                                         |                                        | APAR (all errors)     | 0.797             | 0.826               |
|                                                         | Full 2nd Order (1-FULL)                | R Value               | 0.860             | 0.750               |
|                                                         |                                        | Clipped R Value       |                   | 0.830               |
|                                                         |                                        | APAR (large errors)   | 0.983             | 0.965               |
|                                                         |                                        | APAR (all errors)     | 0.790             | 0.823               |
| VARIABLE GROUP 2: Steering, Accel, and Lane (small set) | Linear Only (2-LIN)                    | R Value               | 0.872             | 0.863               |
|                                                         |                                        | Clipped R Value       |                   | 0.862               |
|                                                         |                                        | APAR (large errors)   | 0.980             | 0.979               |
|                                                         |                                        | APAR (all errors)     | 0.790             | 0.830               |
|                                                         | Cross Products and Linear (2-LINCROSS) | R Value               | 0.904             | 0.402               |
|                                                         |                                        | Clipped R Value       |                   | 0.678               |
|                                                         |                                        | APAR (large errors)   | 0.980             | 0.962               |
|                                                         |                                        | APAR (all errors)     | 0.807             | 0.858               |
|                                                         | Full 2nd Order (2-FULL)                | R Value               | 0.912             | 0.415               |
|                                                         |                                        | Clipped R Value       |                   | 0.701               |
|                                                         |                                        | APAR (large errors)   | 0.980             | 0.965               |
|                                                         |                                        | APAR (all errors)     | 0.810             | 0.861               |
| VARIABLE GROUP 3: Steering, Accel, and Lane (large set) | Linear Only (3-LIN)                    | R Value               | 0.872             | 0.863               |
|                                                         |                                        | Clipped R Value       |                   | 0.862               |
|                                                         |                                        | APAR (large errors)   | 0.980             | 0.979               |
|                                                         |                                        | APAR (all errors)     | 0.790             | 0.830               |
|                                                         | Cross Products and Linear (3-LINCROSS) | R Value               | 0.925             | 0.694               |
|                                                         |                                        | Clipped R Value       |                   | 0.845               |
|                                                         |                                        | APAR (large errors)   | 0.993             | 0.976               |
|                                                         |                                        | APAR (all errors)     | 0.820             | 0.872               |
|                                                         | Full 2nd Order (3-FULL)                | R Value               | 0.929             | 0.590               |
|                                                         |                                        | Clipped R Value       |                   | 0.853               |
|                                                         |                                        | APAR (large errors)   | 0.993             | 0.976               |
|                                                         |                                        | APAR (all errors)     | 0.840             | 0.833               |
| AVERAGE VALUES                                          | Linear Only (LIN)                      | R Value               | 0.841             | 0.839               |
|                                                         |                                        | Clipped R Value       |                   | 0.851               |
|                                                         |                                        | APAR (large errors)   | 0.981             | 0.974               |
|                                                         |                                        | APAR (all errors)     | 0.780             | 0.802               |
|                                                         | Cross Products and Linear (LINCROSS)   | R Value               | 0.888             | 0.412               |
|                                                         |                                        | Clipped R Value       |                   | 0.754               |
|                                                         |                                        | APAR (large errors)   | 0.984             | 0.964               |
|                                                         |                                        | APAR (all errors)     | 0.808             | 0.852               |
|                                                         | Full 2nd Order (FULL)                  | R Value               | 0.900             | 0.585               |
|                                                         |                                        | Clipped R Value       |                   | 0.795               |
|                                                         |                                        | APAR (large errors)   | 0.985             | 0.969               |
|                                                         |                                        | APAR (all errors)     | 0.813             | 0.839               |

### "Clipped" Algorithm Output PERCLOS Values

The modification of the output data for algorithm 1-LINCROSS produced the greatest R value reduction (from original to validation output data). The R value resulting from correlation analysis using "clipped" output data is notably higher. The modification of the output data for algorithm 2-LIN produced almost no change in R values from original to validation data.

### Classification Matrices

Figures 3.1 through 3.9 show classification matrices representing PERCLOS data that have been classified as "awake," "questionable," and "drowsy." Each figure includes two matrices, one representing the multiple regression analysis of the original PERCLOS data (found in the upper portion of each page) and another representing the same algorithm applied to the validation data and compared with new observed PERCLOS data (found in the lower portion of each page). The categories representing observed data are presented along the left side of the matrices and the predicted data are presented across the top. The APAR values for large misclassifications and for all misclassifications are presented below each matrix. All APAR values are also summarized in Table 3.2.

## DISCUSSION

### Interpretation of Results

Stability of algorithms when applied to new subject data. R values and APAR values in comparison of the results from the original and validation data sets (Table 3.2) suggest that, in general, all nine algorithms maintained predictive propensity when applied to new data. Additionally, R values using "clipped" data exhibited an even greater stability between subjects. It should be noted that APAR values were calculated using "pure" algorithm output data ("clipped" data were only used in R value calculations). In general, all algorithms were able to predict appropriate classification of data in 78% to 85% of all cases.

|                      |              | Predicted |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
| Original<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 88.29     | 181   | 22           | 2      |
|                      | Questionable | 43.18     | 12    | 19           | 13     |
|                      | Drowsy       | 54.90     | 3     | 20           | 28     |
|                      | Total        | 76.00     | 196   | 61           | 43     |

PERCLOS (R value =0.779 )

Apparent Accuracy Rate (LARGE misclassifications): 0.983

Apparent Accuracy Rate (ALL misclassifications): 0.760

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 1-LIN. (Independent variables employed included ALL STEERING MEASURES.)

---

|                 |              | Predicted |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
| New<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 77.22     | 183   | 45           | 9      |
|                 | Questionable | 20.00     | 10    | 4            | 6      |
|                 | Drowsy       | 90.32     | 1     | 2            | 28     |
|                 | Total        | 74.65     | 194   | 51           | 43     |

PERCLOS (R value = 0.791; clipped R value = 0.829)

Apparent Accuracy Rate (LARGE misclassifications): 0.965

Apparent Accuracy Rate (ALL misclassifications): 0.747

ALGORITHM 1-LIN applied to new data and compared with new observed PERCLOS data.

Figure 3.1. Classification matrices showing accuracy of Algorithm 1-LIN when applied to development data (upper) and validation data (lower).

|                      |              | Predicted |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
| Original<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 90.73     | 186   | 17           | 2      |
|                      | Questionable | 54.55     | 11    | 24           | 9      |
|                      | Drowsy       | 56.86     | 4     | 18           | 29     |
|                      | Total        | 79.67     | 201   | 59           | 40     |

PERCLOS (R value =0.835 )

Apparent Accuracy Rate (LARGE misclassifications): 0.980

Apparent Accuracy Rate (ALL misclassifications): 0.797

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 1-LINCROSS. (Independent variables employed included ALL STEERING MEASURES.)

---

|                 |              | Predicted |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
| New<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 90.72     | 215   | 18           | 4      |
|                 | Questionable | 20.00     | 11    | 4            | 5      |
|                 | Drowsy       | 61.29     | 9     | 3            | 19     |
|                 | Total        | 82.64     | 235   | 25           | 28     |

PERCLOS (R value = 0.141; clipped R value = 0.739)

Apparent Accuracy Rate (LARGE misclassifications): 0.955

Apparent Accuracy Rate (ALL misclassifications): 0.826

ALGORITHM 1-LINCROSS applied to new data and compared with new observed PERCLOS data.

Figure 3.2. Classification matrices showing accuracy of Algorithm 1-LINCROSS when applied to development data (upper) and validation data (lower).

|                          |              | Predicted |       |              |        |
|--------------------------|--------------|-----------|-------|--------------|--------|
| Original<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                          | Awake        | 87.80     | 180   | 23           | 2      |
|                          | Questionable | 56.82     | 8     | 25           | 11     |
|                          | Drowsy       | 62.75     | 3     | 16           | 32     |
|                          | Total        | 79.00     | 191   | 64           | 45     |

PERCLOS (R value =0.860 )

Apparent Accuracy Rate (LARGE misclassifications): 0.983

Apparent Accuracy Rate (ALL misclassifications): 0.790

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 1-FULL. (Independent variables employed included ALL STEERING MEASURES.)

|                     |              | Predicted |       |              |        |
|---------------------|--------------|-----------|-------|--------------|--------|
| New<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                     | Awake        | 87.76     | 208   | 21           | 8      |
|                     | Questionable | 10.00     | 12    | 2            | 6      |
|                     | Drowsy       | 87.10     | 2     | 2            | 27     |
|                     | Total        | 82.29     | 222   | 25           | 41     |

PERCLOS (R value = 0.750; clipped R value = 0.830)

Apparent Accuracy Rate (LARGE misclassifications): 0.965

Apparent Accuracy Rate (ALL misclassifications): 0.823

ALGORITHM 1-FULL applied to new data and compared with new observed PERCLOS data.

Figure 3.3. Classification matrices showing accuracy of Algorithm 1-FULL when applied to development data (upper) and validation data (lower).

|                          |              | Predicted |       |              |        |
|--------------------------|--------------|-----------|-------|--------------|--------|
| Original<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                          | Awake        | 89.76     | 184   | 18           | 3      |
|                          | Questionable | 47.73     | 7     | 21           | 16     |
|                          | Drowsy       | 62.75     | 3     | 16           | 32     |
|                          | Total        | 79.00     | 194   | 55           | 51     |

PERCLOS (R value = 0.872 )

Apparent Accuracy Rate (LARGE misclassifications): 0.980

Apparent Accuracy Rate (ALL misclassifications): 0.790

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 2-LIN. (Independent variables employed included 7 SELECTED STEERING, LANE, AND ACCELEROMETER MEASURES.)

|                     |              | Predicted |       |              |        |
|---------------------|--------------|-----------|-------|--------------|--------|
| New<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                     | Awake        | 89.45     | 212   | 22           | 3      |
|                     | Questionable | 15.00     | 12    | 3            | 5      |
|                     | Drowsy       | 77.42     | 3     | 4            | 24     |
|                     | Total        | 82.99     | 227   | 29           | 32     |

PERCLOS (R value = 0.863; clipped R value = 0.862)

Apparent Accuracy Rate (LARGE misclassifications): 0.979

Apparent Accuracy Rate (ALL misclassifications): 0.830

ALGORITHM 2-LIN applied to new data and compared with new observed PERCLOS data.

Figure 3.4. Classification matrices showing accuracy of Algorithm 2-LIN when applied to development data (upper) and validation data (lower).

|                          |              | Predicted |       |              |        |
|--------------------------|--------------|-----------|-------|--------------|--------|
| Original<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                          | Awake        | 93.17     | 191   | 12           | 2      |
|                          | Questionable | 43.18     | 10    | 19           | 15     |
|                          | Drowsy       | 62.75     | 4     | 15           | 32     |
|                          | Total        | 80.67     | 205   | 46           | 49     |

PERCLOS (R value = 0.904 )

Apparent Accuracy Rate (LARGE misclassifications): 0.980

Apparent Accuracy Rate (ALL misclassifications): 0.807

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 2-LINCROSS. (Independent variables employed included 7 SELECTED STEERING, LANE, AND ACCELEROMETER MEASURES.)

|                     |              | Predicted |           |       |              |
|---------------------|--------------|-----------|-----------|-------|--------------|
|                     |              | Group     | % Correct | Awake | Questionable |
| New<br><br>Observed | Awake        | 92.83     | 220       | 14    | 3            |
|                     | Questionable | 20.00     | 11        | 4     | 5            |
|                     | Drowsy       | 74.19     | 8         | 0     | 23           |
|                     | Total        | 85.76     | 239       | 18    | 31           |

PERCLOS (R value = 0.402; clipped R value = 0.678)

Apparent Accuracy Rate (LARGE misclassifications): 0.962

Apparent Accuracy Rate (ALL misclassifications): 0.858

ALGORITHM 2-LINCROSS applied to new data and compared with new observed PERCLOS data.

Figure 3.5. Classification matrices showing accuracy of Algorithm 2-LINCROSS when applied to development data (upper) and validation data (lower).

|                      |              | Predicted |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
| Original<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 91.71     | 188   | 15           | 2      |
|                      | Questionable | 52.27     | 9     | 23           | 12     |
|                      | Drowsy       | 62.75     | 4     | 15           | 32     |
|                      | Total        | 81.00     | 201   | 53           | 46     |

PERCLOS (R value = 0.912 )

|                                                    |       |
|----------------------------------------------------|-------|
| Apparent Accuracy Rate (LARGE misclassifications): | 0.980 |
| Apparent Accuracy Rate (ALL misclassifications):   | 0.810 |

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 2-FULL. (Independent variables employed included 7 SELECTED STEERING, LANE, AND ACCELEROMETER MEASURES.)

|                 |              | Predicted |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
| New<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 93.67     | 222   | 11           | 4      |
|                 | Questionable | 15.00     | 11    | 3            | 6      |
|                 | Drowsy       | 74.19     | 6     | 2            | 23     |
|                 | Total        | 86.11     | 239   | 16           | 33     |

PERCLOS (R value = 0.415; clipped R value = 0.701)

|                                                    |       |
|----------------------------------------------------|-------|
| Apparent Accuracy Rate (LARGE misclassifications): | 0.965 |
| Apparent Accuracy Rate (ALL misclassifications):   | 0.861 |

ALGORITHM 2-FULL applied to new data and compared with new observed PERCLOS data.

Figure 3.6. Classification matrices showing accuracy of Algorithm 2-FULL when applied to development data (upper) and validation data (lower).

|                      |              | Predicted |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
| Original<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 89.76     | 184   | 18           | 3      |
|                      | Questionable | 47.73     | 7     | 21           | 16     |
|                      | Drowsy       | 62.75     | 3     | 16           | 32     |
|                      | Total        | 79.00     | 194   | 55           | 51     |

PERCLOS (R value =0.872 )

Apparent Accuracy Rate (LARGE misclassifications):

0.980

Apparent Accuracy Rate (ALL misclassifications):

0.790

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 3-LIN. (Independent variables employed included 10 SELECTED STEERING, LANE, AND ACCELEROMETER RELATED MEASURES.)

|                 |              | Predicted |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
| New<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 89.45     | 212   | 22           | 3      |
|                 | Questionable | 15.00     | 12    | 3            | 5      |
|                 | Drowsy       | 77.42     | 3     | 4            | 24     |
|                 | Total        | 82.99     | 227   | 29           | 32     |

PERCLOS (R value = 0.863; clipped R value = 0.862)

Apparent Accuracy Rate (LARGE misclassifications):

0.979

Apparent Accuracy Rate (ALL misclassifications):

0.830

ALGORITHM 3-LIN applied to new data and compared with new observed PERCLOS data.

Figure 3.7. Classification matrices showing accuracy of Algorithm 3-LIN when applied to development data (upper) and validation data (lower).

|                      |              | Predicted |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
| Original<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 94.15     | 193   | 12           | 0      |
|                      | Questionable | 47.73     | 10    | 21           | 13     |
|                      | Drowsy       | 62.75     | 2     | 17           | 32     |
|                      | Total        | 82.00     | 205   | 50           | 45     |

PERCLOS (R value = 0.925)

|                                                    |       |
|----------------------------------------------------|-------|
| Apparent Accuracy Rate (LARGE misclassifications): | 0.993 |
| Apparent Accuracy Rate (ALL misclassifications):   | 0.820 |

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 3-LINCROSS. (Independent variables employed included 10 SELECTED STEERING, LANE, AND ACCELEROMETER RELATED MEASURES.)

|                 |              | Predicted |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
| New<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 94.09     | 223   | 11           | 3      |
|                 | Questionable | 10.00     | 13    | 2            | 5      |
|                 | Drowsy       | 83.87     | 4     | 1            | 26     |
|                 | Total        | 87.15     | 240   | 14           | 34     |

PERCLOS (R value = 0.694; clipped R value = 0.845)

|                                                    |       |
|----------------------------------------------------|-------|
| Apparent Accuracy Rate (LARGE misclassifications): | 0.976 |
| Apparent Accuracy Rate (ALL misclassifications):   | 0.872 |

ALGORITHM 3-LINCROSS applied to new data and compared with new observed PERCLOS data.

Figure 3.8. Classification matrices showing accuracy of Algorithm 3-LINCROSS when applied to development data (upper) and validation data (lower).

|                          |              | Predicted |       |              |        |
|--------------------------|--------------|-----------|-------|--------------|--------|
| Original<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                          | Awake        | 94.63     | 194   | 11           | 0      |
|                          | Questionable | 54.55     | 8     | 24           | 12     |
|                          | Drowsy       | 66.67     | 2     | 15           | 34     |
|                          | Total        | 84.00     | 204   | 50           | 46     |

PERCLOS (R value = 0.929 )

Apparent Accuracy Rate (LARGE misclassifications): 0.993

Apparent Accuracy Rate (ALL misclassifications): 0.840

Classification matrix generated from multiple regression analysis of ORIGINAL PERCLOS data resulting in ALGORITHM 3-FULL. (Independent variables employed included 10 SELECTED STEERING, LANE, AND ACCELEROMETER RELATED MEASURES.)

|                     |              | Predicted |       |              |        |
|---------------------|--------------|-----------|-------|--------------|--------|
| New<br><br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                     | Awake        | 89.87     | 213   | 21           | 3      |
|                     | Questionable | 5.00      | 13    | 1            | 6      |
|                     | Drowsy       | 83.87     | 4     | 1            | 26     |
|                     | Total        | 83.33     | 230   | 23           | 35     |

PERCLOS (R value = 0.590; clipped R value = 0.853)

Apparent Accuracy Rate (LARGE misclassifications): 0.976

Apparent Accuracy Rate (ALL misclassifications): 0.833

ALGORITHM 3-FULL applied to new data and compared with new observed PERCLOS data.

Figure 3.9. Classification matrices showing accuracy of Algorithm 3-FULL when applied to development data (upper) and validation data (lower).

Effect of higher order algorithms on accuracy of prediction. In all cases (variable groups 1, 2, and 3) the inclusion of higher order terms in the multiple regression process did not increase the predictive abilities of the resulting algorithms. In fact, when applied to new data for validation, the algorithms which used linear only terms produced higher R values in every case. Although small improvements in average APAR values for all errors occur between first and second order algorithms applied to original data, there is no similar improvement when applied to validation data.

Outliers. Higher order algorithms may have a greater propensity to produce outliers than linear algorithms applied to new (validation) data. This propensity is probably a result of multiplying measures together that have moderate statistical instability. Such measures would then occasionally exhibit larger derivations, causing extreme values in algorithm output.

Table 3.2 shows that clipping (limiting) algorithm output to a feasible range can produce large increases in R values when higher order algorithms are applied to new data. For example, in the case of 1-LINCROSS, the value of R went from 0.141 to 0.739 when clipping was applied. The fact that clipping can produce substantial increases in R values further supports the hypothesis that higher order models will have a greater number and larger outliers when applied to new data.

Outliers would have less of an effect on classification matrices. The reason for this is that once the output of an algorithm exceeds a threshold, it does not matter whether it exceeds the threshold by a small amount or a large amount. The classification selected is the same. Nevertheless, outliers are a symptom of underlying instability. Thus, it could be hypothesized that the measures devised for drowsy driver detection do not have sufficient validity to benefit from algorithms using higher-order terms

### Conclusions

The results of this study suggest that the use of second order terms in driver drowsiness detection algorithms does not result in detection accuracy improvement when

the algorithms are applied to new subjects. This is a surprising result and it underscores the importance of testing newly derived algorithms on a second set of data (that is, a validation set). Had this not been done, it would have been concluded that higher order terms were capable of providing detection accuracy improvements.

The results of this study also do not bode well for even more sophisticated detection algorithms, such as pattern recognition or neural networks. Since these latter approaches are actually sophisticated nonlinear optimization procedures, there is a possibility that they would not provide improvement in detection accuracy (over less sophisticated techniques) when they are applied to new (validation) data. At the very least, it can be stated, based on the results of the present study, that all such sophisticated algorithms must be applied to a second set of data for evaluation. Otherwise, when such algorithms are applied in a field experiment, their detection capabilities may be found wanting and the reasons may not be fully understood.

Finally, although not conclusively proven by the present study, the results do support the hypothesis that higher-order algorithms produce more and larger outliers when applied to new data than do linear algorithms (and thus their validity is questionable).

## **Chapter 4**

### **EFFECTS OF TIME-ON-TASK VARIABLES**

## INTRODUCTION

The purpose of this project was to examine the ability of time on driving task measures to increase predictability when introduced to driver drowsiness detection algorithms. It was hypothesized that level of drowsiness tends to increase with driving time. Intuitively, it follows that the introduction of linear and squared time variables to the algorithms would bias the output towards the drowsiness threshold, thus increasing detection accuracy.

## PROCEDURE

Typical algorithms were selected from previous studies (Wierwille, Wreggit, Kirn, Ellsworth, and Fairbanks, 1994) to allow direct comparisons of algorithms accuracy. Six variable groups were selected from baselined data obtained in the development phase of the study, and compared to a total of three dependent variables: PERCLOS, EYEMEAS, and AVEOBS. A linear measure of time on task and a second order (squared) measure of time on task were each added to these six groups yielding a total of 12 variable groups (Tables 4.1 and 4.2). Backwards stepwise multiple linear regression was performed on each variable group, optimal algorithms were obtained, and these algorithms were applied to the previously collected validation data set. Classification matrices were developed, R values were obtained for each new algorithm, and these data were compared to classification matrix and R value data previously obtained from variable groups which did not include time-on-task measures.

## RESULTS

Twelve cases were examined. Six of these cases included the linear-time variable, and six included the squared-time variable. The results of these analyses are detailed in Tables 4.3 and 4.4. For half of these cases, the addition of a time variable produced no increase in R values or APAR rates over the original algorithms. In two cases a small

increase was produced by the addition of time variables (in the magnitude range of 0.006 to 0.007 for R value, and 0.004 to 0.026 for APAR value). In four cases a modest increase was produced (in the magnitude range of 0.02 to 0.12 for R value, and 0.003 to 0.03 APAR value).

Table 4.1. Explanation of Variable Groups.

| Variable Group | Dependent Variables Used | Independent Variable Categories Included                       |
|----------------|--------------------------|----------------------------------------------------------------|
| Group D        | 1. PERCLOS<br>2. AVEOBS  | Steering and Acceleration                                      |
| Group F        | 3. PERCLOS<br>4. EYEMEAS | Steering, Acceleration, LANDEV, LANVAR, LNMNSQ, LANEX, LNERRSQ |
| Group J        | 5. PERCLOS               | Steering, Acceleration, and A/O Task                           |
| Group L        | 6. PERCLOS               | A/O Task, LANDEV, LANVAR, LANEX, LNMNSQ, LNERRSQ               |

Table 4.2. Explanation of Time Variables.

| Time Variable | Definition                                                             |
|---------------|------------------------------------------------------------------------|
| LINTIME       | (T) 1/60, where T is the number of minutes since the start of the run. |
| SQTIME        | (T) <sup>2</sup> (1/3600), or (LINTIME) <sup>2</sup>                   |

Table 4.3. Summary of regression and classification matrices results from inclusion of time variables. Dependent measures: PERCLOS.

| VARIABLE GROUP                                                                                                              | TERMS USED IN REGRESSION                   | ACCURACY MEASURE TYPE | ORIGINAL DATA SET | VALIDATION DATA SET |
|-----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------------------|-------------------|---------------------|
| <b>VARIABLE GROUP D:</b><br>Steering and Acceleration<br><br>VS.<br><br><b>PERCLOS</b>                                      | w/o time variables<br>(Earlier D analyses) | R Value               | 0.789             | 0.800               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.987             | 0.965               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.757             | 0.771               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ LINTIME                                 | R Value               | 0.796             | 0.792               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.987             | 0.969               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.783             | 0.767               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ SQTIME                                  | R Value               | 0.795             | 0.791               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.987             | 0.969               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.780             | 0.764               |
|                                                                                                                             |                                            |                       |                   |                     |
| <b>VARIABLE GROUP F:</b><br>Steering, Acceleration, LANDEV, LANVAR, LNMNSQ, LANEX, LNNERSQ<br><br>VS.<br><br><b>PERCLOS</b> | w/o time variables<br>(Earlier F analyses) | R Value               | 0.872             | 0.862               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.980             | 0.979               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.790             | 0.830               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ LINTIME                                 | R Value               | 0.872             | 0.863               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.980             | 0.979               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.790             | 0.830               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | (LINTIME actually removed by regression)   | R Value               | 0.872             | 0.863               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.980             | 0.979               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.790             | 0.830               |
|                                                                                                                             |                                            |                       |                   |                     |
| <b>VARIABLE GROUP J:</b><br>Steering, Acceleration, and A/O Task<br><br>VS.<br><br><b>PERCLOS</b>                           | w/o time variables<br>(Earlier J analyses) | R Value               | 0.836             | 0.599               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.970             | 0.958               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.790             | 0.833               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ LINTIME                                 | R Value               | 0.863             | 0.698               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.990             | 0.986               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.830             | 0.854               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ SQTIME                                  | R Value               | 0.856             | 0.719               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.990             | 0.986               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.820             | 0.861               |
|                                                                                                                             |                                            |                       |                   |                     |
| <b>VARIABLE GROUP L:</b><br>A/O Task, LANDEV/VAR, LNMNSQ, LANEX, AND LNNERSQ<br><br>VS.<br><br><b>PERCLOS</b>               | w/o time variables<br>(Earlier L analyses) | R Value               | 0.875             | 0.796               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.950             | 0.979               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.930             | 0.868               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ LINTIME                                 | R Value               | 0.872             | 0.836               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.960             | 0.979               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.830             | 0.826               |
|                                                                                                                             |                                            |                       |                   |                     |
|                                                                                                                             | w/ SQTIME                                  | R Value               | 0.763             | 0.738               |
|                                                                                                                             |                                            | APAR (large errors)   | 0.980             | 0.979               |
|                                                                                                                             |                                            | APAR (all errors)     | 0.830             | 0.833               |
|                                                                                                                             |                                            |                       |                   |                     |

Table 4.4. Summary of regression and classification matrices results from inclusion of time variables. Dependent measures: AVEOBS and EYEMEAS.

| VARIABLE GROUP                                                                                                      | TERMS USED IN REGRESSION                   | ACCURACY MEASURE TYPE | ORIGINAL DATA SET | VALIDATION DATA SET |
|---------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------------------|-------------------|---------------------|
| <b>VARIABLE GROUP D:</b><br>Steering and Acceleration<br><br>VS.<br><br><b>AVEOBS</b>                               | w/o time variables<br>(Earlier D analyses) | R Value               | 0.747             | 0.727               |
|                                                                                                                     |                                            | APAR (large errors)   | 0.920             | 0.944               |
|                                                                                                                     |                                            | APAR (all errors)     | 0.687             | 0.785               |
|                                                                                                                     |                                            |                       |                   |                     |
|                                                                                                                     | w/ LINTIME                                 | R Value               | 0.815             | 0.841               |
|                                                                                                                     |                                            | APAR (large errors)   | 0.930             | 0.965               |
|                                                                                                                     |                                            | APAR (all errors)     | 0.670             | 0.799               |
|                                                                                                                     |                                            |                       |                   |                     |
|                                                                                                                     | w/ SQTIME                                  | R Value               | 0.786             | 0.813               |
|                                                                                                                     |                                            | APAR (large errors)   | 0.923             | 0.962               |
|                                                                                                                     |                                            | APAR (all errors)     | 0.663             | 0.806               |
|                                                                                                                     |                                            |                       |                   |                     |
| <b>VARIABLE GROUP F:</b><br>Steering, Acceleration, LANDEV, LANVAR, LNMNSQ, LANEX, LNERRSQ<br>VS.<br><b>EYEMEAS</b> | w/o time variables<br>(Earlier F analyses) | R Value               | 0.837             | 0.838               |
|                                                                                                                     |                                            | APAR (large errors)   | 0.963             | 0.976               |
|                                                                                                                     |                                            | APAR (all errors)     | 0.780             | 0.903               |
|                                                                                                                     |                                            |                       |                   |                     |
|                                                                                                                     | w/ LINTIME                                 | R Value               | 0.843             | 0.837               |
|                                                                                                                     |                                            | APAR (large errors)   | 0.930             | 0.976               |
|                                                                                                                     |                                            | APAR (all errors)     | 0.767             | 0.892               |
|                                                                                                                     |                                            |                       |                   |                     |
|                                                                                                                     | w/ SQTIME                                  | R Value               | 0.839             | 0.838               |
|                                                                                                                     |                                            | APAR (large errors)   | 0.937             | 0.972               |
|                                                                                                                     |                                            | APAR (all errors)     | 0.777             | 0.903               |
|                                                                                                                     |                                            |                       |                   |                     |

## CONCLUSIONS AND DISCUSSION

LINTIME and SQTIME were found to have some predictive capability although they did not consistently add predictive value to the algorithms.

All testing was performed on subjects who had been deliberately sleep-deprived prior to data collection. As a result, these subjects would be more likely to show trends of drowsiness over time and more profound increases with time than would normal drivers. Tying algorithms to time may potentially reduce overall validity when applied to real road conditions. Generally, drowsiness is far less prevalent on the road than in laboratory conditions using sleep deprived drivers. This may result in an increase in the false alarm rate by biasing the algorithm output towards the drowsiness threshold, especially as time goes on. Time variables increase in magnitude as time on task progresses. This increase will tend to bias the algorithm output towards the drowsiness threshold, thus increasing the potential for false alarms, particularly in cases of prolonged driving times.

Close examination of Variable Group L data in Table 4.3 shows a slight reduction in R value with inclusion of LINTIME during the development phase. Theoretically, LINTIME should have been eliminated as an independent variable during the multiple regression process. It has been shown that an algorithm can be developed without LINTIME to yield a slightly higher R value. It should be noted that in practice, multiple regression has a subjective component, the effect of which can be reduced with exhaustive substitution and resubstitution at the end of the regression analyses. This reduction in R value did not appear when the algorithms were applied to the validation data.

In this analysis of a number of "typical" variable groups, inclusion of time on task variables increased the accuracy of the resulting algorithms in one half of the cases. These contributions were modest at best and not consistent. Since data systems have built in time keeping components, time variables would be straightforward additions to

implement. But, in most cases the improvement in algorithm accuracy contributed by time variables can be obtained using other measures already in use. As a result, it is important to carefully examine the benefits balanced against the costs of time variable use.

## **Chapter 5**

### **THE PREDICTIVE POWER OF DRIVER DETECTION ALGORITHMS**

## INTRODUCTION

Research thus far has used independent variables in algorithms to predict the corresponding dependent measures (current driver drowsiness level) at time  $t$ . In all cases thus far, baselined 6-minute average data were used in the algorithm development process. The resulting algorithms were validated in the same form using baselined data collected from a second group of subjects. Because of the use of six-minute averages, there was some degree of "smoothing" of the data. The possibility exists that, during on the road implementation, immediate warning may not provide a fast enough response as the driver becomes drowsy. Although all previously developed algorithms have been validated on a new group of subjects, the success of these algorithms with respect to their response times has not yet been tested. Thus, to be complete, we must look at the predictive ability of algorithms based on these variables.

The purpose of this adjunct study was to evaluate the ability of various independent measures of driver performance to *predict* future driver drowsiness level. Specifically, algorithms were developed and validated which predict driver drowsiness level two minutes, four minutes, six minutes, and twelve minutes in advance of the time that the corresponding independent measure was taken.

## METHOD

Preparation of data for this study was quite involved. All of the data obtained in the main study were prepared, manipulated, and analyzed using six-minute averages for all measures. As a result, all refined data were in this form. In preparation for this study, the raw data which had been collected during the algorithm development phase of the main study were obtained from archival data bases as one-minute averages.

### Baselining of Raw Data.

The raw data, which consisted of 150 one-minute average data sets for each of twelve subjects, were baselined using exactly the same procedure that was followed in the main study (described in Chapter 1). To confirm accuracy and correctness of these data,

six-minute averages were temporarily calculated and compared to the six-minute averages previously calculated in the original study.

The one-minute data were modified in four different ways to create four new data bases: two-minute, four-minute, six-minute, and twelve-minute advance data.

#### Preparation of Advance Data.

Two-minute advance data were created by deleting the first two minutes of dependent measure data and the last two minutes of independent measure data. This change was made for each of the twelve subjects, resulting in data sets that contained dependent measures which were two minutes in advance of the corresponding independent measures. This process was similarly performed on the baselined data to create data files containing independent measure data which were four, six, and twelve minutes ahead of dependent measure data.

In final preparation of the data, six-minute averages were calculated for all modified data, and for each group (two, four, six, and twelve-minute advance data) complete data sets were formed by combining all subject data into one large file (subject 1 data, followed directly by subject 2 data, etc.).

#### Multiple Regression.

Multiple regression was performed on these data to produce algorithms with outputs estimating the dependent definitional measure of drowsiness PERCLOS. Two different groups of independent measures were used. Designation of these groups, "D" and "F," correspond to group names in the main study (see Figure 4.1). Procedures in the analysis were followed according to those used in the main study to minimize variation due to technique.

#### Validation of Resulting Algorithms.

R values and classification matrices were determined for every data set in each variable group. Classification matrices were created using criteria which were defined in the main study. Apparent accuracy rate (APAR) with respect to large errors, and APAR

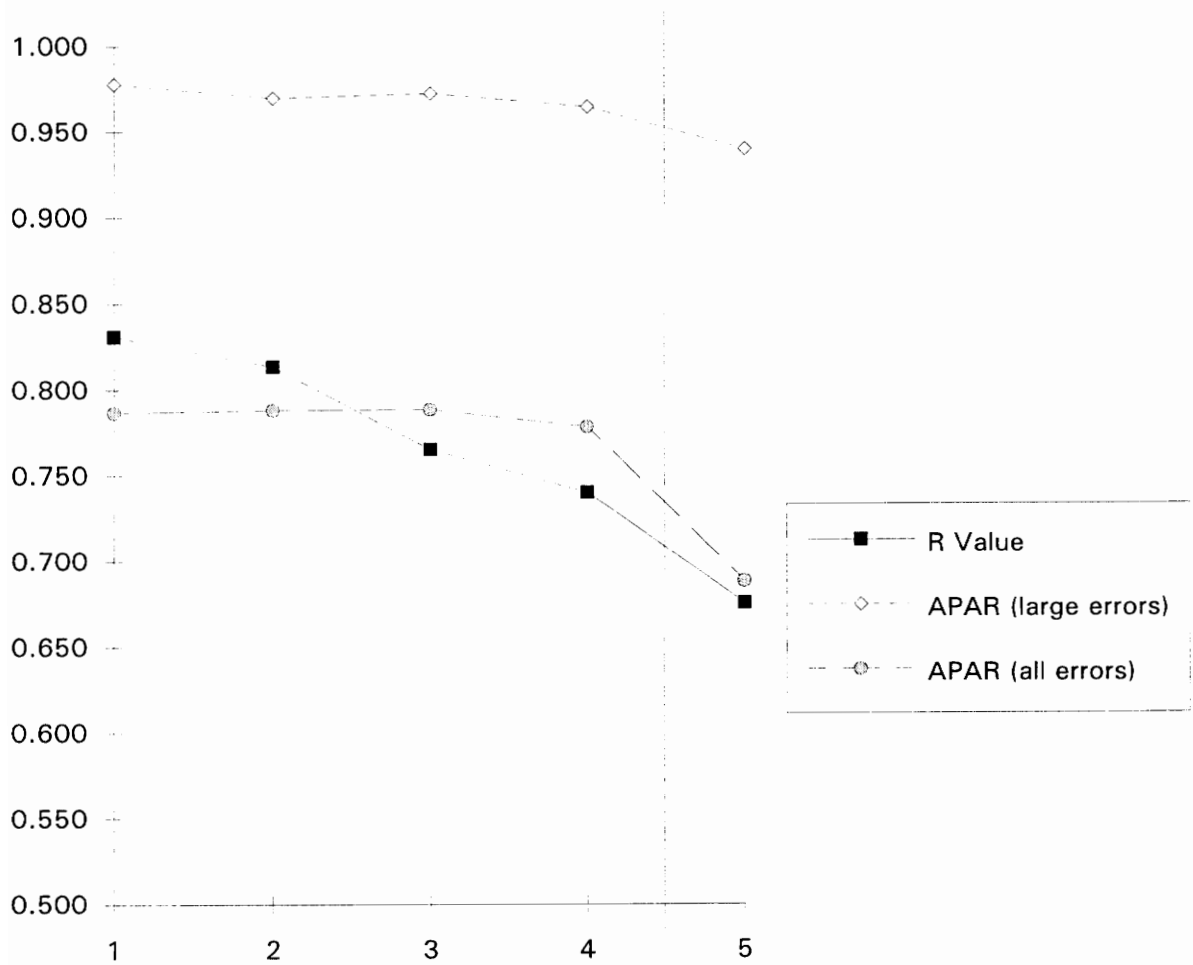
with respect to all errors were calculated. The main study specified thresholds of PERCLOS values defining "drowsy," "questionable," and "awake." A large error was defined as a predicted classification of "drowsy" corresponding to an observed (measured) classification of "awake," or vice versa. All error is defined as any inconsistency between predicted and measured classification. The newly developed algorithms were then applied to the validation data set which had been prepared using the same procedure as described in the preparation of the algorithm development data. Again, R values were calculated, classification matrices were developed, and APAR rates were determined.

## RESULTS

R value and classification matrix results for all regressions and validations are shown in Table 5.1 along with the corresponding real time data (as previously reported). Average values are included in this table as well, to allow the reader to get a general feeling for the trend of the data. Figures 5.1 through 5.5 graphically illustrate these trends. The algorithms developed for prediction appear in Tables 5.2 and 5.3.

Table 5.1. Summary of prediction algorithm accuracy results compared with corresponding real-time results.

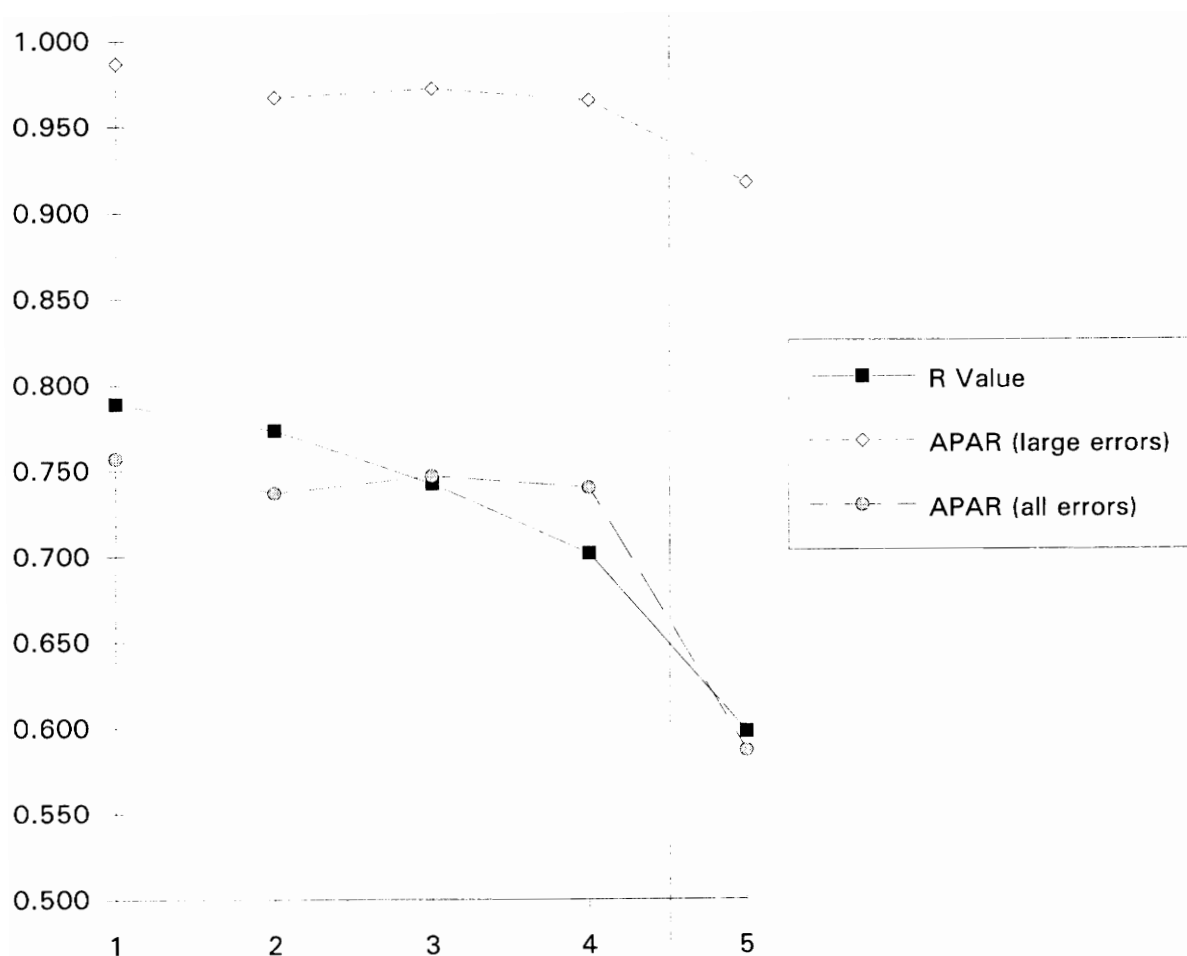
| VARIABLE GROUP                                                                                                        | DATA SET | ACCURACY MEASURE    | REAL TIME | 2 MIN ADV | 4 MIN ADV | 6 MIN ADV | 12 MIN ADV |
|-----------------------------------------------------------------------------------------------------------------------|----------|---------------------|-----------|-----------|-----------|-----------|------------|
| <b>GROUP D:</b><br>Steering<br>and<br>Acceleration<br>VS.<br><i>PERCLOS</i>                                           | DEV      | R Value             | 0.789     | 0.773     | 0.742     | 0.701     | 0.598      |
|                                                                                                                       |          | APAR (large errors) | 0.987     | 0.967     | 0.972     | 0.965     | 0.917      |
|                                                                                                                       |          | APAR (all errors)   | 0.757     | 0.737     | 0.747     | 0.740     | 0.587      |
|                                                                                                                       | VAL      | R Value             | 0.800     | 0.796     | 0.785     | 0.759     | 0.678      |
|                                                                                                                       |          | APAR (large errors) | 0.965     | 0.958     | 0.969     | 0.949     | 0.962      |
|                                                                                                                       |          | APAR (all errors)   | 0.771     | 0.785     | 0.806     | 0.815     | 0.765      |
| <b>GROUP F:</b><br>Steering,<br>Acceleration,<br>LANDEV<br>LANVAR<br>LNMNSQ<br>LANEX<br>LNERRSQ<br>VS. <i>PERCLOS</i> | DEV      | R Value             | 0.872     | 0.815     | 0.771     | 0.733     | 0.650      |
|                                                                                                                       |          | APAR (large errors) | 0.980     | 0.977     | 0.969     | 0.972     | 0.902      |
|                                                                                                                       |          | APAR (all errors)   | 0.790     | 0.773     | 0.750     | 0.736     | 0.620      |
|                                                                                                                       | VAL      | R Value             | 0.862     | 0.870     | 0.762     | 0.766     | 0.775      |
|                                                                                                                       |          | APAR (large errors) | 0.979     | 0.976     | 0.979     | 0.971     | 0.977      |
|                                                                                                                       |          | APAR (all errors)   | 0.830     | 0.858     | 0.851     | 0.822     | 0.780      |
| <b>AVERAGES</b>                                                                                                       | DEV      | R Value             | 0.831     | 0.794     | 0.757     | 0.717     | 0.624      |
|                                                                                                                       |          | APAR (large errors) | 0.984     | 0.972     | 0.971     | 0.969     | 0.910      |
|                                                                                                                       |          | APAR (all errors)   | 0.774     | 0.755     | 0.749     | 0.738     | 0.604      |
|                                                                                                                       | VAL      | R Value             | 0.831     | 0.833     | 0.773     | 0.762     | 0.727      |
|                                                                                                                       |          | APAR (large errors) | 0.972     | 0.967     | 0.974     | 0.960     | 0.970      |
|                                                                                                                       |          | APAR (all errors)   | 0.801     | 0.822     | 0.829     | 0.819     | 0.773      |
|                                                                                                                       | ALL AVE  | R Value             | 0.831     | 0.813     | 0.765     | 0.740     | 0.675      |
|                                                                                                                       |          | APAR (large errors) | 0.978     | 0.970     | 0.972     | 0.964     | 0.940      |
|                                                                                                                       |          | APAR (all errors)   | 0.787     | 0.788     | 0.789     | 0.778     | 0.688      |



**Key to x-axis labels**

- 1- Real Time
- 2- 2 Minute Advance
- 3- 4 Minute Advance
- 4- 6 Minute Advance
- 5- 12 Minute Advance

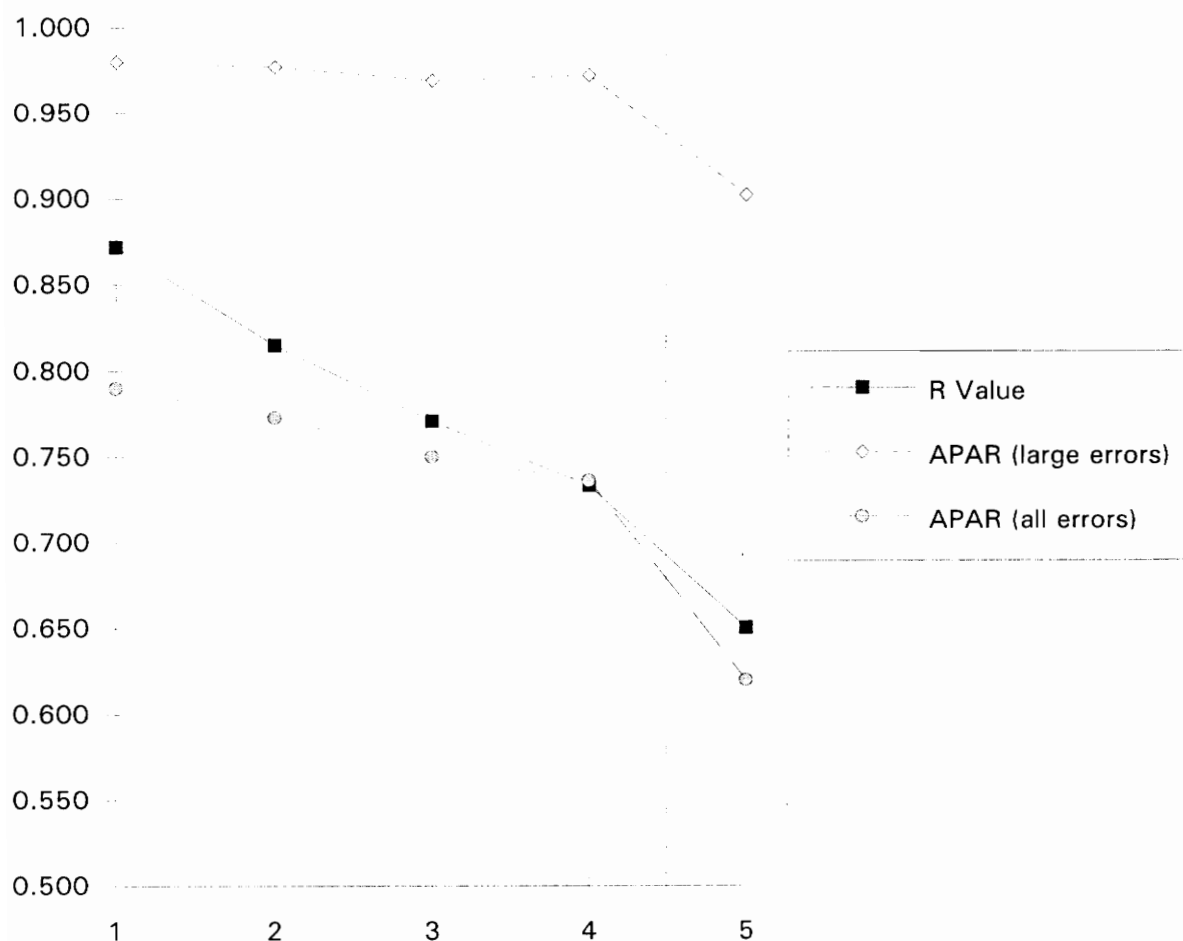
Figure 5.1. Overall average accuracy of algorithms as a function of advance time.



**Key to x-axis labels**

- 1- Real Time
- 2- 2 Minute Advance
- 3- 4 Minute Advance
- 4- 6 Minute Advance
- 5- 12 Minute Advance

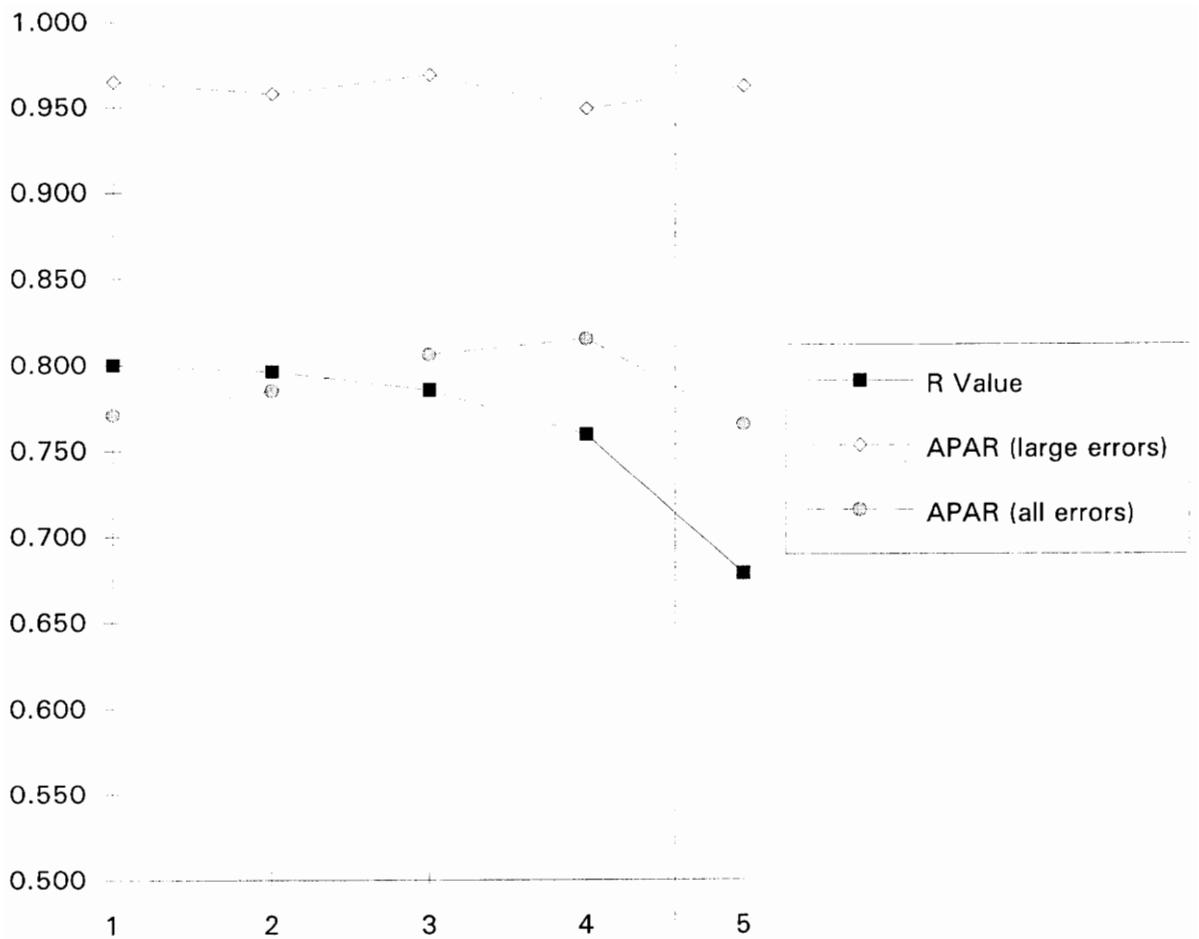
Figure 5.2. Accuracy of the Group D algorithms for the development data set.



**Key to x-axis labels**

- 1- Real Time
- 2- 2 Minute Advance
- 3- 4 Minute Advance
- 4- 6 Minute Advance
- 5- 12 Minute Advance

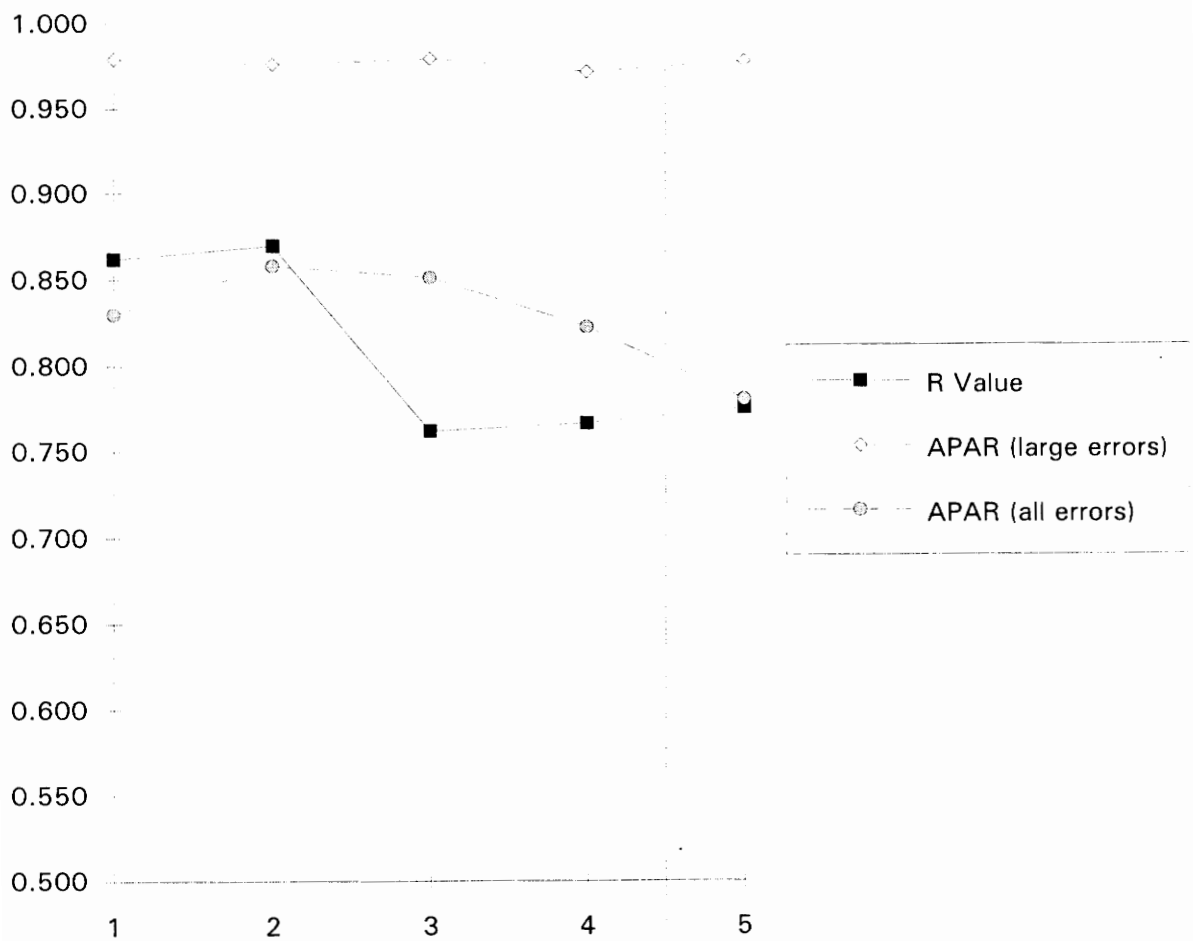
Figure 5.3. Accuracy of the Group F algorithms for the development data set.



**Key to x-axis labels**

- 1- Real Time
- 2- 2 Minute Advance
- 3- 4 Minute Advance
- 4- 6 Minute Advance
- 5- 12 Minute Advance

Figure 5.4. Accuracy of the Group D algorithms applied to the validation data set.



**Key to x-axis labels**

- 1- Real Time
- 2- 2 Minute Advance
- 3- 4 Minute Advance
- 4- 6 Minute Advance
- 5- 12 Minute Advance

Figure 5.5. Accuracy of the Group F algorithms applied to the validation data set.

## DISCUSSION

On the average, there was no appreciable degradation in APAR for large errors between algorithms developed using real time, two-minute advance, four-minute advance, and six-minute advance (Figure 5.1). A slight decrease in accuracy occurred for twelve-minute advance.

The APAR rates produced by the algorithms when they are applied to validation data stay fairly stable through the six-minute advance intervals for both variable groups. The R values remain stable through the six-minute advance interval when applied to group D algorithms (Figure 5.4), although they decrease significantly with four-minute advance data when applied to group F algorithms (Figure 5.5).

Losses in algorithm accuracy are small over the range of zero to four minutes advance, and slight degradation is seen at six-minute advance with a significant loss at twelve-minute advance. This is acceptable since four minutes should allow plenty of advance warning in implementation of these algorithms for on-the-road use.

For both group F and group D, the development data R values experienced a steady decline as the time interval between dependent and independent data increased. The APAR for large errors remained stable through the 2, 4, and 6-minute intervals. As one might expect, there was a significant drop between the 6 and 12-minute intervals. In both groups, APAR values remain fairly stable through the six-minute advance interval, but drop off at twelve.

These results suggest that there is minimal degradation in algorithm accuracy when the algorithms are predicting drowsiness up to six minutes in advance. It follows that if current algorithms do not detect drowsiness soon enough, algorithms with prediction capability can be substituted with no appreciable degradation in detection performance. Additionally, the structure of this study, which uses data collected from one group of subjects to develop algorithms and data collected from an independent group of subjects to validate them, contributes credibility to the results.

Table 5.2. Multiple Regression Summaries for Group D with 2, 4, 6, and 12 Minute Advances. (Corresponding real-time regression summary appears in Wreggit, Kirn, and Wierwille, 1993, p. 65.)

| Regression Summary for Dependent Variable: PERCLOS, 2 Minute Advance Data.<br>R= 0.77326541 R <sup>2</sup> = 0.59793940 Adjusted R <sup>2</sup> = 0.58546166<br>F(9,290) = 47.920 p<0.0000 Std.Error of estimate: 0.06343 |          |                     |          |                  |          |         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                           | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(290)   | p-level |
| Intercpt                                                                                                                                                                                                                  |          |                     | 0.01578  | 0.00628          | 2.51214  | 0.01254 |
| STVELV                                                                                                                                                                                                                    | 0.25866  | 0.08563             | 0.00085  | 0.00028          | 3.02052  | 0.00275 |
| LGREV                                                                                                                                                                                                                     | 0.34659  | 0.07836             | 0.03495  | 0.00790          | 4.42306  | 0.00001 |
| MDREV                                                                                                                                                                                                                     | -0.16731 | 0.06723             | -0.00383 | 0.00154          | -2.48850 | 0.01339 |
| NMRHOLD                                                                                                                                                                                                                   | -0.29640 | 0.05884             | -0.00515 | 0.00102          | -5.03750 | 0.00000 |
| THRSHLD                                                                                                                                                                                                                   | 0.36236  | 0.05008             | 0.33794  | 0.04671          | 7.23540  | 0.00000 |
| ACCVAR                                                                                                                                                                                                                    | -0.83456 | 0.20684             | -0.03656 | 0.00906          | -4.03478 | 0.00007 |
| ACCDEV                                                                                                                                                                                                                    | 0.84298  | 0.23227             | 0.13834  | 0.03812          | 3.62930  | 0.00034 |
| INTACDE                                                                                                                                                                                                                   | -0.19723 | 0.07179             | -0.12254 | 0.04460          | -2.74719 | 0.00639 |
| ACEXEED                                                                                                                                                                                                                   | 0.21753  | 0.06240             | 2.03949  | 0.58505          | 3.48603  | 0.00057 |

| Regression Summary for Dependent Variable: PERCLOS, 4 Minute Advance Data.<br>R= 0.74237398 R <sup>2</sup> = 0.55111912 Adjusted R <sup>2</sup> = 0.54153448<br>F(6,281) = 57.500 p<0.0000 Std.Error of estimate: 0.06721 |          |                     |          |                  |          |         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                           | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(281)   | p-level |
| Intercpt                                                                                                                                                                                                                  |          |                     | 0.00981  | 0.00542          | 1.80821  | 0.07164 |
| LGREV                                                                                                                                                                                                                     | 0.53794  | 0.05675             | 0.05320  | 0.00561          | 9.47967  | 0.00000 |
| NMRHOLD                                                                                                                                                                                                                   | -0.26715 | 0.05917             | -0.00464 | 0.00103          | -4.51515 | 0.00001 |
| THRSHLD                                                                                                                                                                                                                   | 0.31107  | 0.05202             | 0.29358  | 0.04909          | 5.98016  | 0.00000 |
| ACCVAR                                                                                                                                                                                                                    | -0.58659 | 0.20360             | -0.02373 | 0.00824          | -2.88104 | 0.00427 |
| ACCDEV                                                                                                                                                                                                                    | 0.45670  | 0.19513             | 0.07165  | 0.03061          | 2.34050  | 0.01996 |
| ACEXEED                                                                                                                                                                                                                   | 0.19855  | 0.05784             | 1.81877  | 0.52980          | 3.43295  | 0.00069 |

| Regression Summary for Dependent Variable: PERCLOS, 6 Minute Advance Data.<br>R= 0.70142431 R <sup>2</sup> = 0.49199606 Adjusted R <sup>2</sup> = 0.48662982<br>F(3,284) = 91.684 p<0.00000 Std.Error of estimate: 0.07093 |          |                     |          |                  |          |         |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                            | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(284)   | p-level |
| Intercpt                                                                                                                                                                                                                   |          |                     | 0.01181  | 0.00560          | 2.10854  | 0.03586 |
| LGREV                                                                                                                                                                                                                      | 0.62232  | 0.05253             | 0.06465  | 0.00546          | 11.84687 | 0.00000 |
| NMRHOLD                                                                                                                                                                                                                    | -0.14441 | 0.06278             | -0.00253 | 0.00110          | -2.30003 | 0.02217 |
| THRSHLD                                                                                                                                                                                                                    | 0.18626  | 0.05335             | 0.17518  | 0.05017          | 3.49150  | 0.00056 |

| Regression Summary for Dependent Variable: PERCLOS,12 Minute Advance Data.<br>R= 0.73307939 R <sup>2</sup> = 0.53740540 Adjusted R <sup>2</sup> = 0.52752793<br>F(6,281) = 54.407 p<0.00000 Std.Error of estimate: 0.06805 |          |                     |          |                  |          |         |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                            | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(281)   | p-level |
| Intercpt                                                                                                                                                                                                                   |          |                     | -0.00082 | 0.00600          | -0.13708 | 0.89107 |
| INTACDE                                                                                                                                                                                                                    | -0.11247 | 0.04706             | -0.07098 | 0.02970          | -2.39014 | 0.01750 |
| ACEXEED                                                                                                                                                                                                                    | 0.11012  | 0.05138             | 1.06862  | 0.49858          | 2.14333  | 0.03295 |
| LANVAR                                                                                                                                                                                                                     | -0.33796 | 0.12795             | -0.00245 | 0.00093          | -2.64126 | 0.00872 |
| LANDEV                                                                                                                                                                                                                     | 0.42122  | 0.19122             | 0.03275  | 0.01487          | 2.20281  | 0.02842 |
| LANEX                                                                                                                                                                                                                      | 0.19928  | 0.08977             | 0.16370  | 0.07374          | 2.22001  | 0.02722 |
| LGREV                                                                                                                                                                                                                      | 0.38613  | 0.07220             | 0.04011  | 0.00750          | 5.34801  | 0.00000 |

Table 5.3. Multiple Regression Summaries for Group F with 2, 4, 6, and 12 Minute Advances. (Corresponding real time regression summary appears in Wreggit, Kirn, and Wierwille, 1993, p. 87.)

| Regression Summary for Dependent Variable: PERCLOS, 2 Minute Advance Data.<br>R = 0.81495611 R <sup>2</sup> = 0.66415347 Adjusted R <sup>2</sup> = 0.65610235<br>F(7,292) = 82.492 p < 0.0000 Std.Error of estimate: 0.05777 |          |                     |          |                  |          |         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                              | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(292)   | p-level |
| Intercpt                                                                                                                                                                                                                     |          |                     | 0.00390  | 0.00474          | 0.82227  | 0.41160 |
| STVELV                                                                                                                                                                                                                       | 0.14156  | 0.06942             | 0.00046  | 0.00023          | 2.03933  | 0.04232 |
| LGREV                                                                                                                                                                                                                        | 0.18249  | 0.07332             | 0.01840  | 0.00739          | 2.48875  | 0.01338 |
| NMRHOLD                                                                                                                                                                                                                      | -0.13904 | 0.05489             | -0.00241 | 0.00095          | -2.53301 | 0.01183 |
| THRSHLD                                                                                                                                                                                                                      | 0.22236  | 0.04761             | 0.20737  | 0.04440          | 4.67060  | 0.00000 |
| ACCVAR                                                                                                                                                                                                                       | -0.15717 | 0.04068             | -0.00689 | 0.00178          | -3.86380 | 0.00014 |
| LANDEV                                                                                                                                                                                                                       | 0.27408  | 0.07200             | 0.02079  | 0.00546          | 3.80664  | 0.00017 |
| LANEX                                                                                                                                                                                                                        | 0.25599  | 0.06468             | 0.20372  | 0.05147          | 3.95796  | 0.00009 |

| Regression Summary for Dependent Variable: PERCLOS, 4 Minute Advance Data.<br>R = 0.77068459 R <sup>2</sup> = 0.59395474 Adjusted R <sup>2</sup> = 0.58528474<br>F(6,281) = 68.507 p < 0.0000 Std.Error of estimate: 0.06392 |          |                     |           |                  |          |         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|-----------|------------------|----------|---------|
|                                                                                                                                                                                                                              | BETA     | St. Err.<br>of BETA | B         | St. Err.<br>of B | t(281)   | p-level |
| Intercpt                                                                                                                                                                                                                     |          |                     | -0.00195  | 0.00529          | -0.36967 | 0.71190 |
| STVELV                                                                                                                                                                                                                       | 0.49870  | 0.07954             | 0.00160   | 0.00025          | 6.27008  | 0.00000 |
| STEXED                                                                                                                                                                                                                       | -0.28584 | 0.05895             | -139.6402 | 28.79877         | -4.84883 | 0.00000 |
| THRSHLD                                                                                                                                                                                                                      | 0.13312  | 0.04196             | 0.12564   | 0.03960          | 3.17230  | 0.00168 |
| ACCVAR                                                                                                                                                                                                                       | -0.09591 | 0.04658             | -0.00388  | 0.00188          | -2.05913 | 0.04040 |
| LANDEV                                                                                                                                                                                                                       | 0.30771  | 0.08337             | 0.02400   | 0.00650          | 3.69089  | 0.00027 |
| LANEX                                                                                                                                                                                                                        | 0.26125  | 0.07397             | 0.21150   | 0.05988          | 3.53204  | 0.00048 |

| Regression Summary for Dependent Variable: PERCLOS, 6 Minute Advance Data.<br>R = 0.73307939 R <sup>2</sup> = 0.53740540 Adjusted R <sup>2</sup> = 0.52752793<br>F(6,281) = 54.407 p < 0.00000 Std.Error of estimate: 0.06805 |          |                     |          |                  |          |         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                               | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(281)   | p-level |
| Intercpt                                                                                                                                                                                                                      |          |                     | -0.00082 | 0.00600          | -0.13708 | 0.89107 |
| INTACDE                                                                                                                                                                                                                       | -0.11247 | 0.04706             | -0.07098 | 0.02970          | -2.39014 | 0.01750 |
| ACEXEED                                                                                                                                                                                                                       | 0.11012  | 0.05138             | 1.06862  | 0.49858          | 2.14333  | 0.03295 |
| LANVAR                                                                                                                                                                                                                        | -0.33796 | 0.12795             | -0.00245 | 0.00093          | -2.64126 | 0.00872 |
| LANDEV                                                                                                                                                                                                                        | 0.42122  | 0.19122             | 0.03275  | 0.01487          | 2.20281  | 0.02842 |
| LANEX                                                                                                                                                                                                                         | 0.19928  | 0.08977             | 0.16370  | 0.07374          | 2.22001  | 0.02722 |
| LGREV                                                                                                                                                                                                                         | 0.38613  | 0.07220             | 0.04011  | 0.00750          | 5.34801  | 0.00000 |

| Regression Summary for Dependent Variable: PERCLOS, 12 Minute Advance Data.<br>R = 0.65029808 R <sup>2</sup> = 0.42288759 Adjusted R <sup>2</sup> = 0.41220032<br>F(5,270) = 39.569 p < 0.00000 Std.Error of estimate: 0.07672 |          |                     |          |                  |          |         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------|----------|------------------|----------|---------|
|                                                                                                                                                                                                                                | BETA     | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(270)   | p-level |
| Intercpt                                                                                                                                                                                                                       |          |                     | 0.00908  | 0.00696          | 1.30478  | 0.19308 |
| ACCDEV                                                                                                                                                                                                                         | -0.24865 | 0.06264             | -0.04140 | 0.01043          | -3.96939 | 0.00009 |
| ACEXEED                                                                                                                                                                                                                        | 0.13654  | 0.05373             | 1.37607  | 0.54152          | 2.54113  | 0.01161 |
| LANDEV                                                                                                                                                                                                                         | 0.40847  | 0.08065             | 0.03286  | 0.00649          | 5.06474  | 0.00000 |
| LANEX                                                                                                                                                                                                                          | 0.16853  | 0.08445             | 0.14595  | 0.07314          | 1.99552  | 0.04699 |
| MDREV                                                                                                                                                                                                                          | 0.23498  | 0.06064             | 0.00537  | 0.00139          | 3.87506  | 0.00013 |

## **Chapter 6**

### **TIME TREND ANALYSIS**

## INTRODUCTION

All attempts at algorithm development and optimization thus far have used concurrently collected independent measure data. In this optimization study, independent measure data for the current six-minute interval, first previous six-minute interval, and second previous six-minute interval are used together to develop driver-drowsiness detection algorithms. The goal was to determine whether or not inclusion of previous interval data would improve detection accuracy.

## METHOD

A previously developed algorithm, F4a (Wreggit, Kirn, and Wierwille, 1993), was selected to be used for comparison in this study, based on its stability. This algorithm was developed from all steering and accelerometer measures, and selected lane measures (LANDEV, LANVAR, LNERRSQ, LNMSQ, LANEX, and LNERRSQ). In this study, these measures were used in three forms:

- a- current six-minute interval
- b- previous six-minute interval
- c- second previous six-minute interval

Two studies were conducted. Study 1A involved the current and previous six-minute intervals (a and b), and study 2A involved the current and two previous six-minute intervals (a, b and c). In both cases, measures from each time segment were considered independent variables to be included in the multiple regression process, and the current six-minute interval of the measure PERCLOS was the dependent measure.

Multiple regression was performed on both variable groups using the previously collected development data, and algorithms were obtained. R values were determined and classification matrices were created using criteria which have been previously defined. Apparent accuracy rate (APAR) with respect to large errors, and APAR with respect to all errors were calculated. The algorithms were then applied to previously collected validation data (Wierwille, Wreggit, Kirn, Ellsworth and Fairbanks, 1994), R values were

determined, and classification matrices were calculated. These results were compared to the previously obtained results which represent current six-minute interval data only (Wreggit, Kim, and Wierwille, 1993).

## RESULTS

The resulting data, including R value, APAR for large errors, and APAR for all errors, are presented in Table 6.1 along with the corresponding original data.

R values for the development data increase for group 1A and 2A by 0.009 and 0.011 respectively when applied to the development data. APAR (large errors) values increase by 0.003 and 0.006, and APAR (all errors) increase by 0.019 and 0.007. R values for the validation data decrease for group 1A and 2A by 0.006 and 0.021 respectively with respect to the original data. APAR (large errors) values increase by 0.006 and 0.001, and APAR (all errors) increase by 0.061 for study 1A and decrease by 0.031 in study 2A. These data appear in graphical form in Figure 6.1 for the purposes of comparison. The regression algorithms producing these results are presented in Tables 6.2 and 6.3.

## DISCUSSION AND CONCLUSION

The use of previous time intervals in algorithm development produced a small improvement in algorithm accuracy for the development data, but did not remain stable when applied to validation data. This result occurred in algorithms produced using one previous segment as well as those produced using two previous segments.

These results suggest that the use of previous time intervals in driver-drowsiness detection algorithms does not improve algorithm accuracy. While only the two previous six-minute intervals were tested in this study, it seems unlikely that using data from further into the past would be of any benefit.

Table 6.1. A comparison of the original results with the results from studies 1A and 2A.

| DATA SET         | ACCURACY MEASURE    | ORIGINAL DATA<br>(F4a) | STUDY 1A<br>(n, n-1)<br>(1A) | STUDY 2A<br>(n, n-1, n-2)<br>(2A) |
|------------------|---------------------|------------------------|------------------------------|-----------------------------------|
| Development Data | R Value             | 0.872                  | 0.881                        | 0.883                             |
|                  | APAR (large errors) | 0.980                  | 0.983                        | 0.986                             |
|                  | APAR (all errors)   | 0.790                  | 0.809                        | 0.797                             |
| Validation Data  | R Value             | 0.862                  | 0.856                        | 0.841                             |
|                  | APAR (large errors) | 0.976                  | 0.982                        | 0.977                             |
|                  | APAR (all errors)   | 0.830                  | 0.891                        | 0.799                             |

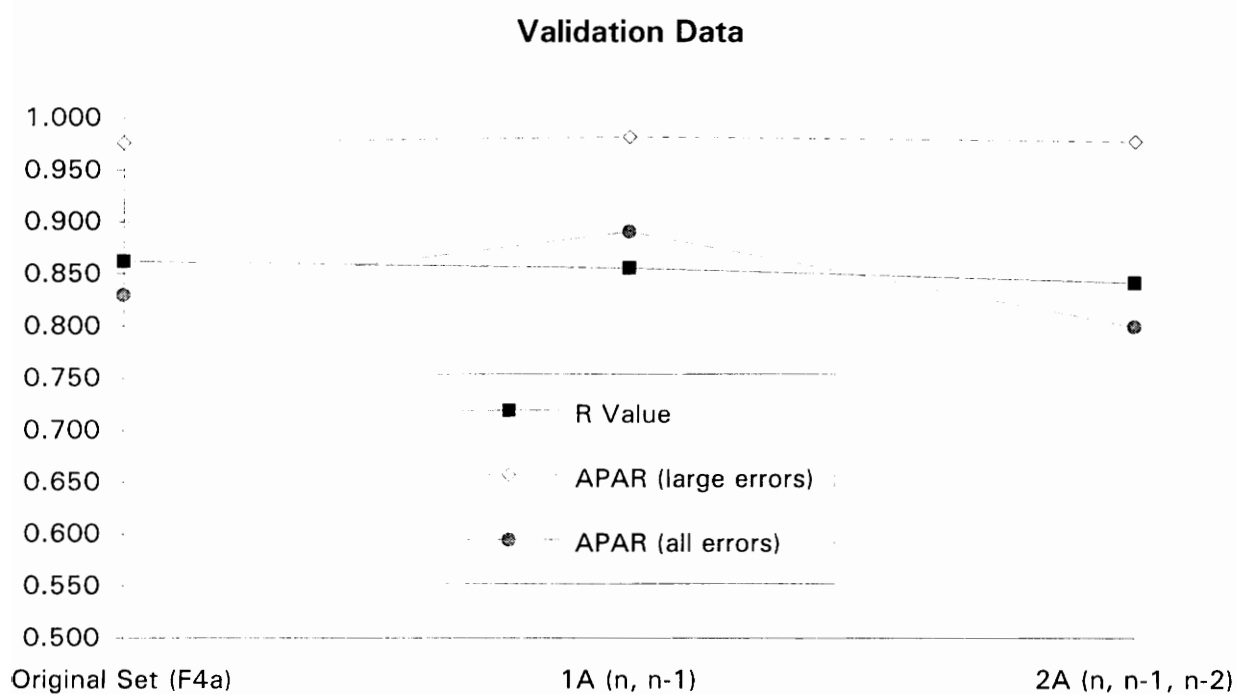
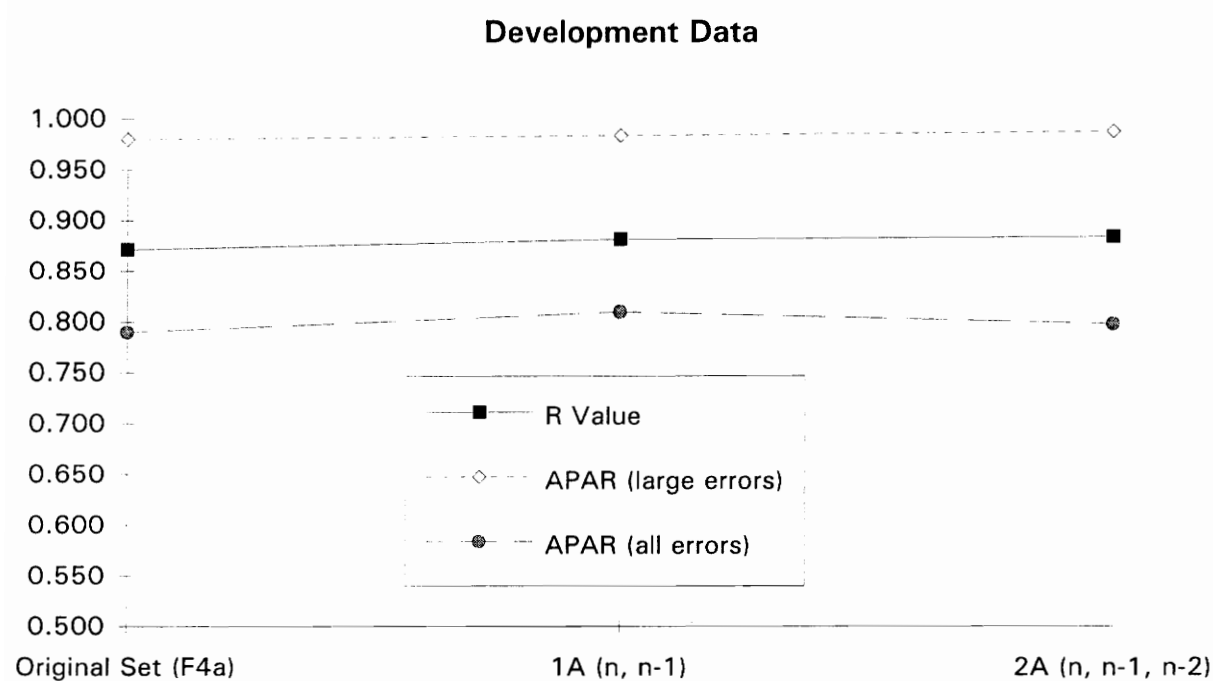


Figure 6.1. Graphical representations of the APAR and R values for development and validation data

**Table 6.2. Regression Summary for Algorithm 1A.**

Dependent Variable: aPERCLOS

R= 0.88079127, R2= 0.77579327, Adjusted R2= 0.77018810

F(7,280)=138.41 p&lt;0.0000 Std.Error of estimate: 0.04746

|           | BETA   | St. Err.<br>of<br>BETA | B         | St. Err.<br>of B | t(280) | p-level |
|-----------|--------|------------------------|-----------|------------------|--------|---------|
| Intercept |        |                        | -0.007852 | 0.004            | -1.824 | 0.069   |
| aACCDEV   | -0.117 | 0.034                  | -0.019121 | 0.006            | -3.386 | 0.000   |
| aLANDEV   | 0.909  | 0.072                  | 0.068383  | 0.005            | 12.580 | 0.000   |
| aLNERRS   | -0.238 | 0.055                  | -0.001811 | 0.000            | -4.300 | 0.000   |
| aNMRHOL   | -0.187 | 0.046                  | -0.003199 | 0.000            | -4.033 | 0.000   |
| aTHRSHL   | 0.240  | 0.041                  | 0.221817  | 0.038            | 5.913  | 0.000   |
| bLNMNSQ   | -0.121 | 0.035                  | -0.000677 | 0.000            | -3.442 | 0.000   |
| bSTVELV   | 0.190  | 0.038                  | 0.000619  | 0.000            | 5.006  | 0.000   |

**Table 6.3. Regression Summary for Algorithm 2A.**

Dependent Variable: aPERCLOS

R= 0.88241777, R2= 0.77866111, Adjusted R2= 0.77202924

F(8,267)=117.41 p&lt;0.0000 Std.Error of estimate: 0.04778

|           | BETA   | St. Err.<br>of<br>BETA | B         | St. Err.<br>of B | t(267) | p-level |
|-----------|--------|------------------------|-----------|------------------|--------|---------|
| Intercept |        |                        | -0.003214 | 0.004            | -0.739 | 0.460   |
| aLANDEV   | 0.714  | 0.052                  | 0.054267  | 0.004            | 13.689 | 0.000   |
| aNMRHOL   | -0.147 | 0.052                  | -0.002517 | 0.000            | -2.826 | 0.005   |
| aTHRSHL   | 0.376  | 0.052                  | 0.345770  | 0.048            | 7.202  | 0.000   |
| bLNMNSQ   | -0.124 | 0.037                  | -0.000687 | 0.000            | -3.395 | 0.000   |
| bSTVELV   | 0.250  | 0.038                  | 0.000812  | 0.000            | 6.536  | 0.000   |
| cLNMNSQ   | 0.806  | 0.188                  | 0.004574  | 0.001            | 4.284  | 0.000   |
| cLANVAR   | -0.892 | 0.192                  | -0.006602 | 0.001            | -4.653 | 0.000   |
| cSMREV    | 0.137  | 0.057                  | 0.001056  | 0.000            | 2.426  | 0.016   |

Measures preceded by "a" represent six-minute time segment n,  
Measures preceded by "b" represent six-minute time segment n-1,  
Measures preceded by "c" represent six-minute time segment n-2.

## **Chapter 7**

### **DEVELOPMENT OF UNBASELINED DRIVER STATUS AND DRIVER PERFORMANCE ALGORITHMS**

## UNBASELINED DRIVER STATUS (PERCLOS) ALGORITHMS

All algorithms that have been developed and reported thus far in the current study have been created using baselined data. The purpose of baselining is to account for (remove) variations in the data due to individual subject idiosyncrasies. The decision to use baselined data is based on the premise that these variations introduce a detrimental factor in the development and implementation of driver drowsiness detection algorithms. But algorithms which use baselined data require complex manipulation of data on-line and may not be implementable in all cases.

In order to assess the feasibility of using unbaselined data, new algorithms were developed from unbaselined data. This analysis was conducted by Fairbanks, Lewin, and Wierwille. A report on this analysis is found in Appendix B.

Procedures for this analysis were followed exactly as in the original development of baselined algorithms (Wreggit, Kirn, Wierwille, 1993). Variable groups D4a, F4a, J4a, and L3a were used as starting points. These groups all include lateral acceleration and steering measures, and F4a, J4a, and L3a add lane measures, A/O task measures, and lane and A/O measures, respectively. In the planned test and evaluation experiment, the A/O task will be presented to several of the subjects as a countermeasure to drowsiness after initial detection. During this time, A/O task data will be available to the system and as algorithm components. Previously developed algorithms which include A/O task data have been found to be at least as accurate as those without. In view of the advantage of involving both A/O and non-A/O task algorithms in the system, all subsequent development studies include both types.

The algorithms were developed using unbaselined development data and were validated using unbaselined validation data. The raw data were the same as those used in baselined algorithm development and validation (Wierwille, Wreggit, Kirn, Ellsworth, and Fairbanks, 1994). Results from this analysis were compared to that of the baselined algorithms. Unbaselined algorithms were found to have no appreciable loss of accuracy

based on classification matrix and correlation values. Consequently, the use of unbaselined data in the implementation of an on-line system is recommended.

## THE DRIVER-PERFORMANCE MONITORING COMPONENT: *Development of eLANEX Algorithms*

### Introduction

The overall goal of this project has been to create a "driver status and performance monitoring system." The focus thus far has been on the estimation of driver status measures such as eye closure and expert-observed drowsiness. Data collected in previous studies (Wierwille, Wreggit, Kirn, Ellsworth, and Fairbanks, 1994) can be used to develop and validate a driver performance component for the system. Here, driver status refers to drowsiness, and driver performance refers to driving performance.

Existing technology may allow on-the-road collection of lane excursion information in many roadway conditions. Since good driving practices in the United States dictate that a driver should remain within the lane boundaries, lane excursion can be used as an indicator of driver performance. LANEX, or "lane exceedance," is a measure of the proportion of time the vehicle is out of lane. When lane information is available, LANEX can be collected directly. But limitations of this technology mean that continuous collection of lane information is not possible. When lane information is not available to the system, it is desirable to estimate lane measures so that driver performance can continue to be monitored. Accordingly, the following investigation examines the ability of steering, lateral acceleration, and secondary task measures to estimate lane exceedance values.

Examination of existing data suggest that there is large variation between individual drivers' in their tendency to stay within the lane during normal, alert driving. To produce algorithms which are sensitive to these variations, existing data sets were combined in three different ways for algorithm development. The specific makeup of each set is described in the following section.

Method

All performance algorithms were developed and validated using the procedures described in Chapter 1. LANEX was selected as the dependent measure, and in each case the procedure was completed twice in order to produce algorithms with and without A/O task components. The two variable groups are defined as follows:

*Variable Group A: containing steering and lateral acceleration measures.*

*Variable Group B: containing steering, lateral acceleration, and secondary (A/O) task measures.*

The measures included in each variable group are described in detail in Chapter 1.

Unbaselined data were compiled into six-minute averages from previously obtained development and validation data sets. Multiple regression analyses were performed on the six combinations of variable groups and data sets as illustrated in Table 7.1.

Table 7.1. Combinations of data sets and variable groups used in algorithm development and validation.

|        | LANEX Development Data Groups                                                                                       | LANEX Validation Data Groups                                                                              |
|--------|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Case 1 | development data (12 subjects)<br>A. steering, lateral accel<br>B. steering, lateral accel, A/O                     | validation data (12 subjects)<br>A. steering, lateral accel<br>B. steering, lateral accel, A/O            |
| Case 2 | all odd numbered subjects (12 subjects)<br>A. steering, lateral accel;<br>B. steering, lateral accel, A/O           | all even numbered subjects (12 subjects)<br>A. steering, lateral accel<br>B. steering, lateral accel, A/O |
| Case 3 | all subjects (24 subjects)<br>A. steering, lateral accel (Alg LDV-1)<br>B. steering, lateral accel, A/O (Alg LDV-4) | (none)                                                                                                    |

In all cases, r value and classification matrix apparent accuracy (APAR) rates were obtained. Classification was accomplished using the following LANEX threshold values:

| <u>Performance Classification</u> | <u>LANEX Value</u>   |
|-----------------------------------|----------------------|
| Satisfactory.....                 | LANEX ≤ 0.075        |
| Borderline.....                   | 0.075 < LANEX < 0.15 |
| Unsatisfactory.....               | LANEX ≥ 0.15         |

These threshold values were determined in the same manner that thresholds have been previously selected (Wreggit, 1994). Specifically, selection was based on visual inspection of the definitional measure PERCLOS with LANEX in conjunction with the known driving performance of each subject. Threshold lines were placed so that LANEX and PERCLOS had similar classifications as often as possible. In Figure 7.1 the two measures have been graphed and the threshold lines drawn.

In Case 1 and Case 2, newly obtained algorithms were then applied to the appropriate validation data, and  $r$  values and APAR rates were similarly obtained. Validation was not performed on Case 3 so as to avoid confound from the use of redundant data.

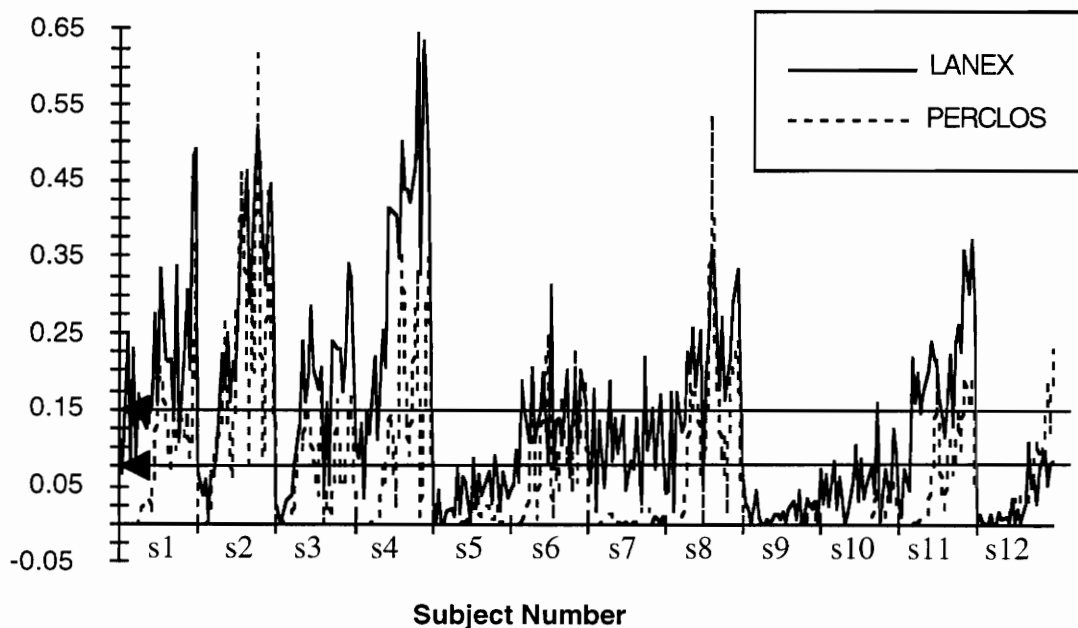


**Figure 7.1. Unbaselined Development LANEX and PERCLOS Data.**

## Results

The results are presented individually for each case, and the rationale for continuing to the next case is presented for Case 1 and Case 2. Note that in this section “development” and “validation” data refer to data sets (as described in Chapter 1) which were collected during the development study and validation study, respectively. “Special development” and “special validation” refer to the Case 2 and Case 3 sets used here for the purpose of LANEX algorithm development.

Case 1- Development/Validation Subjects. Classification matrices, APAR rates, and  $r$  values resulting from Case 1 algorithm development are presented in Table 7.2. Validation values are presented in Table 7.3. In the development phase,  $r$  values in both variable groups are reasonably good: 0.854 and 0.906 for variable groups A and B respectively. Although a moderate loss is observed in the validation phase  $r$  values, the APAR rates for all misclassifications are reduced from 0.667 to 0.468 in group A and from 0.770 to 0.500 in group B. These APAR rates indicate that these algorithms produce unacceptably high misclassifications when applied to new data. It is possible that these algorithms are not sensitive to performance variations found in the validation data set but not represented by any subjects in the development data set. In an attempt to improve on these results, Case 2 uses a new combination of subjects for development and validation.

Case 2- Odd/Even Subjects. Classification matrices, APAR rates, and  $r$  values resulting from Case 2 algorithm development are presented in Table 7.4. Validation values are presented in Table 7.5. Variable group A produces a development  $r$  value of 0.861 and a validation  $r$  value of 0.760. The corresponding APAR rates (all misclassifications) are similar: 0.614 development value and 0.618 validation value. Variable group B results were found to be similar. Although these results are encouraging, the decision was made to utilize the entire data set (Case 3) in the development phase in order to produce as highly proficient an algorithm as possible.

Table 7.2. Case 1 Algorithm Development Results.

### Classification Matrix

**Unbaselined- Case 1 Development Data (Variable Group A: Without A/O)**

| Observed | Predicted      |           |              |            |                |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          | Satisfactory   | 67.74     | 84           | 33         | 7              |
|          | Borderline     | 44.83     | 7            | 26         | 25             |
|          | Unsatisfactory | 76.27     | 4            | 24         | 90             |
|          | Total          | 66.67     | 95           | 83         | 122            |

LANEX (R value = 0.854)

Apparent Accuracy Rate (LARGE misclassifications): 0.963

Apparent Accuracy Rate (ALL misclassifications): 0.667

**Thresholds:** Upper- 0.150

Lower- 0.075

### Classification Matrix

**Unbaselined- Case 1 Development Data (Variable Group B: With A/O)**

| Observed | Predicted      |           |              |            |                |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          | Satisfactory   | 87.50     | 42           | 5          | 1              |
|          | Borderline     | 27.78     | 0            | 5          | 13             |
|          | Unsatisfactory | 88.24     | 0            | 4          | 30             |
|          | Total          | 77.00     | 42           | 14         | 44             |

LANEX (R value = 0.906)

Apparent Accuracy Rate (LARGE misclassifications): 0.990

Apparent Accuracy Rate (ALL misclassifications): 0.770

**Thresholds:** Upper- 0.150

Lower- 0.075

Table 7.3. Case 1 Validation Results.

Classification Matrix

*Unbaselined- Case 1 Validation Data (Variable Group A: Without A/O)*

| Observed | Predicted      |           |              |            |                |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          | Satisfactory   | 33.10     | 47           | 59         | 36             |
|          | Borderline     | 29.41     | 6            | 25         | 54             |
|          | Unsatisfactory | 87.06     | 1            | 10         | 74             |
|          | Total          | 46.79     | 54           | 94         | 164            |

LANEX (R value = 0.812)

Apparent Accuracy Rate (LARGE misclassifications): 0.881  
Apparent Accuracy Rate (ALL misclassifications): 0.468

**Thresholds:** Upper- 0.150  
Lower- 0.075

Classification Matrix

*Unbaselined- Case 1 Validation Data (Variable Group B: With A/O)*

| Observed | Predicted      |           |              |            |                |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          | Satisfactory   | 40.79     | 31           | 39         | 6              |
|          | Borderline     | 45.45     | 2            | 20         | 22             |
|          | Unsatisfactory | 69.57     | 3            | 11         | 32             |
|          | Total          | 50.00     | 36           | 70         | 60             |

LANEX (R value = 0.747)

Apparent Accuracy Rate (LARGE misclassifications): 0.946  
Apparent Accuracy Rate (ALL misclassifications): 0.500

**Thresholds:** Upper- 0.150  
Lower- 0.075

Table 7.4. Case 2 Algorithm Development Results (Odd-Numbered Subjects).

Classification Matrix

**Unbaselined- Case 2 Development (Odd) Data (Variable Group A: Without A/O)**

| Observed |  | Predicted      |           |              |            |                |
|----------|--|----------------|-----------|--------------|------------|----------------|
|          |  | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          |  | Satisfactory   | 57.76     | 67           | 42         | 7              |
|          |  | Borderline     | 52.94     | 9            | 36         | 23             |
|          |  | Unsatisfactory | 69.67     | 4            | 33         | 85             |
|          |  | Total          | 61.44     | 80           | 111        | 115            |

LANEX (R value = 0.861)

Apparent Accuracy Rate (LARGE misclassifications): 0.964

Apparent Accuracy Rate (ALL misclassifications): 0.614

**Thresholds:** Upper- 0.150

Lower- 0.075

Classification Matrix

**Unbaselined- Case 2 Development (Odd) Data (Variable Group B: With A/O)**

| Observed |  | Predicted      |           |              |            |                |
|----------|--|----------------|-----------|--------------|------------|----------------|
|          |  | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          |  | Satisfactory   | 58.62     | 68           | 42         | 6              |
|          |  | Borderline     | 47.06     | 9            | 32         | 27             |
|          |  | Unsatisfactory | 72.95     | 2            | 31         | 89             |
|          |  | Total          | 61.76     | 79           | 105        | 122            |

LANEX (R value = 0.906)

Apparent Accuracy Rate (LARGE misclassifications): 0.974

Apparent Accuracy Rate (ALL misclassifications): 0.618

**Thresholds:** Upper- 0.150

Lower- 0.075

Table 7.5. Case 2 Validation Results (Even-Numbered Subjects).

### Classification Matrix

**Unbaselined- Case 2 Validation (Even) Data (Variable Group A: Without A/O)**

| Observed | Predicted      |           |              |            |                |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          | Satisfactory   | 60.00     | 90           | 54         | 6              |
|          | Borderline     | 57.33     | 9            | 43         | 23             |
|          | Unsatisfactory | 69.14     | 2            | 23         | 56             |
|          | Total          | 61.76     | 101          | 120        | 85             |

LANEX (R value = 0.760)

Apparent Accuracy Rate (LARGE misclassifications): 0.974

Apparent Accuracy Rate (ALL misclassifications): 0.618

**Thresholds:** Upper- 0.150  
Lower- 0.075

### Classification Matrix

**Unbaselined- Case 2 Validation (Even) Data (Variable Group B: With A/O)**

| Observed | Predicted      |           |              |            |                |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|          | Satisfactory   | 58.67     | 88           | 56         | 6              |
|          | Borderline     | 56.00     | 9            | 42         | 24             |
|          | Unsatisfactory | 69.14     | 3            | 22         | 56             |
|          | Total          | 60.78     | 100          | 120        | 86             |

LANEX (R value = 0.755)

Apparent Accuracy Rate (LARGE misclassifications): 0.971

Apparent Accuracy Rate (ALL misclassifications): 0.608

**Thresholds:** Upper- 0.150  
Lower- 0.075

Case 3- All Subjects. Figures 7.2 and 7.3 show the regression summaries,  $r$  values, and apparent accuracy rates resulting from Case 3 algorithm development for non-A/O and A/O task respectively. Algorithm LDV-1, which resulted from the regression of variable group A, is shown in Figure 7.2, and Figure 7.3 contains algorithm LDV-4, which resulted from the regression of variable group B. Algorithm LDV-1 and LDV-4 yielded  $r$  values of 0.830 and 0.835 respectively. In a sense, these algorithms can be considered to be best "programmed" for individual driver performance variations, and are expected to hold up well when applied to new data. Note that there is a healthy increase in APAR rates over both Case 1 and Case 2 despite the slight decrease in  $r$  value.

### Discussion

These analyses were performed sequentially, each one performed based on the preceding results. Specifically, Case 1 was performed first (in an analogous fashion to driver status, or PERCLOS, algorithm development). Results suggested that the development data set may not have produced algorithms sensitive to certain lane-exceedant drivers found in the validation data set. In order to include these drivers in the algorithm development phase, Case 2 special development data was made up of odd numbered subjects from both the development and validation data sets. Accordingly, even numbered subjects were used in validation. This approach produced better algorithms, so it is reasonable to expect that algorithms produced from a more diverse data set will maintain integrity over a larger group of drivers. In view of this finding, a complete data set consisting of all subject data was used in the development of Case 3 algorithms. Although data were not then available for the validation of these algorithms, it is probable that results of such an analysis would support the use of the Case 3 algorithms.

**Regression Summary for Dependent Variable: LANEX**

R = 0.83026466 R<sup>2</sup> = 0.68933941 Adjusted R<sup>2</sup> = 0.68677620

F(5,606) = 268.94 p < 0.0000 Std. Error of estimate: 0.07246

|           | BETA      | St. Err. of BETA | B         | St. Err. of B | t(606)   | p-level  |
|-----------|-----------|------------------|-----------|---------------|----------|----------|
| Intercept |           |                  | -0.006938 | 0.020656      | -0.33587 | 0.737084 |
| ACCDEV    | 0.282832  | 0.028478         | 0.059770  | 0.006018      | 9.93171  | 0.000000 |
| STVELV    | -0.177676 | 0.049757         | -0.000422 | 0.000118      | -3.57086 | 0.000384 |
| LGREV     | 0.672433  | 0.052391         | 0.062359  | 0.004859      | 12.83487 | 0.000000 |
| NMRHOLD   | -0.170117 | 0.029684         | -0.004275 | 0.000746      | -5.73091 | 0.000000 |
| THRSHLD   | 0.381693  | 0.027722         | 0.416193  | 0.030228      | 13.76859 | 0.000000 |

**Predicted**

|                 |                |           |              |            |                |
|-----------------|----------------|-----------|--------------|------------|----------------|
| <b>Observed</b> | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|                 | Satisfactory   | 65.41     | <b>174</b>   | 91         | 1              |
|                 | Borderline     | 77.78     | 28           | <b>161</b> | 18             |
|                 | Unsatisfactory | 69.06     | 1            | 42         | <b>96</b>      |
|                 | Total          | 70.42     | 203          | 294        | 115            |

LANEX (R value = 0.830)

Apparent Accuracy Rate (LARGE misclassifications): **0.997**

Apparent Accuracy Rate (ALL misclassifications): **0.704**

Thresholds Used:

Satisfactory/Borderline: 0.075

Borderline/Unsatisfactory: 0.200

Classification Matrix Generated From Multiple Regression Analysis of **Original and New LANEX** Data (24 Subjects) Resulting in **Algorithm LDV-1**. (Independent variables employed included Steering and Accelerometer.)

Figure 7.2. Regression Summary and Classification Matrix Showing Accuracy of Algorithm LDV-1 When Applied to Combined Data Set (24 Subjects).

**Regression Summary for Dependent Variable: LANEX**  
 $R = 0.83251125$   $R^2 = 0.69307499$  Adjusted  $R^2 = 0.68717258$   
 $F(5,260) = 117.42$   $p < 0.0000$  Std. Error of estimate: 0.07485

|           | BETA      | St. Err.<br>of BETA | B         | St. Err.<br>of B | t(260)   | p-level  |
|-----------|-----------|---------------------|-----------|------------------|----------|----------|
| Intercept |           |                     | -0.210593 | 0.023034         | -9.14274 | 0.000000 |
| ACCDEV    | 0.263242  | 0.041927            | 0.057733  | 0.009195         | 6.27851  | 0.000000 |
| LGREV     | 0.319591  | 0.051864            | 0.036813  | 0.005974         | 6.16206  | 0.000000 |
| THRSHLD   | 0.316681  | 0.035752            | 0.308162  | 0.034790         | 8.85784  | 0.000000 |
| AOTIME    | 0.682708  | 0.086778            | 0.097192  | 0.012354         | 7.86727  | 0.000000 |
| NMWRONG   | -0.362757 | 0.075683            | -0.204829 | 0.042734         | -4.79308 | 0.000003 |

**Predicted**

| Observed | Group          | % Correct | Satisfactory | Borderline | Unsatisfactory |
|----------|----------------|-----------|--------------|------------|----------------|
|          | Satisfactory   | 78.23     | <b>97</b>    | 27         | 0              |
|          | Borderline     | 74.70     | 14           | <b>62</b>  | 7              |
|          | Unsatisfactory | 74.58     | 1            | 14         | <b>44</b>      |
|          | Total          | 76.32     | 112          | 103        | 51             |

LANEX (R value = 0.833)  
 Apparent Accuracy Rate (LARGE misclassifications): **0.996**  
 Apparent Accuracy Rate (ALL misclassifications): **0.763**

Thresholds:  
 Satisfactory/Borderline: 0.075  
 Borderline/Unsatisfactory: 0.200

Classification Matrix Generated From Multiple Regression Analysis of **Original and New LANEX** Data (24 Subjects) Resulting in **Algorithm LDV-4**. (Independent variables employed included A/O Task, Steering, and Accelerometer.)

Figure 7.3. Regression Summary and Classification Matrix Showing Accuracy of Algorithm LDV-4 When Applied to Combined Data Set (24 Subjects).

## **Chapter 8**

### **RECOMMENDATIONS FOR THE ON-LINE DETECTION SYSTEM STRUCTURE AND THRESHOLDS**

## THE ESTIMATION OF BEST SINGLE-THRESHOLD LEVELS

### Introduction

In implementation of a driver status/driver performance monitoring system, a single threshold level must be used to facilitate the identification of a positive detection of drowsiness. Most classifications used thus far in the study have been obtained by applying dual thresholds. Although the resulting intermediate classifications (such as "questionable" or "borderline") have been helpful in the assessment of algorithms, they are not useful in on-line detection. Prior to systems analysis it was assumed that dual thresholds would be used in implementation. Since recent design of the on-line system configuration has dictated the use of single thresholds, it has become necessary to determine single threshold levels for LANEX and PERCLOS, as well as their estimated (algorithm output) values eLANEX and ePERCLOS. Initially, it was believed that signal detection theory may have been useful in the development of algorithm thresholds. Upon further exploration of the problem, though, it was determined that a more straightforward approach was possible; one that was derived directly from the relevant experimental data. The process leading to the determination of these single thresholds, which uses best engineering judgment, is described in this chapter.

### Observed PERCLOS Single Threshold Level

PERCLOS is defined as the proportion of time that a driver's eyes are at least 80% closed. As driver-subjects become increasingly drowsy, their slow eyelid closure level increases over time. With an assumption that the increase is linear, it is possible to determine a threshold value (specific to six-minute average data) using a classic progression of drowsiness model.

Previous studies have lead to the conclusion that a driver with a PERCLOS value over 0.15 is classified as drowsy (in the dual threshold system). It is clear then that a driver with a PERCLOS value of 0.20 is not able to maintain a safe control of the vehicle.

Specifically, such a driver would be experiencing 80% eye closure for a total of 12 seconds per minute. Conversely, a PERCLOS value less than 0.05, defined as eye closure for less than three seconds per minute, is not a considered a detriment to driving performance. Using 0.05 and 0.20 as one-minute endpoints in a six-minute interval, a trend model can be constructed as shown in Figure 8.1. Since we assume a linear increase in drowsiness over time, it is possible to calculate a six-minute average value which corresponds to a model with 0.05 and 0.20 endpoints:

$$PERCLOS\ Threshold = (\sum E_i)/6$$

$$PERCLOS\ Threshold = 0.125$$

where  $E_i$  = PERCLOS value for each minute ( $i$ ) from 1 to 6. It is thus recommended that 0.125 be used as the on-line threshold value for observed-PERCLOS six-minute average data.

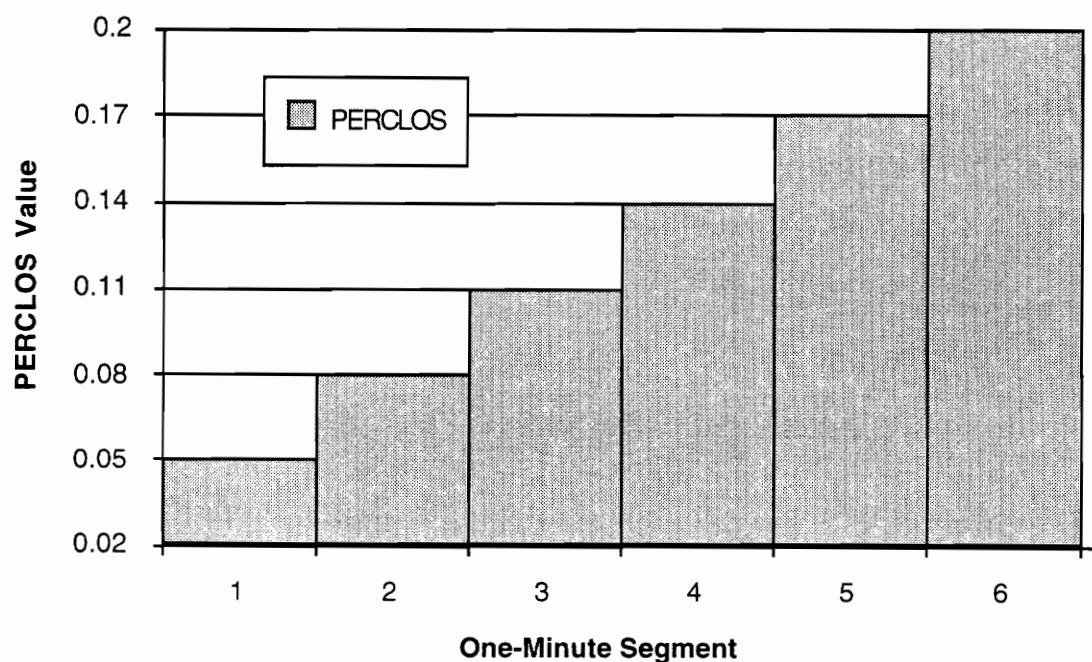


**Figure 8.1. Trend Model of PERCLOS for Linearly Increasing Level of Drowsiness**

Estimated-PERCLOS (ePERCLOS) Single Threshold Level

To determine the appropriate ePERCLOS single threshold level it is necessary to determine the ePERCLOS value corresponding to the chosen PERCLOS threshold of 0.125 which minimizes classification errors. Several ePERCLOS threshold values were selected and used to produce classification matrices when applied to ePERCLOS algorithms D4a-N, F4a-N, J4a-N, L3a-N. Appendix B describes these algorithms in detail. Values for percent missed detections, percent false alarms, and total percent wrong were calculated based on each classification matrix. Figure 8.2 graphically illustrates the threshold values which were used.

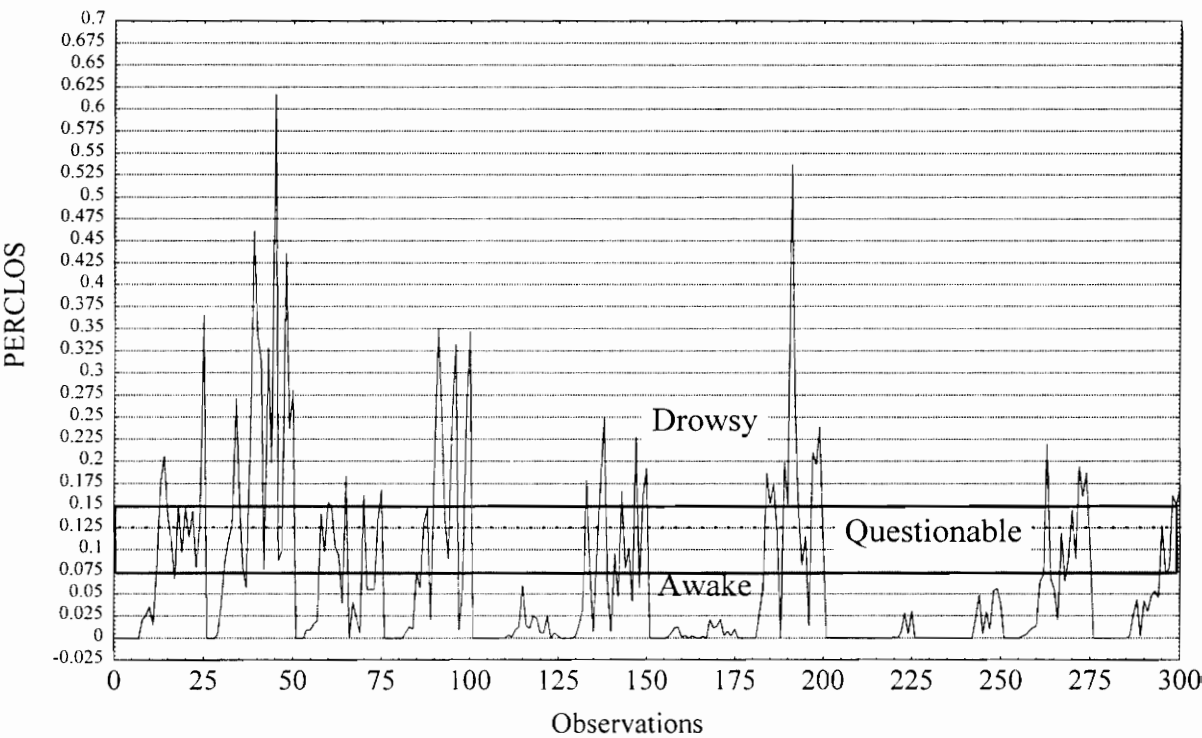


Figure 8.2. PERCLOS Data With Upper and Lower Threshold Lines for Three Categories and Single Threshold for Two Categories (Wreggit, Kirn, and Wierwille, 1993).

The average values for each of the three inaccuracy percentages from these four algorithms are graphically depicted in Figure 8.3. Examination of this diagram reveals a minimum value in “percent wrong,” as well as a balance between “percent missed” and “percent false alarms” when the ePERCLOS threshold of 0.14 is applied. A high false alarm rate is considered to be as detrimental to the system as a high missed detection rate. Drivers will have a tendency to ignore or cancel a system that produces frequent false alarms. Hence it is desirable to find a balanced minimum in these values such as that at threshold level 0.14. Based on this approach a single threshold level of 0.14 is recommended for use with ePERCLOS algorithms.

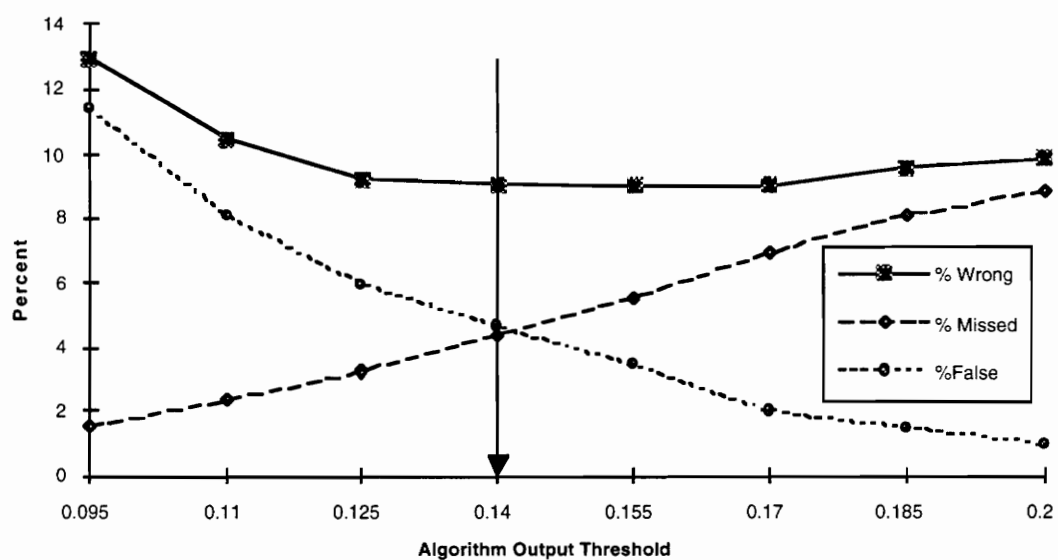


Figure 8.3. Total Error, False Alarm, and Missed Detection Percentages as a Function of ePERCLOS Algorithm Output Threshold (PERCLOS Threshold is at 0.125).

Observed LANEX Single Threshold Level

LANEX, or the proportion of time the vehicle is located outside the lane, is a measure of driver performance. As with PERCLOS, LANEX is expected to increase as the driver becomes drowsy. The process for determination of the LANEX single threshold level corresponds to that described for PERCLOS. Lane excursion is assumed to increase

linearly as drowsiness level increases. An alert driver with good performance is expected to have no lane excursions and thus a LANEX value of zero. In contrast, a LANEX value of 0.20, which represents lane excursions for an average of 12 seconds per minute, is considered unacceptable performance. Using 0 and 0.20 as endpoints, and assuming a linear increase in the typical event, a model trend can be constructed over six one-minute intervals as seen in Figure 8.4. From this model, an appropriate threshold value can be calculated as follows:

$$LANEX\ Threshold = (\sum L_i)/6$$

$$LANEX\ Threshold = 0.10$$

where  $L_i$  = LANEX value for each minute (i) from 1 to 6. It is thus recommended that 0.10 be used as the on-line threshold value for observed-LANEX six-minute average data.

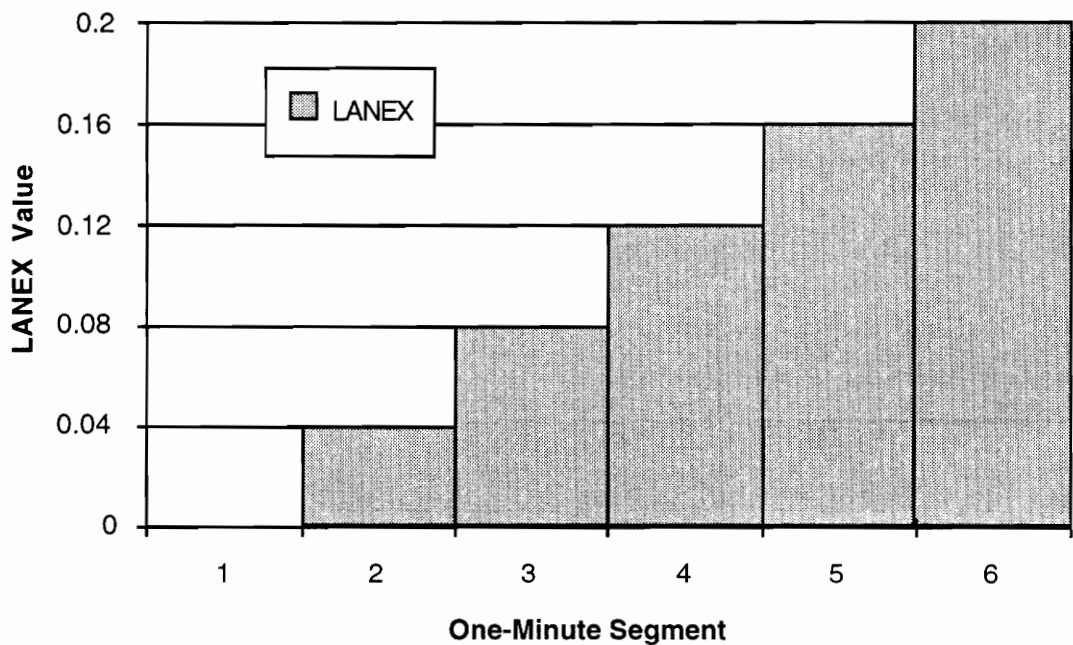


**Figure 8.4. Trend Model of LANEX During Linearly Increasing Level of Drowsiness**

Estimated-LANEX (eLANEX) Single Threshold Level

Just as in the process used to select an appropriate ePERCLOS threshold, the eLANEX single threshold level was selected by determining the value corresponding to the LANEX threshold where classification errors were minimized. Several eLANEX threshold values were selected and used to produce classification matrices when applied to Case 3 eLANEX algorithms LDV-1 and LDV-4. These algorithms were described in Chapter 7 (see Figures 7.2 and 7.3). Values for percent missed detections, percent false alarms, and total percent wrong were calculated based on classification matrices. Figure 7.1 graphically illustrates the threshold values which were used. The average values for each of the three inaccuracy percentages from these two algorithms are graphically depicted in Figure 8.5. Based on the reasoning explained for ePERCLOS, balanced minimum values of percent missed and percent false alarms are sought at the point of approximately the lowest “percent wrong” value. These criteria are met using the eLANEX threshold level of 0.12. Accordingly, a single eLANEX threshold level of 0.12 is recommended.

It should be noted that it is probable that drivers on the road will deviate from the lane less than drivers in the simulator, and full scale tests may be necessary to determine whether this threshold level will prove too conservative on-line.

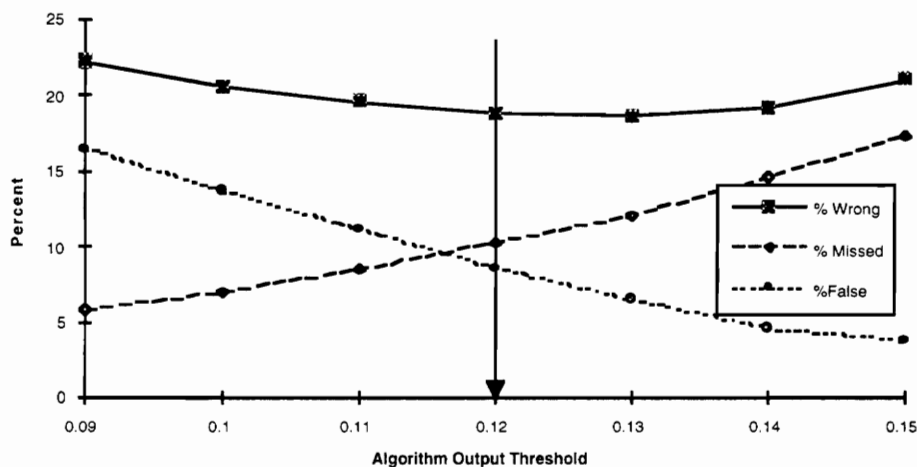


Figure 8.5. Total Error, False Alarm, and Missed Detection Percentages as a Function of eLANEX Algorithm Output Threshold (LANEX Threshold at 0.100).

# THE INTEGRATION OF SIMULTANEOUS DRIVER PERFORMANCE AND DRIVER STATUS MONITORING

## Introduction

This section reports on examination of the hypothesis that the monitoring of both “driver performance” and “driver status” in a driver-drowsiness detection system is an advantage. LANEX is believed to be a good indicator of driver performance, and PERCLOS of driver status (that is drowsiness). Additionally, algorithms have been developed which allow the estimation of these measures. Using “or” logic the two approaches can be combined in an effort to reduce overall error rates. To test this hypothesis, all possible cases must be considered. Since PERCLOS is assumed not to be available and lane information is available only part of the time, it is necessary to depend on ePERCLOS and eLANEX as previously discussed. Consequently, it is necessary to examine the success of the “or” system under three different conditions:

1. LANEX -or- ePERCLOS vs. LANEX -or- PERCLOS
2. eLANEX -or- ePERCLOS vs. LANEX -or- PERCLOS
3. average(LANEX/eLANEX) -or- ePERCLOS vs. LANEX -or- PERCLOS

Here, "or" is defined according to mathematical convention. Specifically, if one or both of the conditions are true (positive detections), then the 'or statement' is true. Otherwise, the 'or statement' is false (no detection) if and only if both conditions are false.

## Lane Information Always Available

When lane information is available, the system would use LANEX-or-ePERCLOS criteria to monitor driver performance and status. In this case, with the availability of lane information, the ePERCLOS algorithm F4a-N is used with observed LANEX. The ePERCLOS algorithm uses lane, steering, and lateral acceleration measures, and produces highly accurate results as shown in Table 8.1.

Table 8.1. Classification Accuracy: ePERCLOS (Alg F4a-N)-or-LANEX v. PERCLOS-or-LANEX.

| LANEX or ePERCLOS (F4a-N) | LANEX or PERCLOS |                  |
|---------------------------|------------------|------------------|
|                           | detection (+)    | no detection (-) |
| detection (+)             | 285              | 1                |
| no detection (-)          | 4                | 322              |

|                     |       |
|---------------------|-------|
| Percent Wrong:      | 0.82% |
| % Missed Detection: | 0.65% |
| % False Alarms:     | 0.16% |

---

Lane Information Never Available

When no lane information is available, the system may use eLANEX-or-ePERCLOS logic to monitor for driver performance and status. In this case the ePERCLOS algorithm D4a-N is used with the eLANEX algorithm LDV-1. Both algorithms use steering and lateral acceleration measures. The system’s ability to monitor status and performance in the absence of lane information is presented in Table 8.2. These results, which contain a total of 21% incorrect classifications, are considered to be unacceptable. From this it is reasonable to conclude that driver performance monitoring is not feasible if lane information is totally unavailable (for six minutes).

Table 8.2. Classification Accuracy: ePERCLOS (D4a-N) -or- eLANEX (LDV-1) v. PERCLOS-or-LANEX

| eLANEX (LDV1) or ePERCLOS (D4a-N) | LANEX or PERCLOS |                  |
|-----------------------------------|------------------|------------------|
|                                   | detection (+)    | no detection (-) |
| detection (+)                     | 214              | 58               |
| no detection (-)                  | 75               | 265              |

|                     |        |
|---------------------|--------|
| Percent Wrong:      | 21.73% |
| % Missed Detection: | 12.25% |
| % False Alarms:     | 9.48%  |

---

Results thus far indicate that the use of an “or” condition representing both driver performance and status is a successful method for the detection of drowsiness when lane information is available, and that driver status (drowsiness) monitoring is a successful method in no-lane information conditions. Implementation of an on-the-road system during normal driving will involve frequent transitions in and out of lane information conditions. It is desirable to monitor both status and performance in as many segments as possible. As a result, the transition segments (those which contain partial lane information) must be closely examined to determine the combinations of lane/no lane that can successfully monitor both status and performance. The appropriate algorithms and threshold levels must be determined for each type of transition six-minute interval .

#### Transitional Interval- Lane Information Sometimes Available

By definition, it is possible for transitional six-minute intervals to include 0, 1, 2, 3, 4, 5, or 6 minute segments which contain lane information. A reasonable transitional segment system using D4a and F4a together can be described as follows: D4a is applied to each one-minute segment without lane information, F4a is applied to each segment with lane information, and the appropriate six-minute average value is calculated. In order to estimate the accuracy of such a system, a linear interpolation between both ends was performed. Table 8.3 demonstrates the accuracy results (in terms of percent wrong, missed detections, and false alarms) that could be expected with a such a system. Table 8.4 summarizes these results.

As less lane information is available, and the system becomes more dependent on e-LANEX, the accuracy rate decreases in a system that is measuring both performance and status. Specifically, the accuracy rates which result from a segment containing less than three minutes of lane information can be considered unacceptable when assessed using both performance and status criteria. For example, the six-minute interval which includes only 2 segments with lane information is estimated to provide 8.5% missed detection rate and 6.21% false alarm rate. As a result, six minute intervals with less than three minutes of

Table 8.3. Linear Interpolation of Expected Classification Matrix Values For Transition Segments.

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 0 <i>LANEX</i> + 6 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 214              | 58               |
| no detection (-)                                                                     | 75               | 265              |
| <b>Resulting in: 21.7% Wrong, 12.3% Missed Detection, 9.5% False Alarm</b>           |                  |                  |

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 1 <i>LANEX</i> + 5 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 226              | 48               |
| no detection (-)                                                                     | 64               | 274              |
| <b>Resulting in: 18.3% Wrong, 10.5% Missed Detection, 7.8% False Alarm</b>           |                  |                  |

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 2 <i>LANEX</i> + 4 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 238              | 38               |
| no detection (-)                                                                     | 52               | 283              |
| <b>Resulting in: 14.7% Wrong, 8.5% Missed Detection, 6.2% False Alarm</b>            |                  |                  |

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 3 <i>LANEX</i> + 3 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 250              | 28               |
| no detection (-)                                                                     | 40               | 292              |
| <b>Resulting in: 11.1% Wrong, 6.5% Missed Detection, 4.6% False Alarm</b>            |                  |                  |

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 4 <i>LANEX</i> + 2 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 262              | 19               |
| no detection (-)                                                                     | 28               | 302              |
| <b>Resulting in: 7.7% Wrong, 4.6% Missed Detection, 3.1% False Alarm</b>             |                  |                  |

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 5 <i>LANEX</i> + 1 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 274              | 10               |
| no detection (-)                                                                     | 16               | 312              |
| <b>Resulting in: 4.3% Wrong, 2.6% Missed Detection, 1.6% False Alarm</b>             |                  |                  |

| esLANEX or ePERCLOS (F4a-N)<br>( <i>esLANEX</i> = 6 <i>LANEX</i> + 0 <i>eLANEX</i> ) | LANEX or PERCLOS |                  |
|--------------------------------------------------------------------------------------|------------------|------------------|
|                                                                                      | detection (+)    | no detection (-) |
| detection (+)                                                                        | 285              | 1                |
| no detection (-)                                                                     | 4                | 322              |
| <b>Resulting in: 0.8% Wrong, 0.7% Missed Detection, 0.2% False Alarm</b>             |                  |                  |

Table 8.4. Summary of transitional interval accuracy rates.

| <u>Interval Composition</u> | <u>Percent Wrong</u> |              |
|-----------------------------|----------------------|--------------|
| 6 LANEX -- 0 eLANEX         | 0.82                 | acceptable   |
| 5 LANEX -- 1 eLANEX         | 4.25                 | acceptable   |
| 4 LANEX -- 2 eLANEX         | 7.68                 | acceptable   |
| 3 LANEX -- 3 eLANEX         | 11.11                | acceptable   |
| 2 LANEX -- 4 eLANEX         | 14.71                | unacceptable |
| 1 LANEX -- 5 eLANEX         | 18.30                | unacceptable |
| 0 LANEX -- 6 eLANEX         | 21.73                | unacceptable |

lane data probably should not be used to monitor driver performance. It has been shown, however, that driver status can be accurately estimated when lane information is not available (see Appendix B). Thus it is recommended that such intervals be used for driver status monitoring only.

Operationally, this means that when lane information is absent for more than three one-minute segments, driver drowsiness level will be determined based only on ePERCLOS values. In view of these results, it is clear that driver performance cannot be accurately monitored when fewer than half of the segments within a six minute interval contain lane information. The optimum obtainable system, then, will include lane estimation only when there are 3, 4, 5, or 6 minutes of lane information available in the six-minute segment. The system will revert to a status-only monitoring mode when there are more than three minutes of lane information missing. Under conditions with sufficient lane information, this system would use an esLANEX-or-ePERCLOS criteria to monitor for driver performance and status. Here esLANEX (for estimated special LANEX) is an average of the eLANEX and LANEX data within a six-minute interval.

### Transitional Interval Thresholds

The corresponding thresholds for each combination is determined by linear interpolation between the two end point threshold values which have been previously determined. These results are presented in Table 8.5. Since intervals missing more than three segments with lane data will not involve eLANEX information, these thresholds are based only on ePERCLOS information (threshold 0.14). The threshold values in parentheses are values which would have been used if eLANEX data had continued to be included. These data are included only for the purpose of illustrating the interpolation.

Table 8.5. Explanation of Transitional Interval Threshold Levels.

| <u>Segment Breakdown</u>                      | <u>Calculation</u>           | <u>Weighted Threshold</u> |                          |
|-----------------------------------------------|------------------------------|---------------------------|--------------------------|
| 6 -- LANEX<br>0 -- e-LANEX                    | $6(0.10)/6$<br>$+ 0(0.12)/6$ | =                         | 0.1000                   |
| 5 -- LANEX<br>1 -- e-LANEX                    | $5(0.10)/6$<br>$+ 1(0.12)/6$ | =                         | 0.1033                   |
| 4 -- LANEX<br>2 -- e-LANEX                    | $4(0.10)/6$<br>$+ 2(0.12)/6$ | =                         | 0.1067                   |
| 3 -- LANEX<br>3 -- e-LANEX                    | $3(0.10)/6$<br>$+ 3(0.12)/6$ | =                         | 0.1100                   |
| 2 -- LANEX<br>4 -- e-LANEX                    | $2(0.10)/6$<br>$+ 4(0.12)/6$ | =                         | 0.1133 (Not Recommended) |
| 1 -- LANEX<br>5 -- e-LANEX                    | $1(0.10)/6$<br>$+ 5(0.12)/6$ | =                         | 0.1167 (Not Recommended) |
| 0 -- LANEX<br>6 -- e-LANEX                    | $0(0.10)/6$<br>$+ 6(0.12)/6$ | =                         | 0.1200 (Not Recommended) |
| <u>Note:</u>                                  |                              |                           |                          |
| Recommended threshold value for LANEX: 0.10   |                              |                           |                          |
| Recommended threshold value for e-LANEX: 0.12 |                              |                           |                          |

**SUMMARY**

## SYSTEM RECOMMENDATIONS

Because of the variety of studies performed in this thesis, it is helpful to summarize the results that have been obtained. These are provided here in concise statements of recommendation.

- *Predictive Algorithms may be used without decrement to accuracy.* Algorithms were developed which utilize current independent measures to predict future dependent measures of driver status. These algorithms were found to experience no appreciable loss in accuracy for up to four minutes advance data, and may be used if time to alarm is found to be too late.
- *Unbaselined algorithms should be used to process unbaselined data on-line.* Algorithms were developed using unbaselined data, and the accuracy rates were compared to those of previously developed baselined algorithms. The unbasedlined algorithms produced no appreciable decrement in accuracy. Therefore, they are recommended because they are more straightforward and thus are easier to use in on-line implementation.
- *The lane measure LANEX should be integrated into the system to add a driver performance monitoring component.* In accordance with the overall project goal of developing a “driver status and performance monitoring system,” LANEX-estimating algorithms have been developed and validated. These algorithms, when combined with existing lane-measuring technology, allow the integration of a driver-performance monitoring component into the driver-monitoring system.
- *The PERCLOS threshold level should be set at 0.125.* A trend model of an ideal six minute progression in level of drowsiness was used to determine the most appropriate six minute interval threshold value (0.125).
- *The ePERCLOS threshold level should be set at 0.14.* Several ePERCLOS single-threshold levels were compared, and the one that corresponds to the PERCLOS threshold level of 0.125 at the point that errors are minimized was determined to be 0.14.
- *The LANEX threshold level should be set at 0.10.* A trend model of an ideal six minute progression in level of drowsiness was used to determine the most appropriate six minute interval threshold value (0.10).

- *The eLANEX threshold level should be set at 0.12.* Several eLANEX single-threshold levels were compared, and the one which corresponds to the LANEX threshold level of 0.10 at the point that errors are minimized was determined to be 0.12.
- *Driver status and driver performance should be monitored together using “or” logic.* Generally speaking, the system should monitor for driver deterioration by signaling a decrement in “driver status -OR- driver performance.”
- *Six minute intervals with less than three minutes of lane data should not be used to monitor driver performance. Under such conditions driver status (drowsiness) only should be monitored.* It was determined that six-minute intervals with less than three minutes of available lane data produce poor estimates of driver performance. As a result it is recommended that such intervals be used for driver status monitoring only.
- *Transition interval thresholds should be set according to the specific availability of lane information.* The threshold for each type of transition interval was determined by linear interpolation between each known endpoint threshold value. Endpoints are defined as six minute intervals containing either all lane information or no lane information.

## REFERENCES

- Cross, R. (1995). The Digital Truck: Do Users Need What NHTSA Wants? Commercial Carrier Journal, 152, 56-62.
- Dingus, T.A., Hardee, H.L., and Wierwille, W.W. (1987). Development of Models for On-Board Detection of Driver Impairment. Accident Analysis and Prevention, 19, 271-283.
- Ellsworth, L.A. (1993). Experimental evaluation of subjective ratings of drowsiness and development of drowsiness definitions. Unpublished Masters Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.
- Ellsworth, L.A., Wreggit, S.S., and Wierwille, W.W. (1993). Research on vehicle-based driver status/performance monitoring. (DTNH 22-91-Y-07266) Third Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 93-02, April.
- Fahey, S.E. (1995). Advisory and Alarm Stimuli Optimization for a Drowsy Driver Detection System. Unpublished Masters Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.
- Faidy, J.P., Mevel, Y., Sairry, P., Cointot, B., and Coblenz, A. (1992). The Detection of Alertness Level Drop at the Wheel: Study of New Behavioural Parameters and Associated Sensors. Safety, the Vehicle, and the Road, 2, 31-37.
- Fairbanks, R.J. and Wierwille, W.W. (1994). Effects of using higher-order algorithms on drowsy driver detection accuracy. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Supplemental Research Report, October.
- Fairbanks, R.J. and Wierwille, W.W. (1995). Refinement of algorithms for on-line detection of driver drowsiness. In Proceedings of the Third Annual Mid-Atlantic

- Human Factors Conference, (pp. 55-61). Blacksburg, VA: Human Factors and Ergonomics Society.
- Fairbanks, R.J., Fahey, S.E., and Wierwille, W.W. (1995). Research on Vehicle-Based Driver Status/Performance Monitoring (DTNH 22-91-Y-07266). Seventh Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 95-06, December.
- Gescheider, G.A. (1985). Psychophysics: Method, Theory, and Application, Second Edition. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc.
- Kirn, C.L., Wreggit, S.S., and Wierwille, W.W. (1994). Research on vehicle-based driver status/performance monitoring. (DTNH 22-91-Y-07266) Sixth Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 94-02, October.
- Knipling, R.R., and Wang, J.S. (1994). Crashes and fatalities related to driver drowsiness/fatigue, NHTSA Research Note, November.
- Knipling, R.R., and Wierwille, W.W. (1994). Vehicle-Based Drowsy Driver Detection: Current Status and Future Prospects. In Proceedings of the IVHS America 1994 Annual Meeting. Atlanta, Georgia: IVHS America.
- Lewin, M.G., Fairbanks, R.J., and Wierwille, W.W. (1995). Effects of the Removal of Baseline Techniques on the Accuracy of Drowsy Driver Detection Algorithms. Unpublished Research Report, Vehicle Analysis and Simulation Laboratory, Industrial and Systems Engineering Department, Virginia Polytechnic Institute and State University, Blacksburg, VA.
- Montgomery, D.C., and Peck, E.A. (1992). Introduction to Linear Regression Analysis, Second Edition. New York: John Wiley and Sons, Inc.

- Office of Crash Avoidance Research (1991). Report No. 4: Drowsy/fatigued driver crashes. (IVHS/Crash Avoidance Countermeasure-Target Crash Problem Size Assessment and Statistical Description) Washington, D. C.: NHTSA, OCAR, September.
- Speaking Device Wakes Drowsy Driver (1981). World Highways, 32, p.12.
- Wierwille, W.W. and Ellsworth, L.E. (1992). Research on vehicle-based driver status/performance monitoring. (DTNH 22-91-Y-07266) Second Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 92-05, October.
- Wierwille, W.W., Wreggit, S.S., and Mitchell, M.W. (1992). Research on vehicle-based driver status/performance monitoring. (DTNH 22-91-Y-07266) First Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 92-01, April.
- Wierwille, W.W., Wreggit, S.S., Kirn, C.L., Ellsworth, L.E., and Fairbanks, R.J. (1994). Research on Vehicle-Based Driver Status/Performance Monitoring: Three Year Report. (ISE Department Report Number 94-04). Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, Virginia (December).
- Wreggit, S.S. (1994). The Development and Validation of Algorithms for the Detection of Driver Drowsiness. Unpublished PhD Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.
- Wreggit, S.S. and Wierwille, W.W. (1994). An investigation of false alarm rates when applying detection algorithms to alert-driver segments. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Supplemental Research Report, August.

- Wreggit, S.S., Kirn, C.L., and Wierwille, W. W. (1993). Research on vehicle-based driver status/performance monitoring (DTNH 22-91-Y-07266). Fourth Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 93-06, October.
- Wreggit, S.S., Kirn, C.L., and Wierwille, W. W. (1994). Research on vehicle-based driver status/performance monitoring. (DTNH 22-91-Y-07266) Fifth Semiannual Research Report. Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. 94-01, April.
- Yoss, R.E. (1969). A Test To Measure Ability To Maintain Alertness and Its Application In Assessing the Automobile Driver. American Association for Auto Medicine, Journal of Papers, 269-292.

## **APPENDIX A**

### **SUMMARIES OF THE MULTIPLE REGRESSION ANALYSES FOR HIGHER ORDER ALGORITHMS STUDY**

Table A.1. Multiple Regression Summary for Algorithm 1-LIN.

**1-LIN**

**Regression Summary for Dependent Variable: PERCLOS**

R= 0.77914669 R<sup>2</sup>= 0.60706956 Adjusted R<sup>2</sup>= 0.60174169  
F(4,295)=113.94 p<0.0000 Std.Error of estimate: 0.06179

|          | BETA   | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(295) | p-level |
|----------|--------|---------------------|----------|------------------|--------|---------|
| Intercpt |        |                     | 0.01411  | 0.005            | 2.915  | 0.004   |
| LGREV    | 0.357  | 0.050               | 0.03620  | 0.005            | 7.129  | 0.000   |
| STEXED   | 0.155  | 0.042               | 79.16572 | 21.584           | 3.668  | 0.000   |
| NMRHOLD  | -0.452 | 0.054               | -0.00780 | 0.001            | -8.357 | 0.000   |
| THRSHLD  | 0.501  | 0.046               | 0.46275  | 0.043            | 10.874 | 0.000   |

Table A.2. Multiple Regression Summary for Algorithm 1-LINCROSS.

### 1-LINCROSS

#### Regression Summary for Dependent Variable: PERCLOS \*

R= 0.83499484 R<sup>2</sup>= 0.69721639 Adjusted R<sup>2</sup>= 0.68673945  
 F(10,289)=66.548 p<0.0000 Std.Error of estimate: 0.05480

|           | BETA   | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(289) | p-level |
|-----------|--------|---------------------|----------|------------------|--------|---------|
| Intercept |        |                     | -0.00107 | 0.005            | -0.203 | 0.839   |
| STVELV    | 0.757  | 0.116               | 0.00247  | 0.000            | 6.535  | 0.000   |
| LGREV     | 0.301  | 0.091               | 0.03054  | 0.009            | 3.293  | 0.001   |
| THRSHLD   | 0.310  | 0.043               | 0.28632  | 0.040            | 7.156  | 0.000   |
| AxB       | -0.527 | 0.132               | -0.00058 | 0.000            | -3.993 | 0.000   |
| AxC       | -0.390 | 0.103               | -0.00011 | 0.000            | -3.791 | 0.000   |
| AxE       | -0.508 | 0.150               | -2.29879 | 0.679            | -3.385 | 0.001   |
| BxE       | 0.533  | 0.140               | 99.96978 | 26.296           | 3.802  | 0.000   |
| AxF       | -0.541 | 0.073               | -0.00019 | 0.000            | -7.370 | 0.000   |
| DxG       | -0.285 | 0.062               | -0.01107 | 0.002            | -4.571 | 0.000   |
| FxG       | -0.328 | 0.058               | -0.04636 | 0.008            | -5.669 | 0.000   |

---

\* Measures designated by a capital letter are defined in Table 3.1, Variable Group 1.

Table A.3. Multiple Regression Summary for Algorithm 1-FULL.

**1-FULL**

**Regression Summary for Dependent Variable: PERCLOS \***

R= 0.86052156 R<sup>2</sup>= 0.74049735 Adjusted R<sup>2</sup>= 0.72679123

F(15,284)=54.027 p<0.0000 Std.Error of estimate: 0.05118

|           | BETA   | St. Err.<br>of BETA | B          | St. Err.<br>of B | t(284) | p-level |
|-----------|--------|---------------------|------------|------------------|--------|---------|
| Intercpt  |        |                     | 0.00091    | 0.006            | 0.158  | 0.875   |
| STVELV    | 1.141  | 0.152               | 0.00373    | 0.000            | 7.512  | 0.000   |
| MDREV     | -0.240 | 0.068               | -0.00548   | 0.002            | -3.513 | 0.001   |
| SMREV     | -0.435 | 0.090               | -0.00322   | 0.001            | -4.812 | 0.000   |
| STEXED    | -0.386 | 0.117               | -196.48261 | 59.592           | -3.297 | 0.001   |
| NMRHOLD   | -0.299 | 0.107               | -0.00516   | 0.002            | -2.796 | 0.006   |
| AxD       | 0.277  | 0.088               | 0.00006    | 0.000            | 3.166  | 0.002   |
| BxE       | 0.493  | 0.120               | 92.44439   | 22.431           | 4.121  | 0.000   |
| CxF       | 0.236  | 0.090               | 0.00061    | 0.000            | 2.607  | 0.010   |
| CxG       | 0.162  | 0.078               | 0.02384    | 0.012            | 2.070  | 0.039   |
| DxG       | -1.068 | 0.171               | -0.04143   | 0.007            | -6.240 | 0.000   |
| ExG       | 0.106  | 0.050               | 444.52088  | 211.382          | 2.103  | 0.036   |
| FxG       | -0.374 | 0.088               | -0.05290   | 0.012            | -4.274 | 0.000   |
| A-SQUARED | -0.569 | 0.117               | -0.00002   | 0.000            | -4.851 | 0.000   |
| D-SQUARED | -0.970 | 0.222               | -0.00025   | 0.000            | -4.380 | 0.000   |
| F-SQUARED | 0.348  | 0.055               | 0.00094    | 0.000            | 6.294  | 0.000   |

\* Measures designated by a capital letter are defined in Table 3.1, Variable Group I.

Table A.4. Multiple Regression Summary for Algorithm 2-LIN.

## 2-LIN

### Regression Summary for Dependent Variable: PERCLOS

R= 0.87159526 R<sup>2</sup>= 0.75967830 Adjusted R<sup>2</sup>= 0.75475703

F(6,293)=154.37 p<0.0000 Std.Error of estimate: 0.04849

|          | BETA   | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(293) | p-level |
|----------|--------|---------------------|----------|------------------|--------|---------|
| Intercpt |        |                     | -0.00281 | 0.004            | -0.694 | 0.488   |
| INTACDE  | -0.109 | 0.030               | -0.06886 | 0.019            | -3.603 | 0.000   |
| LANDEV   | 0.873  | 0.063               | 0.06572  | 0.005            | 13.798 | 0.000   |
| LNERRSQ  | -0.258 | 0.054               | -0.00198 | 0.000            | -4.820 | 0.000   |
| STEXED   | 0.090  | 0.033               | 45.73972 | 16.819           | 2.720  | 0.007   |
| NMRHOLD  | -0.204 | 0.045               | -0.00353 | 0.001            | -4.494 | 0.000   |
| THRSHLD  | 0.250  | 0.041               | 0.23112  | 0.038            | 6.098  | 0.000   |

Table A.5. Multiple Regression Summary for Algorithm 2-LINCROSS.

**2-LINCROSS**

**Regression Summary for Dependent Variable: PERCLOS \***

R= 0.90426529 R<sup>2</sup>= 0.81769571 Adjusted R<sup>2</sup>= 0.81073270

F(11,288)=117.43 p<0.0000 Std.Error of estimate: 0.04260

|          | BETA   | St. Err.<br>of BETA | B          | St. Err.<br>of B | t(288) | p-level |
|----------|--------|---------------------|------------|------------------|--------|---------|
| Intercpt |        |                     | 0.00326    | 0.004            | 0.886  | 0.376   |
| LANDEV   | 0.536  | 0.079               | 0.04035    | 0.006            | 6.783  | 0.000   |
| STEXED   | -0.247 | 0.098               | -126.02238 | 49.857           | -2.528 | 0.012   |
| ExF      | -0.231 | 0.059               | -0.09446   | 0.024            | -3.943 | 0.000   |
| ExG      | 0.217  | 0.095               | 0.01101    | 0.005            | 2.285  | 0.023   |
| FxG      | 0.984  | 0.165               | 0.00105    | 0.000            | 5.973  | 0.000   |
| FxA      | 0.571  | 0.122               | 0.01541    | 0.003            | 4.684  | 0.000   |
| GxA      | -1.356 | 0.157               | -0.00441   | 0.001            | -8.651 | 0.000   |
| AxB      | 0.360  | 0.100               | 67.62873   | 18.763           | 3.604  | 0.000   |
| FxC      | -0.401 | 0.065               | -0.00309   | 0.000            | -6.201 | 0.000   |
| FxD      | 0.548  | 0.070               | 0.27534    | 0.035            | 7.818  | 0.000   |
| GxD      | -0.667 | 0.128               | -0.03773   | 0.007            | -5.205 | 0.000   |

---

\* Measures designated by a capital letter are defined in Table 3.1, Variable Group 2.

Table A.6. Multiple Regression Summary for Algorithm 2-FULL.

**2-FULL****Regression Summary for Dependent Variable: PERCLOS \***R= 0.91159428 R<sup>2</sup>= 0.83100413 Adjusted R<sup>2</sup>= 0.82207829

F(15,284)=93.101 p&lt;0.0000 Std.Error of estimate: 0.04130

|           | BETA   | St. Err.<br>of BETA | B          | St. Err.<br>of B | t(284)  | p-level |
|-----------|--------|---------------------|------------|------------------|---------|---------|
| Intercept |        |                     | 0.00206    | 0.004            | 0.540   | 0.590   |
| LANDEV    | 0.511  | 0.083               | 0.03845    | 0.006            | 6.148   | 0.000   |
| STEXED    | -0.296 | 0.094               | -150.85378 | 47.712           | -3.162  | 0.002   |
| THRSHLD   | 0.198  | 0.031               | 0.18299    | 0.029            | 6.394   | 0.000   |
| ExF       | -0.191 | 0.052               | -0.07826   | 0.021            | -3.677  | 0.000   |
| ExG       | 0.187  | 0.082               | 0.00949    | 0.004            | 2.286   | 0.023   |
| GxA       | -1.207 | 0.120               | -0.00393   | 0.000            | -10.031 | 0.000   |
| GxB       | -0.182 | 0.074               | -2.38802   | 0.965            | -2.474  | 0.014   |
| AxB       | 0.482  | 0.099               | 90.51148   | 18.491           | 4.895   | 0.000   |
| GxC       | -0.496 | 0.103               | -0.00042   | 0.000            | -4.826  | 0.000   |
| GxD       | -0.310 | 0.082               | -0.01752   | 0.005            | -3.780  | 0.000   |
| BxD       | 0.101  | 0.034               | 423.19271  | 141.994          | 2.980   | 0.003   |
| CxD       | -0.221 | 0.045               | -0.03122   | 0.006            | -4.958  | 0.000   |
| F-SQUARED | 1.052  | 0.175               | 0.01361    | 0.002            | 6.016   | 0.000   |
| A-SQUARED | 0.209  | 0.052               | 0.00667    | 0.002            | 4.035   | 0.000   |
| D-SQUARED | 0.187  | 0.043               | 0.93904    | 0.217            | 4.336   | 0.000   |

---

\* Measures designated by a capital letter are defined in Table 3.1, Variable Group 2.

Table A.7. Multiple Regression Summary for Algorithm 3-LIN.

### 3-LIN

#### Regression Summary for Dependent Variable: PERCLOS

R= 0.87159526 R<sup>2</sup>= 0.75967830 Adjusted R<sup>2</sup>= 0.75475703

F(6,293)=154.37 p<0.0000 Std.Error of estimate: 0.04849

|           | BETA   | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(293) | p-level |
|-----------|--------|---------------------|----------|------------------|--------|---------|
| Intercept |        |                     | -0.00281 | 0.004            | -0.694 | 0.488   |
| INTACDE   | -0.109 | 0.030               | -0.06886 | 0.019            | -3.603 | 0.000   |
| LANDEV    | 0.873  | 0.063               | 0.06572  | 0.005            | 13.798 | 0.000   |
| LNERRSQ   | -0.258 | 0.054               | -0.00198 | 0.000            | -4.820 | 0.000   |
| STEXED    | 0.090  | 0.033               | 45.73972 | 16.819           | 2.720  | 0.007   |
| NMRHOLD   | -0.204 | 0.045               | -0.00353 | 0.001            | -4.494 | 0.000   |
| THRSHLD   | 0.250  | 0.041               | 0.23112  | 0.038            | 6.098  | 0.000   |

Table A.8. Multiple Regression Summary for Algorithm 3-LINCROSS.

**3-LINCROSS****Regression Summary for Dependent Variable: PERCLOS \***R= 0.92546629 R<sup>2</sup>= 0.85648785 Adjusted R<sup>2</sup>= 0.84224216

F(27,272)=60.123 p&lt;0.0000 Std.Error of estimate: 0.03889

|          | BETA   | St. Err.<br>of BETA | B          | St. Err.<br>of B | t(272) | p-level |
|----------|--------|---------------------|------------|------------------|--------|---------|
| Intercpt |        |                     | -0.00386   | 0.004            | -0.946 | 0.345   |
| LANDEV   | 0.776  | 0.151               | 0.05846    | 0.011            | 5.131  | 0.000   |
| THRSHLD  | 0.125  | 0.041               | 0.11513    | 0.038            | 3.049  | 0.003   |
| LANEX    | -0.237 | 0.099               | -0.19012   | 0.080            | -2.388 | 0.018   |
| FxG      | -0.698 | 0.139               | -0.28528   | 0.057            | -5.006 | 0.000   |
| FxH      | 0.434  | 0.103               | 0.02203    | 0.005            | 4.210  | 0.000   |
| GxH      | 1.490  | 0.416               | 0.00158    | 0.000            | 3.582  | 0.000   |
| FxA      | 0.207  | 0.071               | 0.10187    | 0.035            | 2.910  | 0.004   |
| HxA      | -0.765 | 0.212               | -0.00249   | 0.001            | -3.601 | 0.000   |
| GxB      | 0.837  | 0.219               | 112.56708  | 29.491           | 3.817  | 0.000   |
| AxB      | 0.385  | 0.094               | 72.31762   | 17.721           | 4.081  | 0.000   |
| HxC      | -0.659 | 0.149               | -0.00056   | 0.000            | -4.432 | 0.000   |
| FxD      | -0.060 | 0.027               | -0.32221   | 0.144            | -2.238 | 0.026   |
| AxD      | 0.117  | 0.046               | 0.08361    | 0.033            | 2.536  | 0.012   |
| CxD      | -0.072 | 0.032               | -0.01015   | 0.004            | -2.271 | 0.024   |
| GxE      | 0.730  | 0.167               | 0.00727    | 0.002            | 4.381  | 0.000   |
| HxE      | -1.004 | 0.177               | -0.00124   | 0.000            | -5.689 | 0.000   |
| AxE      | -0.362 | 0.113               | -0.00363   | 0.001            | -3.202 | 0.002   |
| GxI      | -4.477 | 0.832               | -0.13989   | 0.026            | -5.382 | 0.000   |
| HxI      | 1.918  | 0.429               | 0.00426    | 0.001            | 4.473  | 0.000   |
| AxI      | 2.142  | 0.329               | 0.14546    | 0.022            | 6.507  | 0.000   |
| BxI      | -1.542 | 0.241               | -568.60697 | 88.916           | -6.395 | 0.000   |
| FxJ      | 0.157  | 0.069               | 0.67670    | 0.297            | 2.277  | 0.024   |
| GxJ      | 1.586  | 0.398               | 0.32308    | 0.081            | 3.986  | 0.000   |
| HxJ      | -0.963 | 0.334               | -0.02040   | 0.007            | -2.883 | 0.004   |
| AxJ      | -1.381 | 0.249               | -0.45887   | 0.083            | -5.537 | 0.000   |
| BxJ      | 0.438  | 0.138               | 813.19940  | 255.549          | 3.182  | 0.002   |
| IxJ      | 0.956  | 0.410               | 0.51437    | 0.221            | 2.329  | 0.021   |

\* Measures designated by a capital letter are defined in Table 3.1, Variable Group 3.

Table A.9. Multiple Regression Summary for Algorithm 3-FULL.

**3-FULL****Regression Summary for Dependent Variable: PERCLOS \***R= 0.92891166 R<sup>2</sup>= 0.86287687 Adjusted R<sup>2</sup>= 0.85036564

F(25,274)=68.968 p&lt;0.0000 Std.Error of estimate: 0.03787

|           | BETA   | St. Err.<br>of BETA | B          | St. Err.<br>of B | t(274) | p-level |
|-----------|--------|---------------------|------------|------------------|--------|---------|
| Intercept |        |                     | 0.00183    | 0.004            | 0.483  | 0.629   |
| LANDEV    | 0.596  | 0.111               | 0.04485    | 0.008            | 5.389  | 0.000   |
| THRSHLD   | 0.141  | 0.049               | 0.13005    | 0.045            | 2.865  | 0.004   |
| FxG       | -0.582 | 0.135               | -0.23780   | 0.055            | -4.310 | 0.000   |
| FxH       | 0.285  | 0.101               | 0.01448    | 0.005            | 2.827  | 0.005   |
| FxA       | 0.176  | 0.068               | 0.08672    | 0.033            | 2.589  | 0.010   |
| HxA       | -0.832 | 0.191               | -0.00271   | 0.001            | -4.363 | 0.000   |
| GxB       | 1.046  | 0.213               | 140.63330  | 28.613           | 4.915  | 0.000   |
| AxB       | 0.318  | 0.080               | 59.72029   | 14.952           | 3.994  | 0.000   |
| GxC       | -0.433 | 0.071               | -0.00334   | 0.001            | -6.138 | 0.000   |
| GxD       | 0.858  | 0.197               | 0.43094    | 0.099            | 4.361  | 0.000   |
| HxD       | -0.652 | 0.187               | -0.03686   | 0.011            | -3.483 | 0.001   |
| GxE       | 0.781  | 0.164               | 0.00777    | 0.002            | 4.752  | 0.000   |
| HxE       | -0.872 | 0.157               | -0.00107   | 0.000            | -5.568 | 0.000   |
| AxE       | -0.577 | 0.118               | -0.00579   | 0.001            | -4.871 | 0.000   |
| GxI       | -5.070 | 0.773               | -0.15843   | 0.024            | -6.562 | 0.000   |
| HxI       | 3.398  | 0.424               | 0.00754    | 0.001            | 8.005  | 0.000   |
| AxI       | 1.560  | 0.376               | 0.10593    | 0.026            | 4.153  | 0.000   |
| BxI       | -1.117 | 0.230               | -412.05888 | 84.882           | -4.854 | 0.000   |
| DxI       | -0.472 | 0.157               | -0.53002   | 0.176            | -3.004 | 0.003   |
| FxJ       | 0.136  | 0.067               | 0.58916    | 0.289            | 2.041  | 0.042   |
| GxJ       | 2.223  | 0.332               | 0.45287    | 0.068            | 6.701  | 0.000   |
| AxJ       | -1.315 | 0.233               | -0.43694   | 0.077            | -5.640 | 0.000   |
| IxJ       | 1.410  | 0.382               | 0.75881    | 0.206            | 3.691  | 0.000   |
| A-SQUARED | 0.392  | 0.185               | 0.01251    | 0.006            | 2.126  | 0.034   |
| J-SQUARED | -0.946 | 0.184               | -2.16518   | 0.422            | -5.132 | 0.000   |

---

\* Measures designated by a capital letter are defined in Table 3.1, Variable Group 3.

## **APPENDIX B**

### **EFFECTS OF THE REMOVAL OF BASELINING TECHNIQUES ON THE ACCURACY OF DROWSY DRIVER DETECTION ALGORITHMS**

Mark G. Lewin  
Rollin J. Fairbanks  
and  
Walter W. Wierwille

## Introduction

Development of a drowsy driver detection, alarm, and countermeasures system (DDACS) is dependent upon on-line, accurate measurement of the drowsiness level of a driver. In addition, it is desirable that the method of drowsiness measurement be unintrusive to the driver and have the ability to adapt to varying conditions. Recent research has led to the development of drowsy driver detection algorithms based on driver-vehicle performance measures. The algorithms are accurate, unintrusive estimators of definitional measures of drowsiness found in the literature and in previous research (Ellsworth, Wreggit, and Wierwille, 1993).

Wreggit, Kim, and Wierwille (1993) conducted a simulator study in which five dependent definitional measures were analyzed for estimation accuracy against thirty independent performance measures. Each data gathering session was 150 minutes in length. After the data gathering sessions were completed in that study, a data manipulation procedure was performed. Initially, all measures were computed over one-minute intervals. Then, the first two minutes of data for all measures were removed. This was done because it was thought that in the first two minutes of driving, some subjects demonstrated inconsistencies concerning their driving behavior, reactions, and physiological measures. For each measure, the next ten minutes of data (minutes 3 through 12) were then averaged to create baselines. The baselines were then subtracted from every subsequent one-minute average of data within each independent measure (minutes 3 through 150). After completion of the baselining procedure, the data were averaged across six-minute intervals to complete data manipulation. The first two intervals were five-minute averages to compensate for the earlier removal of the first two minutes of data. In all, 25 data intervals were created for each subject. Following data manipulation, multiple regression and discriminant analyses were performed on the collected data to determine the best predictors of drowsiness. Through these analyses, a number of detection algorithms were developed.

A subsequent simulator study (Kirn, Wreggit, and Wierwille, 1994) was conducted to validate the recently developed detection algorithms. Data were collected over data-gathering sessions of 156 minutes in length. These data were manipulated in a manner similar to that in the algorithm development experiment. Initially, all measures were computed over one-minute intervals. The first two minutes of data for all measures were removed. For each measure, the next ten minutes of data (minutes 3 through 12) were averaged to create baselines; however, these data were removed after baseline creation. The baselines were then subtracted from every subsequent one-minute average within each independent measure (minutes 13 through 156). After completion of the baselining procedure, the data were averaged across six-minute intervals to create a total of 24 data intervals. Following data manipulation, the previously developed algorithms were applied to the new data set. Correlation analyses between the algorithm outputs and the definitional measure (observed) values were performed, allowing a comparison between R values attained from the original data and the new data. Classification analyses were also performed for purposes of comparison.

Baselined regression techniques for drowsy driver detection algorithms were compared against non-baselined techniques by Ellsworth, Wreggit, and Wierwille (1993). Since pooled data make no distinction as to the subject number and do not account for individual differences in initial values for many measures, it was thought that baselining could improve the prediction of drowsiness. It was thought that baselining techniques could be easily accomplished on-line by a computer during an experimental run. The computer could simply calculate averages for all measures during the initial portion of the study and then subtract the average values from all subsequent values. Baselined techniques and non-baselined techniques were shown to produce nearly equal R-values. However, the baselined methods were shown to require an average of 5.0 independent variables to achieve the regression model, while the non-baselined methods required an average of 7.8 independent variables. It was concluded that baselined regression methods

are more efficient than non-baselined methods. When attempts to reduce the number of terms in regression models were made while retaining nearly the same values of R as full models, non-baselined data showed greater vulnerability. It was concluded that baselining is an advantageous procedure because it provides small improvements in the models. For this reason, baselined regression was used in the previously summarized algorithm development and validation experiments.

Baselining techniques can be easily implemented on-line if a single detection algorithm is used throughout an experimental session. However, it is desirable to be able to use “step-up, step-down” procedures. Such a system allows the DDDACS to switch algorithms and continue to function when all parameters are not available. In the planned DDDACS test and evaluation experiment, lane-related measures will be available during some intervals, but not others. Also, a secondary task, the A/O task (Wierwille et al., 1994), will be operating during some portions of the experiment, but not others. These two conditions will determine which detection algorithm is used for any one-minute interval in each experimental session. In all, a combination of four types of detection algorithms must be used. Of the baselined detection algorithms developed and validated by Wierwille et al. (1994), the following were chosen to fulfill these requirements. All are estimators of PERCLOS, the proportion of time a subject’s eyes are 80 to 100 percent closed. PERCLOS was shown to be one of the most reliable measures of drowsiness in previous studies (Wreggit, Kirn, and Wierwille, 1993). The four algorithms are briefly described here:

- Algorithm D4a: Includes only steering-related and lateral-accelerometer-related measures. This algorithm will be used during periods when the lane-related measures are not available and the A/O task is not being performed.
- Algorithm F4a: Includes steering, lateral-accelerometer, and lane-related measures. This algorithm will be used when lane-related measures are available and the A/O task is not being performed.

- Algorithm J4a: Includes steering, lateral-accelerometer, and A/O task-related measures. This algorithm will be used when lane-related measures are not available and the A/O task is being performed.
- Algorithm L3a: Includes steering, lateral-accelerometer, lane-related and A/O task-related measures. This algorithm will be used when lane-related measures are available and the A/O task is being used.

Summaries of regression and classification analyses for the above algorithms are shown in Figures B.1, B.2, B.3, and B.4.

In the planned experiment, availability of lane-related measures for algorithm computation will be determined on a recurring 30-minute cycle. Lane-related measures will be available for 25 of the one-minute intervals in each cycle. They will be unavailable for the remaining five minutes (minutes 4, 17, 18, 19, and 20). These intervals were chosen to simulate the level of performance that a lane-sensing device on an actual vehicle can achieve. Lane boundaries are often either absent or obscured in such a way that they cannot be detected. Difficulty arises in attempting to establish a baseline for lane-related measures when they are not always available. In order to baseline the lane-related measures in a manner compatible with the baselined detection algorithms, lane-related measures must be available for the first twelve minutes of driving. Lane-related measures will not be available for minute 4 in the planned test and evaluation experiment; therefore, calculation of baselines for these measures will be impossible due to incomplete data. In an actual vehicle, it cannot be guaranteed that lane-related measures will be available during the first twelve minutes of driving. Thus, baselining may become difficult or impossible in some situations.

In the test and evaluation experiment, the A/O task will be tested as a part of the DDDACS in six of the eighteen experimental sessions. It will become active as a

**Baselined Regression Summary for Dependent Variable: PERCLOS**

R = 0.78910   R2 = 0.62268   Adjusted R2 = 0.61626

F(5,294) = 97.038   p < 0.0000   Std. Error of estimate: 0.06065

|           | BETA   | St. Err.<br>of BETA | B         | St. Err.<br>of B | t(294) | p-level |
|-----------|--------|---------------------|-----------|------------------|--------|---------|
| Intercept |        |                     | 0.014132  | 0.005            | 2.974  | 0.003   |
| INTACDEV  | -0.134 | 0.038               | -0.084597 | 0.024            | -3.488 | 0.001   |
| LGREV     | 0.395  | 0.050               | 0.040055  | 0.005            | 7.845  | 0.000   |
| STEXED    | 0.146  | 0.042               | 74.427007 | 21.231           | 3.506  | 0.001   |
| NMRHOLD   | -0.427 | 0.054               | -0.007378 | 0.001            | -7.985 | 0.000   |
| THRSHLD   | 0.450  | 0.047               | 0.416209  | 0.044            | 9.491  | 0.000   |

|                      |              | Predicted |            |              |           |
|----------------------|--------------|-----------|------------|--------------|-----------|
| Original<br>Observed | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                      | Awake        | 88.29     | <b>181</b> | 22           | 2         |
|                      | Questionable | 43.18     | 11         | <b>19</b>    | 14        |
|                      | Drowsy       | 52.94     | 2          | 22           | <b>27</b> |
|                      | Total        | 75.67     | 194        | 63           | 43        |

PERCLOS (R Value = 0.789)

Apparent Accuracy Rate (large misclassifications): 0.987

Apparent Accuracy Rate (all misclassifications): 0.757

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm D4a**. (Independent variables employed included Steering and Accelerometer.)

|                 |              | Predicted |            |              |           |
|-----------------|--------------|-----------|------------|--------------|-----------|
| New<br>Observed | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                 | Awake        | 79.32     | <b>188</b> | 40           | 9         |
|                 | Questionable | 30.00     | 8          | <b>6</b>     | 6         |
|                 | Drowsy       | 90.32     | 1          | 2            | <b>28</b> |
|                 | Total        | 77.08     | 197        | 48           | 43        |

PERCLOS (R Value = 0.800)

Apparent Accuracy Rate (large misclassifications): 0.965

Apparent Accuracy Rate (all misclassifications): 0.771

**Algorithm D4a** Applied to New Data and Compared with New Observed **PERCLOS** Data

Figure B.1. Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm D4a When Applied to Original Data and New Data.

**Baselined Regression Summary for Dependent Variable: PERCLOS**

R = 0.87159526 R2 = 0.75967830 Adjusted R2 = 0.75475703

F(6,293) = 154.37 p < 0.0000 Std. Error of estimate: 0.04849

|           | BETA   | St. Err.<br>of BETA | B      | St. Err.<br>of B | t(293) | p-level |
|-----------|--------|---------------------|--------|------------------|--------|---------|
| Intercept |        |                     | -0.003 | 0.004053         | -0.694 | 0.488   |
| INTACDEV  | -0.109 | 0.030               | -0.069 | 0.019114         | -3.603 | 0.000   |
| LANDEV    | 0.873  | 0.063               | 0.066  | 0.004763         | 13.798 | 0.000   |
| LNERRSQ   | -0.258 | 0.054               | -0.002 | 0.000410         | -4.820 | 0.000   |
| STEXED    | 0.090  | 0.033               | 45.740 | 16.818827        | 2.720  | 0.007   |
| NMRHOLD   | -0.204 | 0.045               | -0.004 | 0.000785         | -4.494 | 0.000   |
| THRSHLD   | 0.250  | 0.041               | 0.231  | 0.037904         | 6.098  | 0.000   |

| Predicted            |              |           |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
| Original<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 89.76     | 184   | 18           | 3      |
|                      | Questionable | 47.73     | 7     | 21           | 16     |
|                      | Drowsy       | 62.75     | 3     | 16           | 32     |
|                      | Total        | 79.00     | 194   | 55           | 51     |

PERCLOS (R Value = 0.872)

Apparent Accuracy Rate (large misclassifications): 0.980

Apparent Accuracy Rate (all misclassifications): 0.790

Classification Matrix Generated From Multiple Regression Analysis of Original PERCLOS Data Resulting in Algorithm F4a. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

| Predicted       |              |           |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
| New<br>Observed | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 89.03     | 211   | 22           | 4      |
|                 | Questionable | 15.00     | 12    | 3            | 5      |
|                 | Drowsy       | 80.65     | 3     | 3            | 25     |
|                 | Total        | 82.99     | 226   | 28           | 34     |

PERCLOS (R Value = 0.862)

Apparent Accuracy Rate (large misclassifications): 0.976

Apparent Accuracy Rate (all misclassifications): 0.830

Algorithm F4a Applied to New Data and Compared with New Observed PERCLOS Data

Figure B.2. Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm F4a When Applied to Original Data and New Data.

**Baselined Regression Summary for Dependent Variable: PERCLOS**R = 0.83585799 R<sup>2</sup> = 0.69865857 Adjusted R<sup>2</sup> = 0.68262977

F(5,94) = 43.588 p &lt; 0.00000 Std. Error of estimate: 0.05044

|           | BETA   | St. Err.<br>of BETA | B         | St. Err.<br>of B | t(94)  | p-level |
|-----------|--------|---------------------|-----------|------------------|--------|---------|
| Intercept |        |                     | 0.002620  | 0.008            | 0.341  | 0.734   |
| ACCVAR    | -0.182 | 0.064               | -0.007485 | 0.003            | -2.843 | 0.005   |
| LGREV     | 0.302  | 0.093               | 0.031048  | 0.010            | 3.259  | 0.002   |
| AOTIME    | 1.234  | 0.211               | 0.087985  | 0.015            | 5.839  | 0.000   |
| NMWRONG   | -1.028 | 0.199               | -0.251580 | 0.049            | -5.173 | 0.000   |
| NMNR      | 0.313  | 0.092               | 0.140206  | 0.041            | 3.419  | 0.001   |

|                      |              | Predicted |           |              |          |
|----------------------|--------------|-----------|-----------|--------------|----------|
| Original<br>Observed | Group        | % Correct | Awake     | Questionable | Drowsy   |
|                      | Awake        | 94.29     | <b>66</b> | 3            | 1        |
|                      | Questionable | 43.75     | 2         | <b>7</b>     | 7        |
|                      | Drowsy       | 42.86     | 2         | 6            | <b>6</b> |
|                      | Total        | 79.00     | 70        | 16           | 14       |

PERCLOS (R Value = 0.836)

Apparent Accuracy Rate (large misclassifications): 0.970

Apparent Accuracy Rate (all misclassifications): 0.790

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm J4a**. (Independent variables employed included A/O Task, Steering, and Accelerometer.)

|                 |              | Predicted |            |              |          |
|-----------------|--------------|-----------|------------|--------------|----------|
| New<br>Observed | Group        | % Correct | Awake      | Questionable | Drowsy   |
|                 | Awake        | 93.33     | <b>112</b> | 6            | 2        |
|                 | Questionable | 27.27     | 6          | <b>3</b>     | 2        |
|                 | Drowsy       | 38.46     | 4          | 4            | <b>5</b> |
|                 | Total        | 83.33     | 122        | 13           | 9        |

PERCLOS (R Value = 0.599)

Apparent Accuracy Rate (large misclassifications): 0.958

Apparent Accuracy Rate (all misclassifications): 0.833

**Algorithm J4a** Applied to New Data and Compared with New Observed **PERCLOS** Data

Figure B.3. Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm J4a When Applied to Original Data and New Data.

**Baselined Regression Summary for Dependent Variable: PERCLOS**

R= 0.87487717 R2= 0.76541006 Adjusted R2 = 0.75027522  
F(6,93) = 50.573 p< 0.00000 Std. Error of estimate: 0.04474

|           | BETA   | St. Err.<br>of BETA | B         | St. Err.<br>of B | t(93)  | p-level |
|-----------|--------|---------------------|-----------|------------------|--------|---------|
| Intercept |        |                     | -0.004308 | 0.007            | -0.648 | 0.519   |
| LANVAR    | 0.924  | 0.246               | 0.009506  | 0.003            | 3.749  | 0.000   |
| LANEX     | 0.310  | 0.105               | 0.195697  | 0.066            | 2.964  | 0.004   |
| LNERRSQ   | -0.641 | 0.174               | -0.007871 | 0.002            | -3.683 | 0.000   |
| AOTIME    | 0.548  | 0.236               | 0.039067  | 0.017            | 2.326  | 0.022   |
| NMWRONG   | -0.591 | 0.197               | -0.144499 | 0.048            | -3.002 | 0.003   |
| NMNR      | 0.286  | 0.095               | 0.127975  | 0.042            | 3.014  | 0.003   |

| Original<br>Observed | Predicted    |           |           |              |          |
|----------------------|--------------|-----------|-----------|--------------|----------|
|                      | Group        | % Correct | Awake     | Questionable | Drowsy   |
|                      | Awake        | 94.29     | <b>66</b> | 3            | 1        |
|                      | Questionable | 62.50     | 2         | <b>10</b>    | 4        |
|                      | Drowsy       | 50.00     | 4         | 3            | <b>7</b> |
|                      | Total        | 83.00     | 72        | 16           | 12       |

PERCLOS (R value = 0.875)

Apparent Accuracy Rate (large misclassifications): 0.950  
Apparent Accuracy Rate (all misclassifications): 0.830

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm L3a**. (Independent variables employed included A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

| New<br>Observed | Predicted    |           |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
|                 | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 94.17     | 113   | 5            | 2      |
|                 | Questionable | 54.55     | 3     | 6            | 2      |
|                 | Drowsy       | 46.15     | 1     | 6            | 6      |
|                 | Total        | 86.81     | 117   | 17           | 10     |

PERCLOS (R Value = 0.796)

Apparent Accuracy Rate (large misclassifications): 0.979  
Apparent Accuracy Rate (all misclassifications): 0.868

**Algorithm L3a Applied to New Data and Compared with New Observed PERCLOS**

Figure B.4. Baselined Regression Summary and Classification Matrix Showing Accuracy of Algorithm L3a When Applied to New Data.

drowsiness countermeasure after any detection of drowsiness and remain active for twenty-four minutes after the reset button is pressed. If drowsiness is detected again within that twenty-four minute period, the A/O task will remain active for twenty-four minutes after the most recent activation of the reset button. Since drowsiness cannot be detected in the first twelve minutes of driving in a baselined system, the A/O task cannot be activated in the first twelve minutes. Therefore, it is impossible to collect any A/O task data with which a baseline can be calculated.

The on-line computational difficulties presented by baselining suggest that removal of baselining techniques from detection algorithm computation would be greatly desirable. However, only a minimal loss in predictive accuracy of the detection algorithms is acceptable. Prior research has shown that driver drowsiness detection algorithms gain some of efficiency, but only a small degree of accuracy when baselining techniques are used. As a result, new, non-baselined algorithms have been optimized and validated using the original data collected during the algorithm development and validation experiments. These algorithms were then compared directly with the baselined algorithms. In this manner, the loss in predictive accuracy for those algorithms that will be used in test and evaluation of the DDDACS was determined.

## Method

A revised data manipulation procedure was performed on the original data collected from the algorithm development experiment. The one-minute averages of data calculated previously were converted directly to six-minute averages. No data were either removed or averaged to create a baseline. It was thought that allowing the first two minutes of data for each subject to remain in the regression analysis would have a minimal effect on the outcome of the regression and discriminant analyses. Also, it would allow the DDDACS to become active immediately upon the commencement of driving. A total of 25 data

intervals, all of which represented six-minute averages, were created for each subject. Six-minute averages for all subjects were pooled, for a total of 300 data points.

Independent measures were selected and placed in the following groupings:

- Steering-related and lateral-accelerometer-related measures only.
- Steering, lateral-accelerometer, and lane-related measures.
- Steering, lateral-accelerometer, and A/O task-related measures.
- Steering, lateral-accelerometer, lane, and A/O task-related measures.

These groupings of measures are equivalent to those originally used to develop the baselined algorithms D4a, F4a, J4a, and L3a. The definitional measure PERCLOS was selected to be the dependent measure for all analyses. This allowed for reliable comparisons between the baselined algorithms and the non-baselined algorithms.

Backwards stepwise multiple regression and resubstitution were performed on each of the four groupings of the non-baselined data to find optimized combinations of variables that would best predict values of PERCLOS. Algorithms were produced using the B weights resulting from multiple regression as coefficients for the corresponding independent variables. Each algorithm was then applied to the six-minute averages of independent measures to predict average values of PERCLOS. In classification analysis, these predicted values were compared against the measured PERCLOS values. The same dual-threshold, three-tiered classification scheme used in the algorithm development study was used. Each measured and calculated value of PERCLOS was classified as “Awake”, “Questionable”, or “Drowsy” according to the following criteria:

| <u>Classification</u> | <u>PERCLOS Value</u>               |
|-----------------------|------------------------------------|
| Awake                 | $\text{PERCLOS} \leq 0.075$        |
| Questionable          | $0.075 < \text{PERCLOS} \leq 0.15$ |
| Drowsy                | $\text{PERCLOS} > 0.15$            |

Classifications were scored as correct classifications (“hits”), small misclassifications, or large misclassifications. If the predicted classification was one category away from the

observed classification, it was considered a small misclassification; if it was two categories away, it was considered a large misclassification. After classification, apparent accuracy rates (APARs) were calculated for large misclassifications and for all misclassifications. Regression R-values, classification matrices, and APAR values for the four new, non-baselined algorithms were compared with values previously obtained for the baselined algorithms.

The algorithms obtained using the development data were then applied to data collected during the validation experiment. The validation data were converted directly from one-minute averages to six-minute averages with no baselining or removal of data. A total of 26 data intervals were created for each subject. The data were pooled to create a total of 312 data points. The new algorithms were applied to the independent measures to estimate PERCLOS values for each six-minute period. Correlation analysis produced R values for comparison. Classification analysis was performed as with the development data to produce classification matrices and APAR values for comparison.

## Results

Summaries of regression and discriminant analyses for non-baselined drowsy driver detection algorithms D4a-N, F4a-N, J4a-N, and L3a-N are presented in Figures B.5, B.6, B.7, and B.8. The name of each algorithm denotes the starting set of independent measures used to optimize the algorithm. In this respect, each algorithm corresponds to one of the baselined algorithms summarized in Figures B.1, B.2, B.3, and B.4. The B weights shown in the regression summaries are used as coefficients in calculating algorithm values. Classification matrices are shown for both the development data set and the validation data set to allow for comparison. Direct comparisons for R values, APAR values for large misclassifications, and APAR values for all misclassifications between the baselined algorithms and the non-baselined algorithms are

presented in Figure B.9. The comparisons in Figure B.9 are made for both the development data set and the validation data set.

### Interpretation of Results

R values and APAR values in comparison of the results produced by the baselined and non-baselined algorithms suggest that, in general, the non-baselined algorithms are able to predict drowsiness almost as well as the baselined algorithms. The results show both minor losses and minor gains in R values and APAR values for both development data and validation data. In fact, the average of all gains and losses in R values and APAR values is a loss of 0.0004 between baselined algorithms and non-baselined algorithms. The efficiency of the non-baselined algorithms also compares favorably with that of the baselined algorithms, with the non-baselined algorithms requiring an average of 5.25 independent variables and the baselined algorithms requiring an average of 5.5 variables per algorithm.

The results suggest that baselining techniques generally increase the predictive accuracy of the drowsy driver detection algorithms. However, the increase is so small that it does not justify the increased computational complexity that would be required to implement baselining in a “step up, step down” algorithm system. The results also suggest that there is no difference in efficiency between the baselined algorithms and non-baselined algorithms. Based on these conclusions, non-baselined algorithms are clearly the best choice for use in a “step up, step down” detection system as in the planned test and evaluation experiment.

Previous attempts at refining the drowsy driver detection algorithms (Wierwille et al., 1994; Fairbanks, Fahey, and Wierwille, 1995) have suggested that increases in algorithm sophistication do not result in corresponding increases in algorithm accuracy. The results of this study suggest that the same trend holds for the increase in sophistication from a non-baselined algorithm to a baselined algorithm.

**Non-Baselined Regression Summary for Dependent Variable: PERCLOS**

R = 0.78785881 R<sup>2</sup> = 0.62072151 Adjusted R<sup>2</sup> = 0.61427120

F(5,294) = 96.231 p < 0.0000 Std. Error of estimate: 0.06098

|           | BETA      | St. Err.<br>of BETA | B        | St. Err.<br>of B | t(294)   | p-level  |
|-----------|-----------|---------------------|----------|------------------|----------|----------|
| Intercept |           |                     | 0.11788  | 0.02382          | 4.94994  | 0.000001 |
| INTACDEV  | -0.137132 | 0.038813            | -0.09201 | 0.02604          | -3.53315 | 0.000477 |
| LGREV     | 0.401964  | 0.048588            | 0.04060  | 0.00491          | 8.27288  | 0.000000 |
| STEXED    | 0.136825  | 0.041765            | 69.92649 | 21.34442         | 3.27610  | 0.001179 |
| NMRHOLD   | -0.292849 | 0.045575            | -0.00684 | 0.00107          | -6.42562 | 0.000000 |
| THRSHLD   | 0.458615  | 0.049091            | 0.44023  | 0.04712          | 9.34208  | 0.000000 |

|                      |              | Predicted |            |              |           |
|----------------------|--------------|-----------|------------|--------------|-----------|
| Original<br>Observed | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                      | Awake        | 86.27     | <b>176</b> | 25           | 3         |
|                      | Questionable | 50.00     | 11         | <b>23</b>    | 12        |
|                      | Drowsy       | 62.00     | 5          | 14           | <b>31</b> |
|                      | Total        | 76.67     | 192        | 62           | 46        |

PERCLOS (R value = 0.788)

Apparent Accuracy Rate (LARGE misclassifications): 0.973

Apparent Accuracy Rate (ALL misclassifications): 0.767

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm D4a-N**. (Independent variables employed included Steering and Accelerometer.)

|                 |              | Predicted |            |              |           |
|-----------------|--------------|-----------|------------|--------------|-----------|
| New<br>Observed | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                 | Awake        | 72.80     | <b>190</b> | 58           | 13        |
|                 | Questionable | 50.00     | 6          | <b>10</b>    | 4         |
|                 | Drowsy       | 83.87     | 1          | 4            | <b>26</b> |
|                 | Total        | 72.44     | 197        | 72           | 43        |

PERCLOS (R value = 0.769)

Apparent Accuracy Rate (LARGE misclassifications): 0.955

Apparent Accuracy Rate (ALL misclassifications): 0.724

**Algorithm D4a-N** Applied to New Data and Compared with New Observed **PERCLOS** Data

Figure B.5. Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm D4a-N When Applied to Original Data and New Data.

**Non-Baselined Regression Summary for Dependent Variable: PERCLOS**

R = 0.85702904 R2 = 0.73449877 Adjusted R2 = 0.72906189

F(6,293) = 135.10 p < 0.0000 Std. Error of estimate: 0.05111

|           | BETA      | St. Err. of BETA | B        | St. Err. of B | t(293)   | p-level  |
|-----------|-----------|------------------|----------|---------------|----------|----------|
| Intercept |           |                  | 0.06088  | 0.02027       | 3.00296  | 0.002904 |
| ACCVAR    | -0.167453 | 0.034934         | -0.00808 | 0.00169       | -4.79340 | 0.000003 |
| LANDEV    | 0.929554  | 0.076055         | 0.06550  | 0.00536       | 12.22208 | 0.000000 |
| LNERRSQ   | -0.225729 | 0.057392         | -0.00173 | 0.00044       | -3.93310 | 0.000105 |
| STEXED    | 0.082472  | 0.035086         | 42.14847 | 17.93123      | 2.35056  | 0.019408 |
| NMRHOLD   | -0.210594 | 0.038488         | -0.00492 | 0.00090       | -5.47166 | 0.000000 |
| THRSHLD   | 0.134577  | 0.050396         | 0.12918  | 0.04838       | 2.67042  | 0.007999 |

| Original<br>Observed | Predicted    |           |            |              |           |
|----------------------|--------------|-----------|------------|--------------|-----------|
|                      | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                      | Awake        | 93.63     | <b>191</b> | 10           | 3         |
|                      | Questionable | 43.48     | 12         | <b>20</b>    | 14        |
|                      | Drowsy       | 68.00     | 4          | 12           | <b>34</b> |
|                      | Total        | 81.67     | 207        | 42           | 51        |

PERCLOS (R value = 0.857)

Apparent Accuracy Rate (LARGE misclassifications): 0.977

Apparent Accuracy Rate (ALL misclassifications): 0.817

**Classification Matrix Generated From Multiple Regression Analysis of Original PERCLOS Data Resulting in Algorithm F4a-N.**

(Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

| New<br>Observed | Predicted    |           |            |              |           |
|-----------------|--------------|-----------|------------|--------------|-----------|
|                 | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                 | Awake        | 90.42     | <b>236</b> | 22           | 3         |
|                 | Questionable | 35.00     | 8          | <b>7</b>     | 5         |
|                 | Drowsy       | 70.97     | 2          | 7            | <b>22</b> |
|                 | Total        | 84.94     | 246        | 36           | 30        |

PERCLOS (R value = 0.871)

Apparent Accuracy Rate (LARGE misclassifications): 0.984

Apparent Accuracy Rate (ALL misclassifications): 0.849

**Algorithm F4a-N Applied to New Data and Compared with New Observed PERCLOS Data**

Figure B.6. Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm F4a-N When Applied to Original Data and New Data.

**Non-Baselined Regression Summary for Dependent Variable: PERCLOS**

R = 0.84140802 R2 = 0.70796745 Adjusted R2 = 0.69567134

F(4,95) = 57.577 p < 0.00000 Std. Error of estimate: 0.04992

|           | BETA      | St. Err.<br>of BETA | B         | St. Err.<br>of B | t(95)    | p-level  |
|-----------|-----------|---------------------|-----------|------------------|----------|----------|
| Intercept |           |                     | 0.114695  | 0.026601         | 4.31160  | 0.000040 |
| LGREV     | 0.343015  | 0.072384            | 0.035013  | 0.007388         | 4.73886  | 0.000008 |
| NMRHOLD   | -0.438793 | 0.079892            | -0.008136 | 0.001481         | -5.49230 | 0.000000 |
| THRSHLD   | 0.643609  | 0.086890            | 0.440463  | 0.059465         | 7.40714  | 0.000000 |
| NMNR      | 0.220279  | 0.068832            | 0.099736  | 0.031165         | 3.20023  | 0.001867 |

|                      |              | Predicted |           |              |          |
|----------------------|--------------|-----------|-----------|--------------|----------|
| Original<br>Observed | Group        | % Correct | Awake     | Questionable | Drowsy   |
|                      | Awake        | 91.30     | <b>63</b> | 5            | 1        |
|                      | Questionable | 55.56     | 4         | <b>10</b>    | 4        |
|                      | Drowsy       | 61.54     | 0         | 5            | <b>8</b> |
|                      | Total        | 81.00     | 67        | 20           | 13       |

PERCLOS (R value = 0.841)

|                                                    |       |
|----------------------------------------------------|-------|
| Apparent Accuracy Rate (LARGE misclassifications): | 0.990 |
| Apparent Accuracy Rate (ALL misclassifications):   | 0.810 |

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm J4a-N**.  
(Independent variables employed included A/O Task, Steering, and Accelerometer.)

|                 |              | Predicted |            |              |           |
|-----------------|--------------|-----------|------------|--------------|-----------|
| New<br>Observed | Group        | % Correct | Awake      | Questionable | Drowsy    |
|                 | Awake        | 78.87     | <b>112</b> | 24           | 6         |
|                 | Questionable | 45.45     | 2          | <b>5</b>     | 4         |
|                 | Drowsy       | 76.92     | 1          | 2            | <b>10</b> |
|                 | Total        | 76.51     | 115        | 31           | 20        |

PERCLOS (R value = 0.662)

|                                                    |       |
|----------------------------------------------------|-------|
| Apparent Accuracy Rate (LARGE misclassifications): | 0.958 |
| Apparent Accuracy Rate (ALL misclassifications):   | 0.765 |

**Algorithm J4a-N** Applied to New Data and Compared with New Observed **PERCLOS** Data

Figure B.7. Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm J4a-N When Applied to Original Data and New Data.

# Non-Baselined Regression Summary for Dependent Variable: PERCLOS

R = 0.87153552 R<sup>2</sup> = 0.75957416 Adjusted R<sup>2</sup> = 0.74406281

F(6,93) = 48.969 p < 0.00000 Std. Error of estimate: 0.04578

|           | BETA      | St. Err.<br>of BETA | B         | St. Err<br>of B | t(93)    | p-level  |
|-----------|-----------|---------------------|-----------|-----------------|----------|----------|
| Intercept |           |                     | 0.047027  | 0.029750        | 1.58071  | 0.117340 |
| ACCVAR    | -0.179261 | 0.062437            | -0.007425 | 0.002586        | -2.87106 | 0.005066 |
| LANDEV    | 0.494766  | 0.113252            | 0.032746  | 0.007496        | 4.36873  | 0.000032 |
| STVELV    | 0.211349  | 0.073406            | 0.000764  | 0.000265        | 2.87918  | 0.004947 |
| NMRHOLD   | -0.279452 | 0.079623            | -0.005182 | 0.001476        | -3.50970 | 0.000694 |
| THRSHLD   | 0.395668  | 0.107084            | 0.270781  | 0.073284        | 3.69495  | 0.000371 |
| NMNR      | 0.139885  | 0.070148            | 0.063336  | 0.031761        | 1.99413  | 0.049066 |

| Original<br>Observed | Predicted    |           |       |              |        |
|----------------------|--------------|-----------|-------|--------------|--------|
|                      | Group        | % Correct | Awake | Questionable | Drowsy |
|                      | Awake        | 95.65     | 66    | 1            | 2      |
|                      | Questionable | 38.89     | 4     | 7            | 7      |
|                      | Drowsy       | 61.54     | 0     | 5            | 8      |
|                      | Total        | 81.00     | 70    | 13           | 17     |

PERCLOS (R value = 0.872)

Apparent Accuracy Rate (LARGE misclassifications): 0.980

Apparent Accuracy Rate (ALL misclassifications): 0.810

## Classification Matrix Generated From Multiple Regression Analysis of Original PERCLOS Data Resulting in Algorithm L3a-N.

(Independent variables employed included A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

| New<br>Observed | Predicted    |           |       |              |        |
|-----------------|--------------|-----------|-------|--------------|--------|
|                 | Group        | % Correct | Awake | Questionable | Drowsy |
|                 | Awake        | 91.55     | 130   | 11           | 1      |
|                 | Questionable | 45.45     | 2     | 5            | 4      |
|                 | Drowsy       | 61.54     | 1     | 4            | 8      |
|                 | Total        | 86.14     | 133   | 20           | 13     |

PERCLOS (R value = 0.785)

Apparent Accuracy Rate (LARGE misclassifications): 0.988

Apparent Accuracy Rate (ALL misclassifications): 0.861

## Algorithm L3a-N Applied to New Data and Compared with New Observed PERCLOS Data

Figure B.8. Non-Baselined Regression Summary and Classification Matrices Showing Accuracy of Algorithm L3a-N When Applied to Original Data and New Data.

**Algorithm D4a** (Steering, Lateral-Accelerometer)

|                       | Development |               |             | Validation |               |             |
|-----------------------|-------------|---------------|-------------|------------|---------------|-------------|
|                       | R           | APAR<br>Large | APAR<br>All | R          | APAR<br>Large | APAR<br>All |
| D4a (Baselined)       | 0.789       | 0.987         | 0.757       | 0.800      | 0.965         | 0.771       |
| D4a-N (Non-Baselined) | 0.788       | 0.973         | 0.767       | 0.769      | 0.955         | 0.724       |
| Gain (+) / Loss (-)   | -0.001      | -0.014        | +0.010      | -0.031     | -0.010        | -0.047      |

**Algorithm F4a** (Steering, Lateral-Accelerometer, Lane)

|                       | Development |               |             | Validation |               |             |
|-----------------------|-------------|---------------|-------------|------------|---------------|-------------|
|                       | R           | APAR<br>Large | APAR<br>All | R          | APAR<br>Large | APAR<br>All |
| F4a (Baselined)       | 0.871       | 0.980         | 0.790       | 0.862      | 0.976         | 0.830       |
| F4a-N (Non-Baselined) | 0.857       | 0.977         | 0.817       | 0.871      | 0.984         | 0.849       |
| Gain (+) / Loss (-)   | -0.014      | -0.003        | +0.027      | +0.009     | +0.008        | +0.019      |

**Algorithm J4a** (Steering, Lateral-Accelerometer, A/O Task)

|                       | Development |               |             | Validation |               |             |
|-----------------------|-------------|---------------|-------------|------------|---------------|-------------|
|                       | R           | APAR<br>Large | APAR<br>All | R          | APAR<br>Large | APAR<br>All |
| J4a (Baselined)       | 0.836       | 0.970         | 0.790       | 0.599      | 0.958         | 0.833       |
| J4a-N (Non-Baselined) | 0.841       | 0.990         | 0.810       | 0.662      | 0.958         | 0.765       |
| Gain (+) / Loss (-)   | +0.005      | +0.020        | +0.020      | +0.063     | 0             | -0.068      |

**Algorithm L3a** (Steering, Lateral-Accelerometer, Lane, A/O Task)

|                       | Development |               |             | Validation |               |             |
|-----------------------|-------------|---------------|-------------|------------|---------------|-------------|
|                       | R           | APAR<br>Large | APAR<br>All | R          | APAR<br>Large | APAR<br>All |
| L3a (Baselined)       | 0.875       | 0.950         | 0.830       | 0.796      | 0.979         | 0.868       |
| L3a-N (Non-Baselined) | 0.872       | 0.980         | 0.810       | 0.785      | 0.988         | 0.861       |
| Gain (+) / Loss (-)   | -0.003      | +0.030        | -0.020      | -0.011     | +0.009        | -0.007      |

Figure B.9. Comparison of R Values and Apparent Accuracy Rates For Baselined and Non-Baselined Algorithms When Applied to Original Data and New Data.

## **VITA: Rollin J. Fairbanks**

419 Seminole Drive, Blacksburg, Virginia 24060. (540) 552-8832. Fairb@vt.edu

### **EDUCATION:**

**Master of Science**, Industrial and Systems Engineering, Human Factors Engineering/Safety Option, Virginia Polytechnic Institute and State University, Blacksburg, VA.  
Thesis advisor: Walter W. Wierwille, GPA : 3.54, (Anticipated May 1996).

**Bachelor of Arts**, Mathematics and Physics (dual majors). Potsdam College of the State University of New York, May 1990.

- New York State Regents scholarship
- National Mathematics Honor Society
- Lab Assistant, Physics Department: Introductory physics course, 1988-1989.
- Research Assistant, Potsdam College Physics Department, 1989-1990.

#### **Additional Education:**

- Paramedic Program, State University of New York Health Science Center at Syracuse, 1992-1993. Included three semesters of course work, clinical rotations, and field internship.
- Physics Education (graduate study). Potsdam College of SUNY, 1990-91.
- NSF Graduate Assistant, Potsdam College: Hypercard multimedia tutorial developer and Laboratory Teaching Assistant.

#### **Professional Associations**

- Human Factors and Ergonomics Society
- American Society of Safety Engineers
- Alpha Pi Mu, ISE Honor Fraternity
- National Registry of EMT-Paramedics

### **GRADUATE RESEARCH EXPERIENCE**

**Graduate Research Assistant**, Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University; 11/93 to present.

- Conduct automobile simulator experiments, monitor human subjects with physiological recording and data collection equipment, operate and maintain a motion-based automobile simulator.
- Use signal detection theory, multiple regression, correlation, and classification matrix techniques in the refinement of algorithms for the detection of driver impairment due to drowsiness, fatigue, and time-on task.
- National Institute for Occupational Safety and Health Program Grant

#### **Publications and Technical Reports**

Fairbanks, R.J., Fahey, S.E., and Wierwille, W.W. (1995). Research on Vehicle-Based Driver Status/Performance Monitoring: Seventh Semi-Annual Research Report (Report Number DOT HS 808 299). Washington, DC: U.S. Department of Transportation National Highway Traffic Safety Administration.

Fairbanks, R.J., Lewin, M.G., and Wierwille, W.W. (1995) Research on Vehicle-Based Driver Status/Performance Monitoring: Eighth Semi-Annual Research Report (Report No. ISE 95-23). Blacksburg, VA: Virginia Polytechnic Institute and State University, Department of Industrial and Systems Engineering.

Fairbanks, R.J. and Wierwille, W.W. (1995). Refinement of algorithms for on-line detection of driver drowsiness. In Proceedings of the Third Annual Mid-Atlantic Human Factors Conference (pp. 55-61). Blacksburg, Virginia, March 26-28, 1995, pp. 55-61.

Wierwille, W.W., Wreggit, S.S., Kirn, C.L., Ellsworth, L.E., and Fairbanks, R.J. (1994). Research on Vehicle-Based Driver Status/Performance Monitoring: Development, Validation, and Refinement of Algorithms for Detection of Driver Drowsiness. (Report Number DOT HS 808 247). Washington, D.C.: U.S. Department of Transportation National Highway Traffic Safety Administration.

## **PROFESSIONAL EXPERIENCE**

**Residence Hall Director and Coordinator of Residence Hall Judicial Board**, State University of New York at Cortland; 8/91 to 8/93. Full time position with responsibility for overall administration of one residence hall and shared responsibility for administration of the Residential Services and Judicial Affairs departments.

- Coordinate campus-wide Residence Hall Judicial Board and act as Administrative Judicial Hearing Officer.
- Directly supervise, select, and train 7 undergraduate resident assistants (RAs), 3 desk staff members, 13 night clerks, and a peer academic advisor.
- Instruct RA training course.

**Senior Paramedic/Cardiac Technician**, TLC Emergency Medical Services, Cortland, NY; 8/91 to 8/93. Paramedic in command on ambulance providing 911 emergency service to city population and surrounding suburban area. Provided basic and advanced invasive patient care in the pre-hospital setting.

**Assistant Health and Safety Officer**, Severson Environmental Services, Niagara Falls, NY; 5/89 to 9/89.

- Monitored and documented air contaminant levels and personnel heat stress levels at toxic waste remedial site to ensure safety of work crews.
- Utilized chemical analysis to classify toxic waste samples as member of the drum sampling and analytical team; Provided triage and emergency care for injured workers.

**On-Site Safety Technician/EMT**, Yolam Construction Company, Latham, NY; Summer 1988.

- Supervised precautionary and emergency medical care to personnel on (superfund) hazardous waste remedial project.

**Merchandiser**, Golub Corp., Price Chopper Book Division. (1984-1989).

- Held various full and part time positions within wholesale and retail book reseller including shop manager, sales representative, and special services clerk.
- Working independently, determined schedule and logistics for controlling inventory and displays at ten retail centers.

## **VOLUNTEER SERVICE**

**Paramedic**, Blacksburg Rescue Squad, Blacksburg, VA: 10/93 to present.

**Paramedic**, Virginia Tech Rescue Squad, Blacksburg, VA: 6/94 to present.

**Advanced Cardiac Life Support Instructor**, American Heart Association, Montgomery Regional Hospital, Blacksburg, VA: 1993 to 1994.

**Paramedic**, Roanoke Emergency Medical Services, Roanoke, VA: 9/93 to 6/94.

**Cardiac Technician**, Potsdam Volunteer Rescue Squad, Potsdam, NY; 10/86 to 8/91.

**Emergency Medical Technician**, Wilton Emergency Squad, Saratoga Springs, NY; 8/85 to 12/89.

## **UNIVERSITY AND COMMUNITY ACTIVITIES**

- Graduate Student Assembly delegate
- Affirmative Action/Equal Opportunity University Committee, graduate student member.
- Funding subcommittee of the Midatlantic HF conference committee, co-chair.
- Virginia Tech Rescue Squad
- Blacksburg Rescue Squad
- Roanoke City EMS
- CPR, ACLS, and EMS instructor
- Blacksburg Town Band
- Virginia Tech Water-ski Club
- Private pilot

