THE SYNTHESIS OF NAVISECTION: MODERNIZING DRIVER REHABILITATION PROGRAMS TO ENCOMPASS INTELLIGENT VEHICLE TECHNOLOGIES

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The synthesis of NAViSection introduced a concept for using vehicle-based sensor data to improve the practice of driver evaluation. This project to reinforce licensing recommendations acknowledges that pen and paper documentation confines the expertise of evaluators to driving programs, while advances in vehicle sensors could address driving privilege as people age, experience medical impairments, and acquire disabilities. Through a review of medical record data, client files showed internal and external limitations to current practice. Within the program, a majority of evaluations resulted in a recommendation to continue driving despite the medical conditions referenced in the physician's referral. This finding connected to concerns of client intake waiting lists before evaluation. Additionally, driver rehabilitation programs lack insight to council clients with poor medical prognosis on when to review driving capability. The NAViSection methodology proposed a way to integrate data collection with the standard processes of a driver rehabilitation program. While collecting event data based on evaluator intervention, the broader vision sought to correlate interventions with vehicle data patterns for typical driving errors.

Through multiple tests and simulations, a design project yielded a novel data collection system based on the NAViSection methodology. The pilot study results showed that assisted-driving events (steering, braking, and verbal cue assistance) correlate best with the recommendations of a Certified Driver Rehabilitation Specialist (CDRS). The NAViSection

correlation presented improved predictive values compared to clinical assessment scores and driver history as screening tools. Future work could extend the reach of the CDRS by establishing correlations to telematics products (ex. OBD2 readers) and other sensing technologies as a screening system in future vehicles. In relation to driving simulators and naturalistic driving studies, the NAViSection system is better suited to help with at-risk drivers (teen and older Americans) within the setting of driving programs. Lastly, the assisted-driving events by a CDRS present a unique source of collision-avoidance, which may provide an opportunity to validate collision avoidance technologies from automotive manufacturers through real drivers, on real roads, and in real scenarios.

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PREFACE

The Synthesis of NAViSection is the miraculous story of my PhD journey, because I could never have predicted that my efforts would direct me towards a new passion in life. The passion I developed relates to a common decision made in many people's lives: "When is it the right time to start or stop driving?" I can say that my new passion was handed to me as a research project for a topic I had never intentionally prepared myself for. For this miraculous gift, I would like to acknowledge my creator and give praise to God. In continuation, I thank my parents and my brother for the many years of support to complete my dissertation study. For me, the PhD was a milestone set while in high school. Thus, my gratitude and celebration is due to the achievement of a 17 year goal and promise to self.

My transition to Pittsburgh was an unexpected step in life, yet grounded in sound reasoning. I aspired to be in one of the best programs in the nation, with the top researchers, and a healthy funding pool to increase the likelihood of my completion. The University of Pittsburgh Department of Rehabilitation Science and Technology with collaborations in the Quality of Life Technology Center met this standard for the challenge I wished to take on. My greatest expressions of thanks are due to Dr. Rory Cooper, Dr. Aaron Steinfeld, and Mrs. Amy Lane, OTR/L, CDRS for their continuous role in my training and achievements as a doctoral student. I am certain that any story I share of my experiences would involve mention of their names as a person in the room, within the car, or on the phone at the time of the marquee events during my

program. In addition, I would like to thank Dr. Kate Seelman and Dr. Tom Songer for instructing my two most favorite courses as well as honoring me as members of my dissertation committee.

The infrastructure, resources, and partnerships available to me were truly outstanding and honestly empowered me to form goals in a new way…impromptu! What was previously just another style of speaking became a method for my continuous self-improvement. I would like to acknowledge the entire team of faculty, staff, and students from the Human Engineering Research Laboratories for being a home away from home. An individual note of thanks is especially due to Mr. Josh Brown for his dedication and support to my dissertation project as a staff member of the machine shop. I must also extend an acknowledgement to faculty and staff from the entire Department of Rehabilitation Science and Technology. In our partnership with Carnegie Mellon University, I would like to acknowledge the Robotics Institute's NavLab. My direct thanks are due to Mr. Arne Suppe and Mr. John Kozar for repeat consultations and direct support of my dissertation project. Finally, I acknowledge the Center for Assistive Technology as a facility of professionals dedicated to tailored service and quality of care for all clients. I spent numerous hours working under Amy Lane with the Adaptive Driving Program, and the staff at the Center for Assistive Technology kept a watchful eye on me to ensure I stayed out of trouble. There is a fun inside joke there related to me being barred from installing anything, anywhere, ever again.

As I progressed towards the end of my PhD journey, I surprised myself by deciding to venture out as an entrepreneur! I would like to acknowledge to Office of Technology Management and Office of Enterprise Development for multiple events and programs that reshaped my ambitions over the years. From the position of our Quality of Life Technology Center, I would like to thank Mr. Jim Osborn, Mr. Randy Eager, and Mr. Gary Miller for encouraging my efforts and persistence to follow a passion. Throughout my competitions and submissions to elevate awareness for my venture, I must also personally thank Mr. Andrew Wolf for his long standing support and teamwork as an undergraduate marketing major in the College of Business Administration at Pitt.

I would like to dedicate my dissertation in the memory of family members and loved ones that I have lost during this journey. Particularly, to the memory of my grandfather, Ababa Beyene, whose wisdom and pride demonstrated to me how to contribute as a blessing to the life of others until our time for eternal rest comes. I would like to share this dedication also with my godfather, Gebretsadik Hadera, whose generosity and energy made all who interacted with him wish to continue being in his presence due to the value and respect he received people with.

All development towards the NAViSection project was a product of the Human Engineering Research Laboratory in partnership with the Quality of Life Technology Center. This dissertation is based upon work supported by the National Science Foundation under Cooperative Agreement EEC-0540865 and an Innovation Corps Teams Grant IIP-1345368. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation. The contents do not represent the views of the Department of Veterans Affairs or the United States Government.

Key Terms and Nomenclature

PITT: University of Pittsburgh –Main Campus

CMU: Carnegie Mellon University

QoLT ERC: Quality of Life Technology Engineering Research Center supported by the National Science Foundation

HERL: Human Engineering Research Laboratories

UPMC: University of Pittsburgh Medical Center

CAT: Center for Assistive Technology in Forbes Tower at the University of Pittsburgh

ADP: Adaptive Driving Program in Forbes Tower at the University of Pittsburgh

PHAATE: Model for the provision of assistive technology based on the themes of Policy, Human, Activity, Assistive Technology, and Environment

DriveCap: low-cost, easily installable suite of vehicle-based sensors for the study of driver capability; developed at CMU by NavLab

NAViSection: a methodology to measure assistance by a driving evaluator to quantify driver capability; (as a system) the technology to flag assisted driving events in the practice of driver rehabilitation for segmentation and enhancement of vehicle-based sensor data

AMA: American Medical Association

AMA ADReS: American Medical Association's Physician Guidelines for Addressing Driving Related Skills

ADED: Association for Driver Rehabilitation Specialists

CDRS: Certified Driver Rehabilitation Specialist

HIPAA: Health Insurance Portability and Accountability Act as regards to protected health data

CTA: abbreviation created to connote citations, tickets, or accidents in self-reported driving history

SIPDE: Scan, Identify, Predict, Decide and Execute; a driver safety education framework for driving operations

NHTSA: National Highway Traffic Safety Administration

RITA: Research and Innovative Technology Administration

NTSB: National Transportation Safety Board

AARP: American Association of Retired Persons

PennDOT: Pennsylvania Department of Transportation

DMV: Department of Motor Vehicles

GDL: Graduated Driver Licensing

MAB: Medical Advisory Board established by state to address medical-impairment concerns and provide decisions on cases reported under mandatory physician reporting rules and other sources

EDR: Event Data Recorder

IVDR: In-Vehicle Data Recorder

V2V: Vehicle-to-Vehicle communications

V2I: Vehicle-to-Infrastructure communications

V2X: Vehicle-to-“X” (anything) communications (ex. Social Media, Infotainment, Maintenance)

ITS: Intelligent Transportation Systems

DAQ: Data Acquisition

OBD II/OBD 2: On-Board Diagnostics Port standard for vehicles

IVBSS: Integrated Vehicle-Based Safety Systems with reference to phase II of the program

SHRP-2: Strategic Highway Research Program authorized under SAFETEA-LU and continuing resolutions

1.0 INTRODUCTION TO THE NAVISECTION PROJECT

The NAViSection project was formed under the Quality of Life Technologies Engineering Research Center (QoLT ERC) managed by Carnegie Mellon University (CMU) and the University of Pittsburgh (PITT). The QoLT ERC consists of many projects organized by research thrusts and QoLT Systems. The Safe Driving QoLT System sustains core and associated projects to quantify and enhance independent transportation. Driver capability was termed “DriveCap” and evolved to include an in-vehicle data recorder. The DriveCap data collection system integrated multiple sensors with the potential for installation in most vehicles within an hour.

DriveCap incorporated multiple studies in the investigation of driver capability among senior citizens and people with disabilities. The Adaptive Driving Program (ADP) within the Center for Assistive Technology (CAT), which is managed by PITT and UPMC was a testbed for DriveCap. In order to provide context to the capacity of the DriveCap project’s data collection effort, NAViSection facilitated the segmentation and contextual enhancement of continuous data collection files.

The DriveCap project sought to address the mobility needs of seniors in transportation. Considering the full spectrum of mobility-related needs, the DriveCap project was limited to the aspects of mobility related only to driving. NAViSection facilitated the operationalization of

DriveCap by testing what benefits may be realized through the incorporation of intelligent vehicle technologies in the setting of driver rehabilitation programs during on-road evaluation.

NAViSection relates directly to the QoLT ERC's central motivation by addressing the mobility needs among people of all age groups and major populations in society who have emerged from institutional living. With independent living, mobility is at the forefront of daily life and driving as an instrumental activity of daily living (Gibson, 2003; Lachat, 1988). The advocacy and policy reforms necessary to end the status quo of institutionalization secured major protections in safety and preservation of dignity for senior citizens and people with disabilities. This trend, and an aging population in many countries, elevates the urgency to address mobility as a whole, with an acute focus on the management of driving privileges.

These changes brought forth the movements for independent/assisted living programs and "aging in place" defined by the Center for Disease Control (2013) as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level." At the same time, the shift in status quo introduced greater reliance on individual mobility as people who were formally institutionalized, had greater need to acquire their own products and resources. Institutionalization created an environment where products and resources are brought to patients (occupants), while the aging in place and independent living movements worked to extend the full participation of all people in society. In this context, full participation of individuals requires solutions for seniors and people with disabilities to obtain income, purchase goods, seek leisurely activities, and utilize transportation options to achieve all expected needs.

The need to understand driver capability is important to the mission of the QoLT ERC. The NAViSection studies, presented in the following chapters, focus on modernizing driving evaluation. The main goal of the project is to assist individuals in their personal mobility choices when their driving capability is in question. NAViSection summarizes all studies with two overarching study questions/aims:

1. What are the determinants of driver capability?
2. How can we relate driver capability to safety on the road?

This dissertation is organized into chapters that will sequentially present evidence and opportunities to evaluate the potential benefits and costs from using intelligent vehicles in driver rehabilitation programs or other driver training settings.

Chapter 2: Medical Record Review of the Adaptive Driving Program

Chapter 3: Proposal of the NAViSection Methodology

Chapter 4: Design of a NAViSection Data Collection System

Chapter 5: NAViSection Pilot Study and System Demonstration

Chapter 6: Future Directions to Advance NAViSection

The remainder of this chapter provides an overview of key issues that fuel debates on how to manage driving privilege in society. Further discussion of these issues will be presented more formally in the chapters ahead.

1.1 CHANGING ASSUMPTIONS ABOUT DRIVER CAPABILITY

Within the DriveCap studies, the term "driver capability" is assumed to fulfill the expectation for an individual to receive a driver's license. A major shift in assumptions takes place as sources of impairments are better defined. The study of disability in society can be introduced succinctly in the PHAATE (Policy, Human, Activity, Assistive Technology, Environment) Model (Cooper, Ohnabe, & Hobson; 2006), and it is readily applicable to the Haddon Matrix (Runyan, 1998) for crash safety shown in Figure 1. The rows of the Haddon Matrix break down an event into pre, during, and post events. The crash event connotes driving to be the activity (A) in PHAATE. The columns of the Haddon Matrix show an activity with respect to the human, vehicle, and environment (physical or social). The PHAATE model corresponds to these columns where the human (H) is still the human, the assistive technology (AT) is any modification to a vehicle, and the environment (E) is shared across the physical/social/economic environment portrayed in the Haddon Matrix. Unique to the PHAATE model are policy (P) considerations that have the power to influence all decisions intended to promote safe activity, produce inclusive environments, propagate assistive technologies, provide cost reimbursements, and protect quality of life.

Thus, the PHAATE model appends a level of detail to explain why driving schools, law enforcement, and public safety education campaigns are not sufficient to encompass the needs of driver licensing. Understanding the activity of humans with disabilities, driver capability with adaptive equipment, and the influence of policy allows driving to be more inclusive and essentially guides the thought process behind maximizing independence within the bounds of personal safety to sustain quality of life.

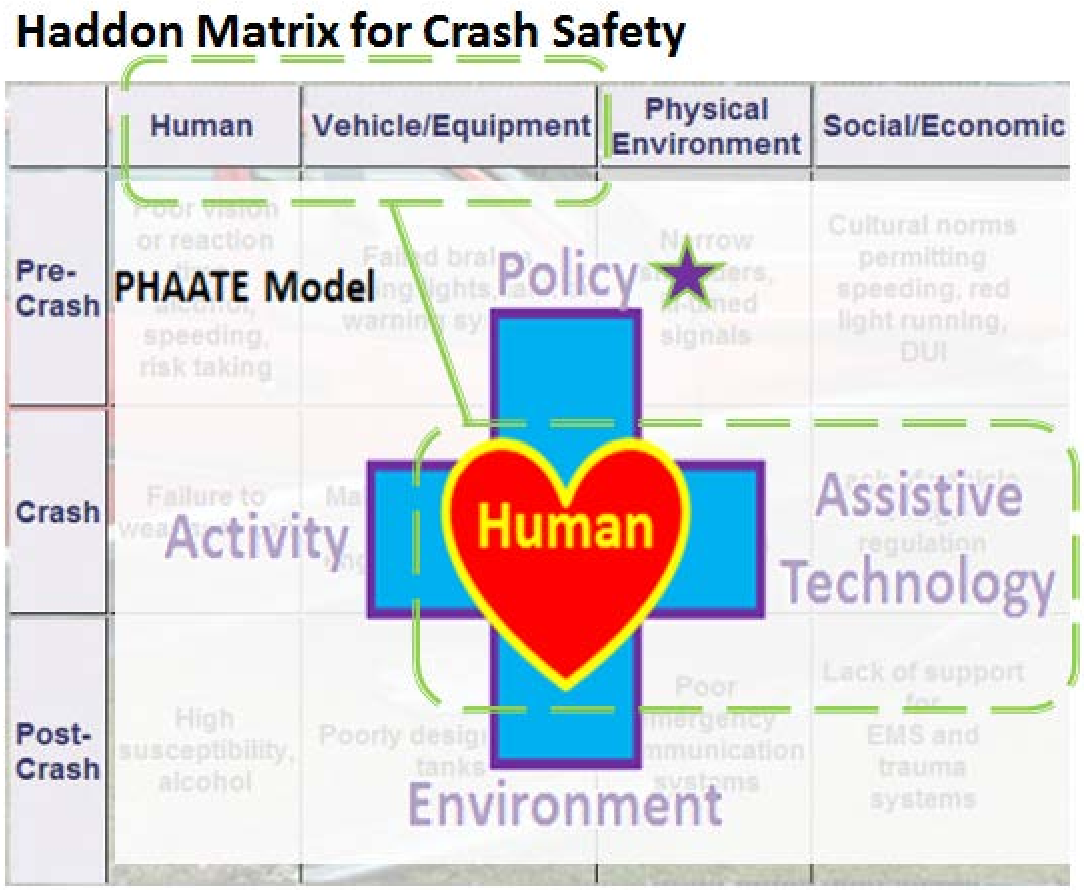


Figure 1-1. Integration of the PHAATE Model into the Haddon Matrix for Injury Prevention

The expectation is that all young, prospective drivers as teenagers are capable of driving provided proper education and accumulated driving experiences. The level of investment by law enforcement and public safety education campaigns follows the perspective that capable people will occasionally make unsafe decisions while driving. This view reflects the consensus that the benefits related to licensing outweigh the risks. In other words, people normally become acceptable drivers after receiving proper education and experience on roads. Educational efforts aim to reduce risk on the road while guiding individuals to avoid distractions and transient impairments caused by their own actions.

Perspectives shift as people age, because years of driving experience are no longer sufficient to explain why driving errors occur. Despite driving experience, fixed or chronic impairments modify true driving capability. As people acquire chronic impairments, their driving experience is augmented by changes to their own capabilities on the same roads traveled upon and with the same vehicle technologies used over the years. However, impairments occur at all ages of life. When impairment restricts an individual from participating in an activity (ex. driving), it results in a disability that limits participation in popular societal norms. Unfortunately, driver impairments that cannot be avoided or removed introduce a scenario where driver capability may not be recovered or even initially achieved. The study of disabilities is essential to the basis of defining impairment and driver capability.

1.2 EXPOSING CHALLENGES TO MONITORED DRIVING

A commonly discussed concern about drivers is self-rating bias (Holland, 1993; Marottoli & Richardson, 1998; Freund et al., 2005), defined as the belief by a majority of drivers that they are above average drivers. This is clearly a fallacy because only a minority of drivers can be better than average. Carrying the self-rating bias forward as they age, each driver is biased in their ability to properly select when it is time to retire from driving. Driving cessation is a decision which often carries as much emotion as the diagnosis of a terminal disease due to its effect on social well-being and mobility in society. The challenge to individuals occurs when weighing the benefits of driving against the risks to themselves, their passengers, and other drivers. Despite the great challenge in properly self-rating driver capability, the ultimate goal is to maintain "locus of control" in the decision as a license holder.

High rates of crashes and fatalities among senior drivers prompted most state policies for age-based driver license renewal and retesting, while some states seek alternatives under political pressure to stop screening by age. Various research studies have segmented the constituency of senior drivers according to specific characteristics believed to cause increased crash risk. These characteristics include terms such as the frail-old (Braver & Trempel, 2004), reduced mileage drivers (Marottoli et al., 1993; Langford, Methorst, & Hakamies-Blomqvist, 2006), polypharmacy (Janke, 1994), and moderate dementia (Stutts, Stewart, & Martell, 1998) among others. Age-based policies persist, despite concerns with ageism as a factor in policies targeting older adults. The challenge for the state is to enact policy that does not burden drivers who have not increased the crash risk on our public roads.

Mandatory physician reporting is a newer policy in some states (Snyder & Bloom, 2004) that view family doctors and specialized physicians to be in a position of moral obligation to address driving-related skills during conversations with their patients. Compared to age-based screening, physician reporting creates a direct relationship between a detected medical-impairment and the recommendation for retesting or follow-up assessment of driving capability. With this policy, physicians are obligated to report a patient to their state's licensing authority if the patient is not receptive to the physician's guidance. Despite the benefit of reducing the risks of ageism, physician reporting has separate challenges in becoming adopted among physicians and the states. Provided extensive research efforts, limited clinical assessment protocols (ex. vision test and history of seizures) definitively affect state driver licensing decisions. Physician assessment has thus been viewed negatively by some as a step towards enforcement of state license requirements (ex. vision requirements or seizure-free periods). The challenge to physicians is how to systematically review their patients' driving related skills without damaging the patient-physician relationship built upon trust.

A driver rehabilitation program can inform cases that are ambiguous for physicians or the state licensing authorities, by conducting a comprehensive evaluation. This ultimate level of review best determines an individual's fitness to drive. Following a clinical assessment, the driver rehabilitation program allows for an on-road driving evaluation. Ideally, this level of evaluation can be initiated by individuals, with a physician's referral, to aid self-awareness regarding driving capability affected by functional limitations related to new or existing health conditions.

In the face of a growing need for driver rehabilitation services (Landry et al., 2008), people who enroll in the service unwillingly still have concerns. In society, the demand on driver rehabilitation by older drivers is growing at up to three times the rate of increase among license holders overall (NHTSA, 1997; NHTSA, 2004). The driver rehabilitation setting is perceived as an extension of the medical system rather than a platform for advocacy. Any negative disposition towards the healthcare system as a whole presents challenges to the driver rehabilitation specialist. As mentioned earlier, realizing that driving cessation is a possible outcome of driver rehabilitation can cause a great deal of anxiety and tension prior to an initial visit to the program. Although on-road evaluation provides the greatest face validity of any available tests, clients may still complain of differences between the evaluation vehicle and their personal vehicle or the differences between the evaluation course versus their typical driving routes.

The challenge to driver rehabilitation specialists is two-fold in nature. On one hand, the professional must provide a recommendation in favor or against driving for their client upon conclusion of each case, but the decision is ultimately made by the state. At the same time, the professional must advocate for and provide guidance to clients, while all results must be provided to a primary care or specialist physician for inclusion in the client's medical record.

The sum total of challenges faced by the individual, state, physicians, and driver rehabilitation specialists culminates into one overarching problem. We do not prepare people to willfully retire their driving privilege or quantify what mechanisms empower them to do so successfully. There is no tracking mechanism to capture how many people are reported to the medical advisory board of the state departments of transportation compared to direct referrals to driver rehabilitation programs. Even the cases reported to medical advisory boards lack programmatic reviews for the impact of mandatory physician reporting laws when put into effect, as shown superficially in Figure 2. PennDOT (2011) is the only state found to publish fact sheets.

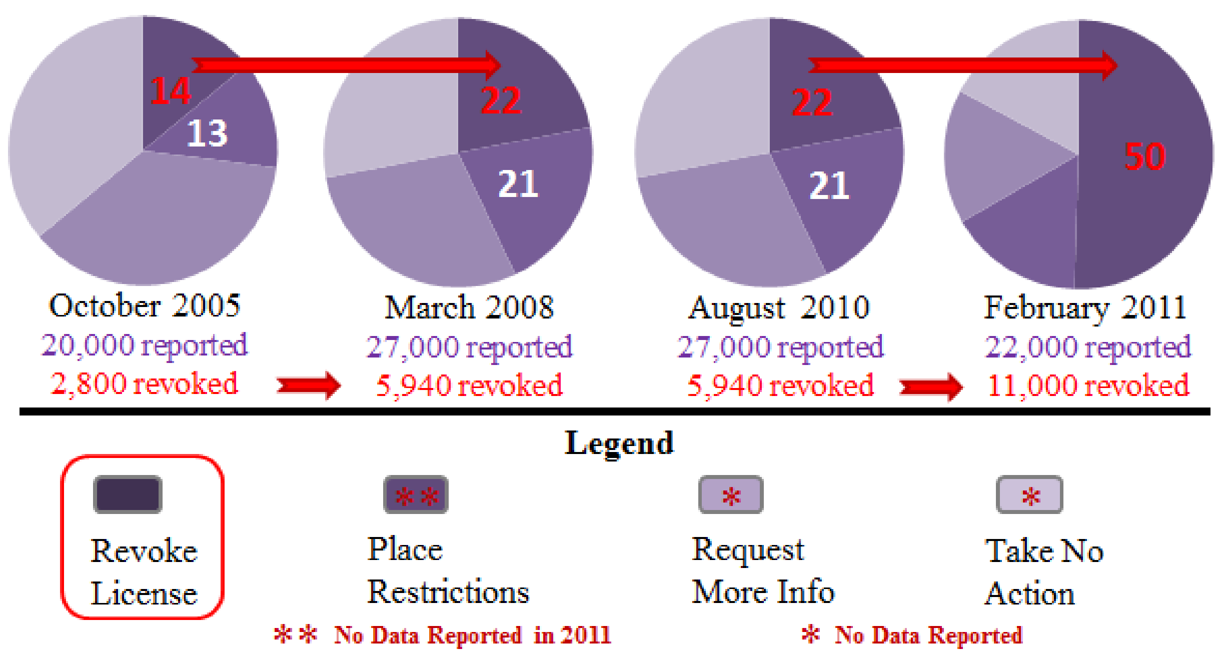


Figure 1-2. PennDOT Report Resolutions from the Mandatory Physician Reporting Fact Sheet

Additionally, reported cases that require additional information prior to medical suspension should be tracked to compare to outcomes from voluntary/self-requested referral to driver rehabilitation programs. Ultimately, the challenge to society is the same challenge faced by the individual: how to self-identify when the privilege of driving should be reviewed along with consideration for alternative modes of transportation to maintain participation in society.

This dissertation presents a series of studies conducted to promote the design, development, and evaluation of NAViSection. Motivated by the challenges discussed here, the challenge of the research project was to envision a system that addresses driving privilege holistically. The determinants of driver capability serve as the basis for ruling on the right for driving privilege and spans considerations for all age groups when seeking to obtain or retain a driver's license. All research recommendations that follow acknowledge that technologies for assessment/evaluation must extend from the foundations of clinical practice and include decisions made by professionals to ensure the integrity of care for Quality of Life.

2.0 MEDICAL RECORD REVIEW OF THE ADAPTIVE DRIVING PROGRAM

2.1 INTRODUCTION

Many campaigns for driver safety in the United States' have focused on some form of impaired driving. The core issue of impairment has revolved around substance use or abuse (alcohol consumption, prescription medications, and illegal substances), while efforts targeting distracted, aggressive, and drowsy driving presented a similar promotion of safe driving behavior (Hedlund, 2011). In these safety campaigns, the combination of driver education and legal enforcement comprised the majority of deployed resources. However, another paradigm departed from the basis of impairment to target age as a factor increasing driver safety risk. Analyses of crash involvement and mortality rates on the road precipitated additional resources for the management of younger and older drivers (Stutts, 2009) with respect to driving experience and age-related decline in driving performance.

2.1.1 Age-Based Concerns with Driver Capability

For age-based driver risk, safety campaign strategies focus on driver licensing restrictions. The difference in strategy exists because the safety risk is associated with (accrual or loss of) experience for drivers over their lifetime. A driver with a transient or chronic impairment has compromised driving capability due to a decline of experience upon onset of functional limitations. Basically, impairments in vehicle operation or decision-making negatively impact the influence of a driver's years of experience on the road. Although young/new drivers lacking experience are expected to change with education and supervised time on the road, older drivers, with declines in driving capability due to medical issues, reflect people with impairments that may not be reversible or avoidable.

At-risk older drivers represent a segment of the population where a fixed or recurring impairment is disabling for the activity of driving. In this light, driver fitness can be addressed through specialized evaluation of driving capability such that independent vehicle operation is demonstrated to be intact along with safe driving decisions on the road. While the programs report a recommendation on driver fitness, there are no claims made to ensure driver safety from crash involvement. Thus, driver rehabilitation programs provide specialized services needed for the evaluation of older drivers who might acquire a disability for the act of driving (Basore et al., 2009). These programs also service young/new drivers when medical impairments are present during initial training.

Referrals to driver rehabilitation are typically based on clinical test outcomes in order to assess driver capability. A number of computer based tests have emerged to provide further evidence on functional skills associated with driving. The functional skills assessed include medical history (Staplin & Dinh-Zarr, 2006), visual scanning (Ball & Owsley, 1993; Myers et al., 2000), decision making (Dobbs, 2005; Korner-Bitensky & Sofer, 2009), and other behavioral traits (Lajunen & Summala, 2003; Ozkan, Lajunen & Summala, 2006). The concerns of friends, family members, and physicians are common sources to generate the referral for this level of focused assessment with medically impaired, older drivers.

2.1.2 Perspectives of Physicians Screening At-Risk Drivers

Physicians face great difficulty when addressing concerns with driving, especially when they are voiced by family members and friends who are unable to reach an agreement with the license holder (the patient). In order to ease the tension between physicians and their patients, a (Certified) Driver Rehabilitation Specialist can provide additional evidence to assist in the determination of fitness to drive. Seventy-five percent of physicians surveyed in a study (Jang et al., 2007) viewed the act of reporting as a conflict of interest in the physician-patient relationship, and 45% were not confident with the responsibility of reporting. The American Medical Association (AMA) Guide to Address Driving Related Skills (ADReS) (Carr, 2010) presents a standard for primary care physicians to assess driving related skills for patients who are known to be driving.

2.1.3 Reviews by Driver Rehabilitation Programs

Multiple programs have contributed to the body of literature on how to structure driver rehabilitation services. Most studies summarized passing rates from on-road driving evaluations and explored additional aspects in the determination of driver capability or fitness to drive.

The Bloorview MacMillan Centre in Toronto, Canada demonstrated (Klavora, Young, & Heslegrave, 2000) the benefits of using an electronic database for medical record review to track changes in client demographics over the years. The database served as a support tool for choosing between acquiring new equipment for a client versus providing referral to another program. The Scottish Driving Assessment Service (Prasad, Hunter, & Hanley, 2006) surveyed their clients three years post-evaluation to address crash involvement by type of vehicle modification provided by the program.

In a survey across 31 driver rehabilitation programs (French & Hanson, 1999), researchers asked questions about offered services and received a 100% response in favor of on-road evaluation upon successful completion of a pre-driver (clinical) assessment rather than predicting driver capability without a driving session. This was an important finding at the time considering that only 39% of participating programs conducted on-road driving evaluations. A separate survey of driver rehabilitation specialists (Korner-Bitensky, Bitensky, Sofer, Man-Son-Hing, & Gelinas, 2006), reported that 61% proceed with on-road driving evaluation regardless of the results from clinical or pre-driver assessment. While responses to the survey showed the lack of scoring protocols or cut-point measures to determine fitness to drive, another survey demonstrated the strength of on-road driving evaluation to help older drivers with the decision to stop driving (Stutts, 2009). Having included survey responses by mainstream driving instructors (non-medical pathway of driving evaluation), Stutts proposed benefits if the greater population of driving instructors could provide this service without physician referral of clients.

Additional studies reported the passing rates of clients both overall and grouped by types of disability (Fox, Bashford, & Caust, 1992; Marshall, Man-Son-Hing, Molnar, Hunt, & Finestone, 2005; O'Connor, Kapust, & Hollis, 2008). The overall and group passing rates were similar, whereas the most predictive elements noted varied from clinical assessment tests to following road signs, detecting road hazards, and receiving driving assistance from a CDRS.

Nearly all driving evaluations involve a report that either enumerates or scores performance based on errors committed under observation. The challenge of driver capability measurement relates to the complexity of the many factors which contribute to a “Swiss cheese” model of risk (Sheridan, 2008). In each scenario of a committed driving error, driving maneuver, posted traffic signals and signs, road obstacles, road quality, weather conditions, presence of other road users, and pedestrians are among the many factors complicating a direct question: Is my client fit to drive based on today's demonstration of driver capability?

2.1.4 Study Objectives

Any recommendations for driver cessation should be based on the dominant scenario of driver error as the causal basis for a potential collision. The specific nuance of each crash condition defines a myriad list of unique driving errors. Yet, driver error can be documented via measures of independence and safety in vehicle operations and driving decisions. The purpose of the present study is to illustrate how driver capability could be measured based on the presence of assistance during on-road evaluation.

Focusing on older drivers, our study explored how on-road evaluations could identify critical errors that indicate loss of driver capability plus limitations in situational awareness that preclude any possibility of driver retraining or remediation. The ADP in Pittsburgh, Pennsylvania provides driver rehabilitation services and was the source of a medical record review.

The central aim of the study was to compare safe driving experience to specific errors on the road and driver capability to CDRS-assisted driving events. The following objectives were selected in order to study experience and capability among older drivers under review for the demonstration of independence and safety on the road:

- Identify the client volume for services provided to the 2009 ADP client base,
- Investigate frequency and hierarchy of driving errors as associated with assistance,

- Apply recorded CDRS-assistance in evaluations as a metric for reduced capability
- Explore the distribution of committed driving errors as a surrogate for driver experience.

2.2 METHODS

A medical record review, or chart review, of all client cases in 2009 was approved by the University of Pittsburgh Institutional Review Board. The review included all medical record documents generated by the ADP at the Center for Assistive Technology in Pittsburgh, PA. The inclusion criteria required that the initial visit took place in 2009. In this way, clients served in 2009 whose initial intake was completed in 2008 were excluded. Any clients pending case closures at the end of 2009 were tracked into the following year in order to obtain the outcomes of their on-road evaluation and case resolution following training whenever applicable. All clients served during the review period were evaluated by the same CDRS. The study design did not use sampling techniques since the inclusion of client records was comprehensive for our retrospective analysis of findings and recommendations from on-road driving evaluation.

2.2.1 Digitization Protocol

Each client's case record was digitized using raw data recording, and sensitive data were omitted where HIPAA identifiers were documented. A single coder reviewed the findings and recommendations from on-road evaluations for any legible documentation of assistance by the CDRS. Any reported assistance with driving received the label of a "cue" or "assist" to the client during the baseline driving evaluation. For the purpose of clarity, the baseline driving evaluation occurred as part of a comprehensive evaluation. The comprehensive evaluation takes place at the first session with a client and entails a pre-driver (clinical) assessment (unless performed by a third-party) and concludes with on-road driving evaluation. Records for training and the associated documents from those follow up client sessions were also digitized, but the records from those sessions were beyond the scope of the present analysis.

2.2.2 Data Collection and Management Procedure

The scope of data collection included a driver inquiry sheet, intake forms (driver history and medical history), clinical assessment results, vehicle checkout form (if applicable for consulting on vehicle modifications), on-road evaluation findings, training logs (if applicable), vehicle modification prescription form (if applicable), and the summary report for a client's case resolution. Written data was digitized via entry into a Microsoft Access database with form fields for standardized data entry options (except for the free-response fields/text boxes). A single co-investigator entered all of the data into the database, and the principle investigator of this study was the only CDRS to complete all client evaluations. No HIPAA identifiers or linked protected health information was entered into the database. The data management plan ensured access-controlled (password protected) storage on servers within the Human Engineering Research Laboratories (HERL).

2.2.3 Data Analysis

All client demographical data were analyzed using the SPSS statistical software package (version 19) for development of descriptive statistics and hypothesis testing. In addition, individual case histories were used to populate a flow chart of client services by enumerating the clients at all points of entry and departure through each stage of their case at the ADP. The data collected from case resolution reports only reflects the presence of factors during the course of a driving session, but not the frequency, duration, or sequence of each event that actually took place. The numbers of errors only reflect the number of unique errors committed, not the total number of bad driving events.

2.2.3.1 Content Analysis of Findings from On-Road Driving Evaluations

Upon review of the ADP's checklist and narrative comments from the initial driving evaluations, each client's case was processed for the number of error types documented, any mention of cues or assistance provided to the client and all findings/recommendations from the driving session. This analysis did not include training sessions following the baseline on-road evaluation. Then, each subject ID was linked with the client's age, number of errors, an intervention code, and outcome of the evaluation. The intervention code classified CDRS assistance during driving as none, cues, assistance, or both. For this code, the CDRS assistance was simply documented as taking place during a session without indication of frequency or duration of any assistance.

Exclusion of cases was necessary for this analysis when considering on-road driving sessions among clients using adaptive equipment. This was due to the reality that an initial driving session would not be treated as a standard evaluation. At best, the initial session with vehicle modifications would reflect a "fitting" to prescribe adaptive equipment and a baseline for estimating the number of hours required in training. Clients prescribed with adaptive equipment are generally required to complete state testing for the modifications to be listed as a restriction on the driver's license.

The processing procedure was to assign one error for each unique commentary. In addition, one error was assigned if a section of the evaluation was “not tested” or listed as “not enough exposure to assess.” Some errors were not considered. These included incorrect hand position on the steering wheel (due to a risk where potential airbag deployment could cause injury), one-handed steering, and not using a turn signal when departing from a curb (stationary position). No analysis was performed for “parking” or “driving in reverse” due to variable (non-routine) testing of clients for these skills during on-road evaluation.

The primary analysis produced an enumerated list of unique driving errors committed by all clients who received a comprehensive evaluation from the ADP. Along with the list, frequency counts demonstrated how many clients committed each specific error. Similar error types took on class assignments, and coded entries maintained the context in which they were observed. Indications of assisted driving events flagged whether the assistance was implied (found in writing or evident in the words used to document an error) or potential (possible in the absence of explicit documentation).

Based on the list, our secondary analysis compared errors possibly involving assistance versus the outcome of on-road evaluations among all clients with implied (documented) assistance listed in their case report. The coder determined percentages by totaling the number of assisted-events indicated within a class of errors and dividing by the total number of unique errors attributed to the class. In this manner, the percentage of cases involving assistance also split the value among two groups: those that “passed” and others who “did not pass.”

2.2.3.2 Exploratory Cluster Analysis and Attribution to ADP Outcomes

While considering driving experience across the age spectrum, CDRS-assistance during driving sessions was compared to the number of driving errors committed as well as the final outcomes of client cases at the ADP. Each error documented was assigned to a summary title so that similar errors could be recognized by a single phrase. The summary titles were categorized by their relationship to four characteristics of error generation: approach, maneuver, response, and reaction. Within these categories, the summary titles were formalized into classes of errors. Again, the errors documented in this process only indicated the occurrence of a unique error, but not the number of times the error was executed.

To strengthen acceptance of the named categories with an established construct for safe driving strategy, three characteristics of error generation (approach, maneuver, response) were mapped to the SIPDE method (Kenel, 2000; Nead, 2009). Before attempting any driving maneuver, the driver should be engaged in a cycle of scaning, identifying, and predicting (SIP). Performance of a driving maneuver reflected when the driver ended the SIP cycle to decide (D) on a driving maneuver. Lastly, driver interactions with the vehicle interface to perform a driving maneuver were categorized under execute (E). The characteristic labeled reaction was withheld from formal analysis, but the error classes associated reflected driver attitude and awareness.

With this coding structure in place, every single error was coded according to the three categories (SIP, D, and E) while remaining traceable to the participant ID of the client committing the error. In this way, the errors could be analyzed by age groups as well as by outcome of the on-road evaluation (pass/train/fail). First, errors committed within any age group with an evaluation outcome were normalized by the number of clients with the given outcome and within the group. Next, sums of the error rates (errors/person) were calculated for all outcomes within age groups for each of the three main categories (SIP, D, and E) and their classes (the core driving maneuvers/activities). Lastly, the overall sum across categories was clustered by age group with stacked bars to reflect passing, vehicle modification and not passing.

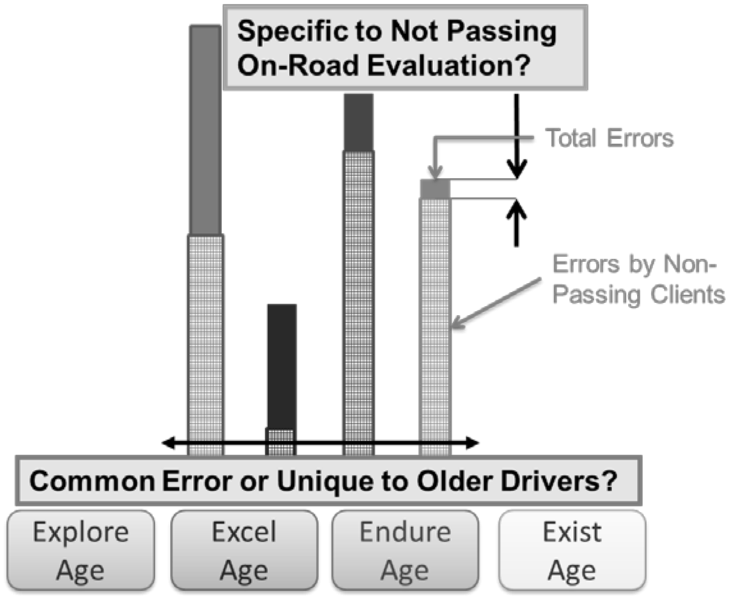


Figure 2-1. Visual Inspection Strategy Exploring Committed Errors Unique to Age Groups and Error Types Indicating Against Safe Driver Experience.

This exploratory analysis applied the visual inspection of the descriptive statistics based on Figure 2-1 above. All errors committed by clients with non-passing outcomes could be inspected for their specific attribution to clients who had marginal or failing outcomes in any age group. Additionally, any error type attributed to older drivers could be compared across the age groups to determine if it was unique or common to all drivers. Participants were categorized into four age groups: Explore Age (16-34), Excel Age (35-54), Endure Age (55-74) and Exist Age (75 and up). While the group names reflect a sense of progression in experiences with driving privilege, they are also fitting as general descriptors for challenging periods across a lifetime.

2.3 RESULTS

In 2009, 132 clients were documented as receiving ADP services. The age range for all clients was 16 to 95 and the distribution within age groups was as follows: Explore Age (avg: 23.5, +/- 5.1; N=29), Excel Age (avg: 46.0, +/- 6.0; N=27), Endure Age (avg: 61.8, +/- 5.3; N=41) and Exist Age (avg: 82.4, +/- 4.8; N=25). Despite the population-level risk of crash involvement and the elevation of mortality among younger and older drivers, 50% of the ADP clients were between the ages of 35-64 and mostly presented with the following medical impairments: cerebrovascular accident/stroke (19), traumatic brain injury (8), amputation (6), spinal cord injury (4), and diabetic neuropathy (3).

Most of the clients were comprehensively evaluated (clinical assessment and on-road evaluation) by the ADP, while a few only requested clearance of their vehicle modification setup and a small group received third party assessment/evaluation prior to visiting the ADP. This distribution of client services and outcomes is shown in Figure 2-2.

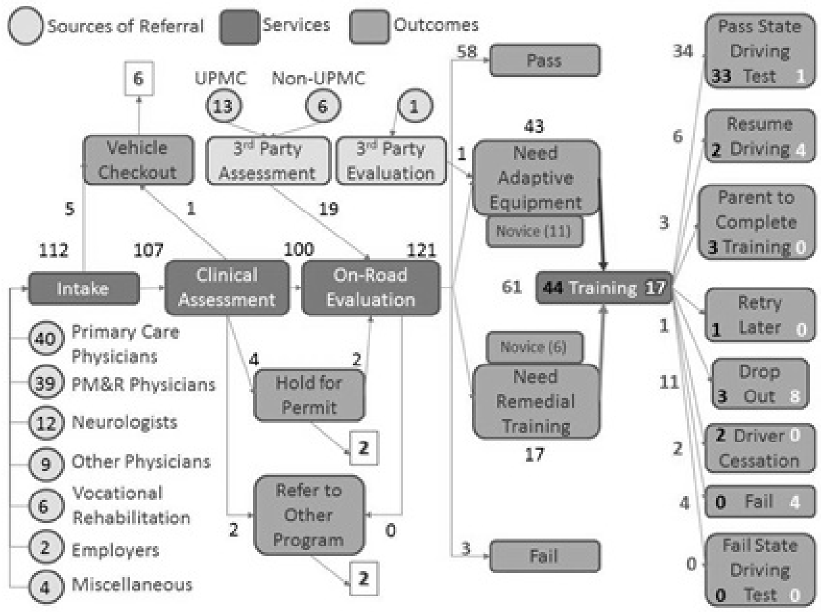


Figure 2-2. 2009 ADP Client Pathways for Referrals, Services, and Outcomes

Among the 112 clients entering the program directly, 102 received on-the-road evaluation. The on-the-road driving outcomes resulted in pass (48%), training with vehicle modifications (35.5%), remedial training (14%) and fail (2.5%). Recommendations from the ADP were for 101 clients (82.8%) to continue or commence driving, while 21 clients (17.2%) failed to resume or begin driving. Of the 21 clients, three dropped out without a final case resolution, two self-selected driving cessation, and four failed to complete the training intervention at a level satisfactory to the ADP.

2.3.1 Frequency of Errors and Hierarchy under Assistance

An enumerated list of unique errors committed reflected two contexts based on locations where driving errors occurred - road segments and road crossings (intersections). Table 2-1 shows three classes of errors that occurred on road segments traveled by 122 ADP clients. “Tracking” is a term used to indicate an effort to maintain stable positioning within a lane. The merge and lane change lists of errors indicate any intentional departure from a lane on a road segment.

Table 2-1. Errors Associated with Driving on Road Segments

Class	Total	Frequency	Errors	Context	Potential CUE	Potential ASSIST
Tracking	101	31	too close to side of lane ---**CUE**	steering	**X**	
		15	oriented to keep hand on spinner knob ---**CUE**	steering	**X**	
		12	tends to drive under speed limit	speed control	**X**	
		10	would exceed speeding limit	speed control	**X**	**X**
		5	required assistance at times---**ASSIST**	steering		**X**
		5	poor lane position	highway driving	**X**	**X**
		3	speed variable throughout session	speed control		
		3	simultaneously gas and brake (pedal strike errors)	speed control		
		3	oriented to proper vehicle spacing ---**CUE**	steering	**X**	
		2	unsafe hand positioning	steering		
		2	vehicle spacing not tested	steering		
		2	too slow, caused traffic to pass on right	highway driving	**X**	
		2	poor speed matching to flow of traffic	highway driving		
		1	slow to react to lane position errors	steering	**X**	**X**
		1	unaware of lane departure	steering	**X**	
		1	dismissive of steering problem	steering	**X**	
		1	became nervous	highway driving		
		1	not tested	highway driving		
		1	just nervous	decision making		
Merge	8	5	need to work on entry and exit	highway driving	**X**	**X**
		2	overyielding for merge of lane change	steering		
		1	unnecessary stop on exit for merge	highway driving		
Lane Change	12	6	lane change by mirrors only	rt and left turn		
		2	lane change without checking for traffic	rt and left turn		
		1	questionable check for traffic during lane changes	steering		
		1	switched turn lanes unsafely	rt and left turn	**X**	**X**
		1	help with appropriate lane selection ---**CUE**	rt and left turn	**X**	
		1	required assistance for lane change ---**ASSIST**	highway driving		**X**

The coding for indications of assistance applied the label "CUE" when words such as "help with…selection," "oriented," "cued," and "too…" were included in an error description. For the most part, the cues are constructive criticisms, but driving cues that point out the right of way or a nearby road hazard also reflected reduced levels of driving capability. The "ASSIST" label applied when a description included the word "assistance." Error listings with a possible assisted event were labeled "X" to show the potential extent of documented plus undocumented assistance for critical or unsafe errors that may also require cues or physical assistance while driving. Implied assistance (shown as the highlighted driving errors, where “CUE” or “ASSIST” was labeled) was associated with low-frequency driving errors except for the top two errors classified under tracking.

In Table 2-2, the enumerated list of errors continued on to show documented concerns that occurred with turns and intersection negotiations. Once again, “CUE” and “ASSIST” labels designated where steering assistance, braking assistance, and driving cues were explicitly used during on-road evaluation.

Table 2-2. Errors Associated with Driving on Road Crossings (Intersections)

Class	Total	Frequency	Errors	Context	Potential CUE	Potential ASSIST
Turn	69	28	over accel on left turns	rt and left turn	X	X
		16	inconsistent use of turn signal	signaling		
		13	over shoot and under shoot	rt and left turn	X	X
		5	no mirror checks or unsatisfactory	rt and left turn		
		3	awkward wheel recovery	steering	X	X
		1	oversteering	steering	X	X
		1	poor access of turn signals	signaling		
		1	cues to turn signal off after turn ---**CUE**	signaling	X	
		1	nervous with quick actions	decision making		
Intersections	102	59	rolled through stops	stopping	X	X
		7	hard acceleration	speed control		
		6	insufficient opportunity to observe	traffic signs and signals		
		5	trouble deciding right of way	traffic signs and signals	X	
		4	fast approach	intersections	X	X
		3	questionable check for traffic at intersections	rt and left turn		
		3	long rolling stop towards stopped vehicles	intersections		
		3	hard braking	stopping		
		2	required assistance for late braking ---**ASSIST**	stopping		X
		2	hesitant and slow	intersections		
		2	missed stop sign	traffic signs and signals	X	X
		2	hesitant and stopped in middle of intersection	rt and left turn	X	
		2	cued to make more mirror checks ---**CUE**	intersections	X	
		1	overly cautious and slow stops	stopping		
		1	missed waive through sign from driver yielding right of way	steering	X	

All ADP clients were reviewed according to the outcome of their on-road evaluation and the ultimate recommendations reported in their case record. The secondary analysis excluded the records for clients needing adaptive equipment, because vehicle modifications require training and state testing to add a restriction to the driver's license. Below, Figure 2-3 presents the percentage of cases where documented assistance was associated with passing or not passing (remedial training in a standard vehicle or failing). In addition, the figure shows how documented and potential assistance relates to the percentage of detectable errors within each of the five classes defined in the prior tables.

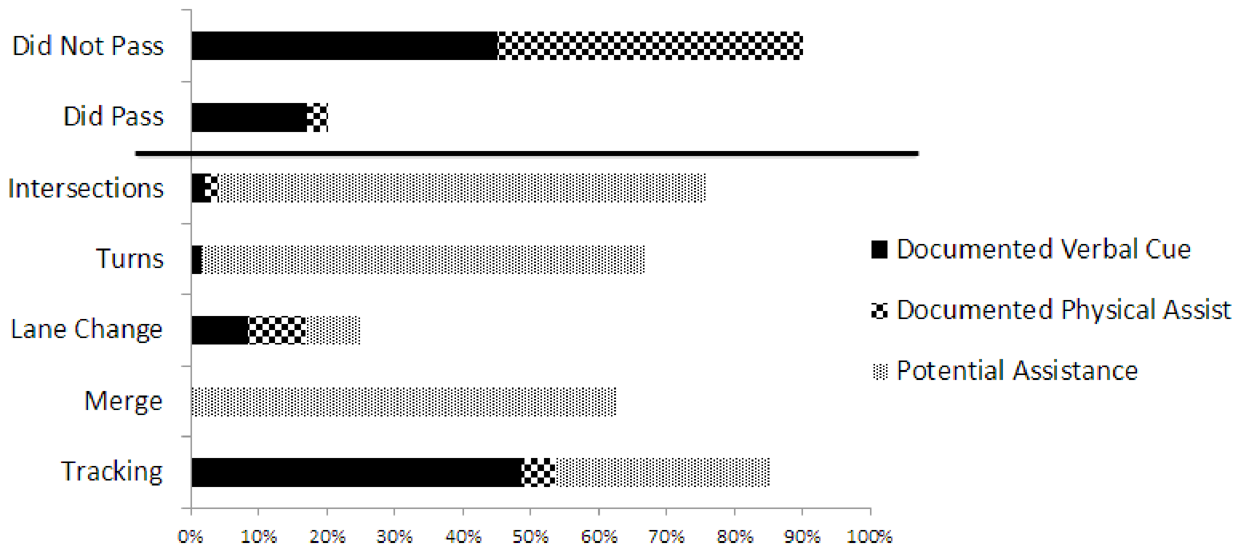


Figure 2-3. Percentages of Assistance Linked to Error Classes and On-Road Outcomes

Overall, 18 of the 20 clients who did not pass their on-road evaluation had an assisted-event (cues or assistance) reported in their baseline driving session findings. However, assisted-events were also documented in 14% of the 58 clients who directly passed their on-road evaluation. Most of the detectable errors related to an assisted-event aligned with tracking within the lane of a road segment. This driving task of remaining "centered" within a lane has been reported in prior studies on driving assessment (Hoggarth, 2011) and driving simulation (Longhitano, 2012) as a critical source of driving errors. Steering errors were also associated with senior drivers in each of those prior studies.

While very few documented events of assistance occurred for driving maneuvers related to road crossings (intersections and turns), there was ample documentation of assistance for driving maneuvers over road segments. There is no certainty whether these findings indicate that documentation accuracy declines with road crossings or if errors with road segment maneuvers are more significant when determining fitness to drive.

2.3.2 Documented CDRS-Assistance and Driving Errors

When separated by outcomes from on-road evaluation, a scatter plot of the number of unique errors by client age reveals two salient points. First, the number of unique errors showed a very distinct cut point at two as the maximum number of unique errors among clients (except for three cases) found to pass without need for any training interventions. Three clients only committed two unique errors and were recommended to take additional training. A second result showed a similar correlation for clients who were not aided during evaluation in any form (cues, assistance, or both) during driving. Much like the previous exception, two clients still needed training despite only committing two and three unique errors respectively during their evaluation session. Conversely, nearly a dozen clients were assisted during driving and received a passing recommendation. This included two clients committing three unique errors.

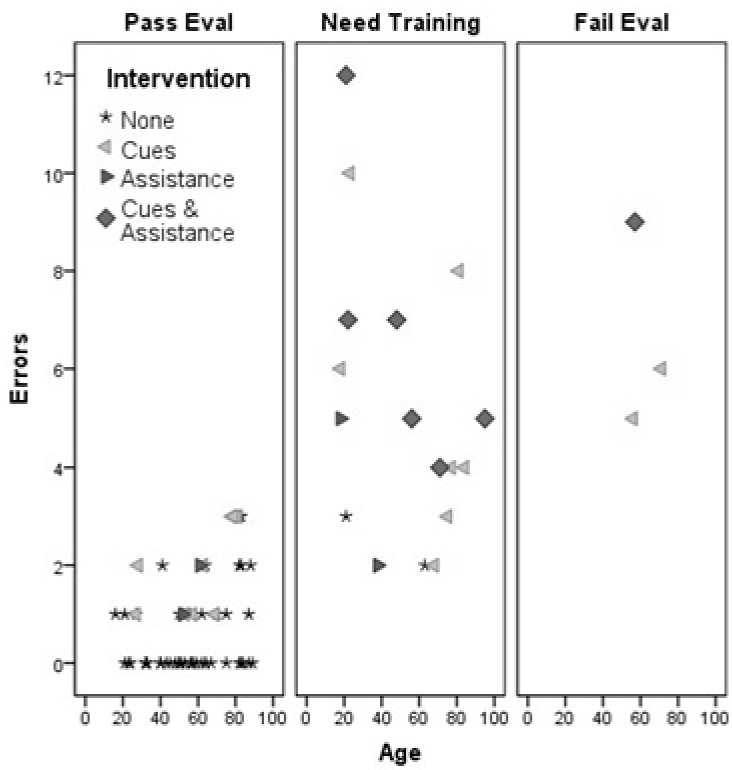


Figure 2-4. Graph of the Number of Error Types by Age of Individual Clients as Indicated by the Outcome and Documented Need for Cues and/or Assistance during a Driving Evaluation

In Figure 2-4, the analysis included only 78 clients to focus on evaluations using a standard vehicle interface. When considered as a whole picture, the results demonstrate that tracking two forms of assisted driving yields nearly the same differentiation between passing and non-passing clients as counting the number of specific errors during an on-road session. However, as many as 12 unique errors were committed by a client who was recommended for additional training. The final consideration to note is that there were no visible trends relating increasing errors with client age.

For a more formal analysis of CDRS assistance versus number of unique errors, Table 2-3 shows the calculations of predictive values given these two exposures during on-road evaluation and the final outcomes from the ADP. For the best results, exclusion of the clients training for use of adaptive equipment and exposure to more than two (2) unique errors during the driving session yielded the best predictive values, as shown in the far right column. The calculated error values were greatly reduced with both exposure categories based on the exclusion of clients requiring training with vehicle modifications using adaptive equipment. As the scatter plot had shown, the predictive values in Table 1 of CDRS assistance are closely comparable to a driving exposure with more than two unique driving errors. While specificity improves with the exclusion of training for adaptive equipment, the positive predictive value remains high for all clients.

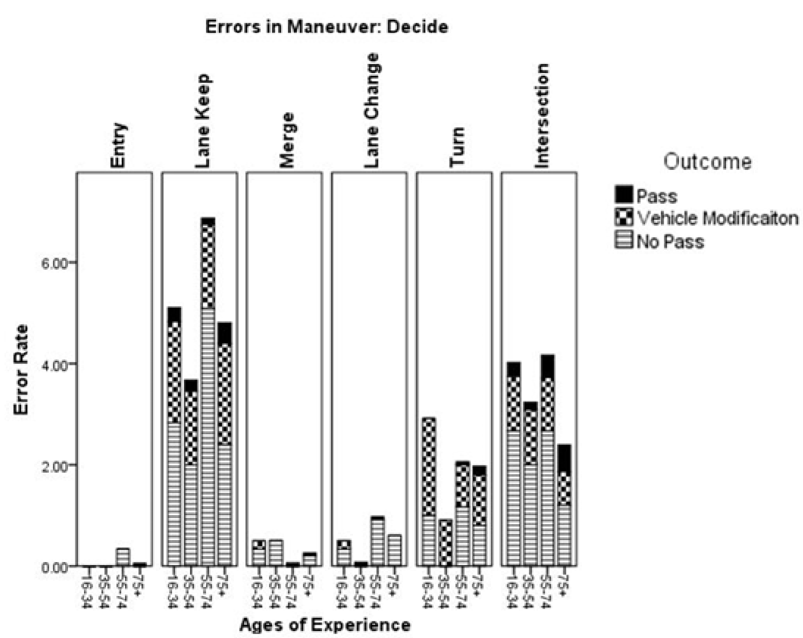
Table 2-3. Predictive Values for Driving Outcomes Given Exposure to CDRS Assistance Vs. Two or More Errors

	Overall (N=121)		Excluding Vehicle Modifications (N=78)		Excluding Vehicle Modifications (N=78)		
	Driving	Not Driving	Driving	Not Driving	Driving	Not Driving	
Unassisted	65	5	47	1	55	2	≤ 2 Errors
Assisted (cued, assisted, or both)	35	16	16	14	8	13	> 2 Errors
sensitivity	65.0		74.6		87.3		
specificity	76.2		93.3		86.7		
Error	58.8		32.1		26.0		
positive pred. val.	92.9		97.9		96.5		
negative pred. val.	31.4		46.7		61.9		

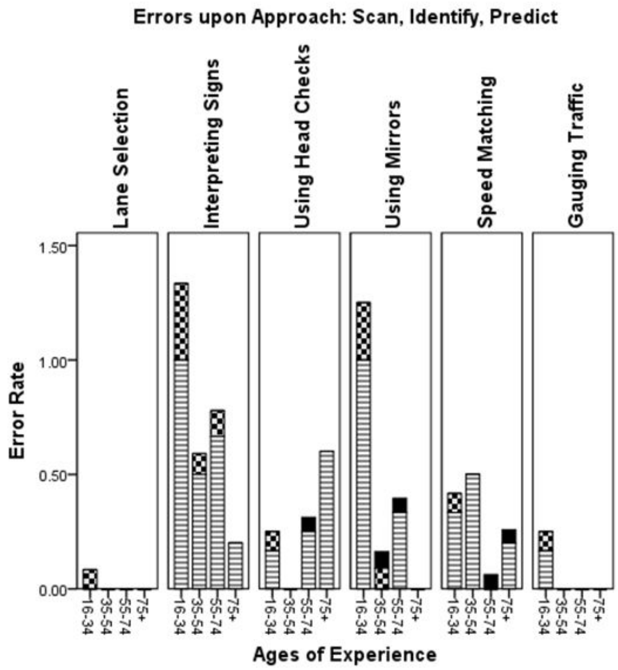
2.3.3 Driving Errors and the Signs of Driving Experience

The error coding process yielded six classes of errors for the SIP (Scan, Identify, Predict) category, another six classes for the D (decide) category, and three classes for the E (execute) category. Within each class, one or more unique reported errors from the client case records were combined to reflect the relative complexity each driving maneuver entails. For example, two of the classes of errors for the SIP category each had five unique errors, while the other four only had one or two unique errors. All of the 54 unique errors were classified by driving maneuvers in the D category. The errors not assigned to the SIP category were listed in the E category or related to driver reaction.

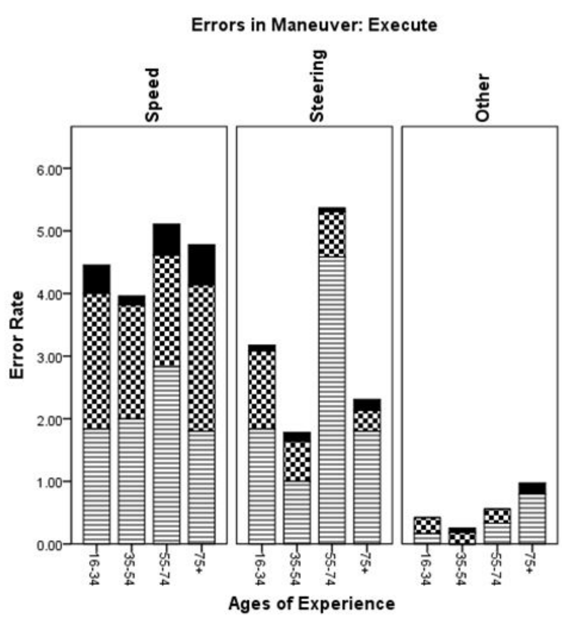
Figure 2-5 shows the error rate for each class of errors in three graphs to reflect the three categories of errors. The SIP category represents errors on approach to a driving maneuver, while category E related to errors in the course of performing a driving maneuver. In combination, the SIP and E categories divide the unique errors in category D between approach and reaction.



(a)



(b)



(c)

Figure 2-5. Plots of Error Rates by Age Group Stacked by Outcomes of Evaluation and Paneled by Classes of Error for the Main Category of (a) Decide with Subcategories of (b) Scan, Identify, Predict and (c) Execute

Errors upon approach showed that interpreting signs and using mirrors were the most prevalent issues for younger drivers in the Explore Age group (16-34). These two classes of errors were also the more complex of the SIP category, because they had five specific errors associated with each class. Some of the errors attributed to individuals using vehicle modifications from other age groups show how the use of a new driving interface can challenge experienced drivers and novice drivers alike. Clients within the Exist Age group (75+) were least likely to commit errors on approach except in performing head checks. Conversely, the younger clients were represented in all classes of errors and had the highest rate of errors committed in nearly all classes.

Rates of category D and E errors were more uniform error across the age groups. However, the Endure Age group (55-74) committed a much greater rate of errors in lane keeping as well as steering. Speed-related errors were almost the same for all age groups although elevated for the Endure Age group. For the most part, the Excel Age group (35-54) performed the best in nearly all classes of errors overall. Among all driving maneuvers, traversing intersections and lane keeping presented the greatest challenges to drivers. While those two classes of errors were challenging to drivers in all age groups, clients using vehicle modifications experienced difficulty with them as well as with errors associated with turns. Entry, merge, and lane change class errors were extremely rare although they were mostly attributable to non-passing clients.

2.4 DISCUSSION

The study results allow for multiple comparisons between age, disability, use of vehicle modifications, errors committed, and outcomes from driving evaluation or training. With this overview of client services and outcomes, it is possible to address broader trends and likelihoods that may impact quality of service and optimize successful outcomes. At the same time, the construction of measurable variables that relate to concepts of driving experience and capability will allow practical evidence from driver rehabilitation services to inform and guide state or national policies affecting driver licensing decisions.

2.4.1 Client Driving Errors versus CDRS Assistance

CDRS assistance showed results similar to the number of unique errors in relation to outcomes from on-road evaluation. Another indication of the results is that CDRS-aided driving correlates well with unique errors related to a non-passing outcome. However, the correlation of CDRS-aided driving did not present a high sensitivity or negative predictive value for a holistic picture of clients that should not be driving. Only the absence of CDRS assistance supported a high positive predictive value and strong specificity. Many clients did not commit any errors during on-road evaluation. Client scheduling demands may lead towards increased wait list times at intake with so many clients demonstrating fitness to drive despite the referral.

These findings presented a classification structure that may link errors during driving evaluation to the contributing factors of at-risk motor vehicle collisions reported in police reports (Classen, 2010). Unique to this study, our comparison of assistance to classes of errors also illustrates that explicitly documented assistance corresponded to relatively few of the total enumerated errors in reports. Though the errors may be few or less-frequent, assistance during supervised driving yields a specificity of 93.3%. With the addition of “Potential Assistance” percentages, it is possible to make broader associations among errors related to steering or braking. The mapping of assistance to outcomes from baseline driving sessions provides significant support towards the advancement of the novel NAViSection methodology (Beyene, 2011) using the very measures reviewed in this study.

Thus, there is an opportunity to classify these events with naturalistic driving data in order to study data patterns for driving maneuvers where CDRS assistance takes place compared to those where no assistance is required. That way, the determination of when a person should stop driving remains with the state licensing authority along with supporting recommendations from a CDRS. If a driver does not show evidence of these data patterns in their personal vehicle, then it is reasonable to suspect that they may be fit to continue driving until impact to driving performance is evident. This approach to incorporate naturalistic driving data would enable a triage effect on driver screening through mandatory physician reporting, age-based retesting standards, and age-based randomized sampling for retesting. Results of high specificity from CDRS assistance may be conducive to screening as an intelligent referral tool if translated into vehicle sensor data from intelligent vehicles (Grimes & Schulz, 2002). The diagnostic role of on-road driver evaluation should remain the premier standard for recommendation of driver cessation until definitive evidence supports revocation of driver licensing by any other means. This suggestion has been supported by many sources cited in the introduction, and the most direct call for on-road evaluation as the basis to decide driver fitness is presented by physicians (Laycock, 2011).

Within the present study, a closer look at the three clients who failed their baseline driving session from the ADP presented varying justifications regarding why follow up training was not offered. One client required assistance with steering and dismissed the issue, while excessive speed on normal roads occurred despite driving at slow speeds on the highway with an impact to surrounding traffic. A second client committed multiple traffic law violations and claimed to be unaware of their occurrence. In addition to missing a stop sign, the client also changed lanes across the full width of the road. These errors, in conjunction with shifting lane positioning and rolling stops, resulted in failing the baseline driving evaluation. Lastly, the third client documented to have failed on-road evaluation, had issues with lane positioning and was slow to react. The noted commentary of being “slow to react” was listed multiple times without further documentation of the driving maneuvers associated with the driving behavior. Ultimately, failing outcomes from on-road evaluation involved issues with attitude, awareness, or reaction time. Two of the three cases clearly documented multiple error types during the sessions.

2.4.2 Explorations of Driver Experience and Errors

Similar to the present study, findings from a review of cognitively impaired drivers (Hoggarth, 2011) reported that participants who failed on-road evaluations committed more road errors than those who passed. Lack of scanning techniques was a major attributable error among those who failed evaluations. Furthermore, four of the seven most common errors among participants who failed evaluation in the study are related to SIP category errors presented in the current study. The comparison across age groups showed that SIP category errors occurred more frequently in the Explore age group (16-34). This finding may indicate the association of driving experience to errors in hazard prediction and general awareness of a driver’s influence on the flow of traffic on the road. “Interpreting Signs” as shown in Figure 2-5, directly relates to one of the four errors in the study on cognitively impaired drivers. The study by Hogarth *et al*. highlighted awareness as an important factor, since the top two errors attributable to failing outcomes did not even involve control/driver input to the vehicle. A limitation of their study was that most errors lack association to specific driving maneuvers, which limits the potential to target affected driving maneuvers or the potential relation to crash involvement risk using existing records. This may support the need to capture errors previously associated with the "reaction" source of error generation, as long as the errors are coupled with "response" related errors within category E.

Having discussed errors specific to failing a driving evaluation, additional cases should be considered, in which errors were attributed to client cases requiring training before continuing to drive. Four evaluated clients had documented exposures that were not expected to result in a non-passing outcome on the on-road evaluation. Three clients had two error types documented in their evaluation findings. The fourth case involved three errors, yet there was no documentation of cues or assistance on record. The common error type listed in these cases was lane positioning, except for one client who exhibited higher driving speeds with questionable awareness of the error. The other two clients had lane position issues where one required "severe" assistance during a shift out of lane and hard braking, while the other was noted to need improvement with lane positioning for independent driving (although unassisted). The fourth case was the other client who was unassisted with lane positioning issues, yet exhibited declines in performance over time in the driving session.

A prior study of traffic violations by older adults (Classen, Shechtman, Awadzi, Joo, & Lanford, 2010) presented information to relate driving errors to the probability of injury in a crash. This association provides additional validity to the formulation of a hierarchy of errors. The study by Classen *et al*. found that lane maintenance, yielding, and gap acceptance were the driving tasks most probable to cause injury. A full definition of gap acceptance would involve any instance where the driver of a vehicle encroaches upon a space in the roadway to execute a maneuver within the traveling path of oncoming traffic/pedestrians (turns) or adjacent lane motorists (lane changes and merges). However, the violation-to-error classification applied in their study truncates all instances of gap acceptance errors to failures to obey a traffic control device. While the study by Hoggarth *et al*. listed gap selection as a top driving error associated with failing outcomes, the ADP records did not use the same terminology in the documentation of findings and recommendations. The limitation of traffic violation classification is that nearly all collisions can be interpreted as a driver's failure to yield for a motorist/pedestrian/obstacle/hazard. Thus, yielding and gap acceptance may be overrepresented and underrepresented respectively in the findings, while lane maintenance closely relates to the present study's mention of lane positioning as having greater influence on the recommendations from on-road evaluation.

All errors classified under Category D showed that the maneuvers for merges, lane changes, and turns were seldom committed among passing clients, although they were less likely to take place altogether. The distinction between turns and intersections was the segmentation of turning at an intersection from driving straight through an intersection. All intersection errors were divided into the SIP category as sign interpretation errors or category E as speed errors. Turns, on the other hand, were almost exclusively associated with category E involving steering errors. Within category E, steering was more critically linked to non-passing outcomes than speed. Comparison between the subcategories revealed more of the errors committed by clients with passing outcomes were associated with category E. This result supports a hierarchy of the category SIP subset of errors within the category D classification of all errors. Another interpretation may be that category SIP errors may indicate a lack of or decline in driving experience. The Classen *et al*. study also supported the relation of category SIP errors to crashes, although "adjustment to stimuli" was linked to 10 separate violations.

The results from error types committed and outcomes to on-road evaluation present a number of considerations on how driver rehabilitation specialists consolidate their findings into recommendations out of the baseline evaluation. There is a need to justify two main recommendations: (1) my client does not currently show independent driving capability reflecting fitness to drive (2) my client does not show a driving capacity within reason to attain the necessary driving capability through training. Overall, issues involving lack of awareness and dismissive attitudes to noted driving errors led to failing outcomes. The frequency/severity of a situation has shown the impact of leading to non-passing outcome (lane positioning) and a failing outcome (slow to react). While the occurrence of multiple error types was the basis for cases associated with driving cessation, a few cases demonstrated that lane positioning presented a more powerful error type that could almost independently justify a non-passing baseline evaluation in support of remedial training. Lane positioning is likely of higher importance due to the default, or continuous, responsibility for drivers to stay in their lane. Lane keeping reflects a level of vigilance by a driver to maintain a safe distance between their vehicle and other motorists/people in adjacent lanes, sidewalks, or road shoulders.

2.4.3 Study Limitations

Despite the clear results of CDRS assistance in relation to error types committed and outcomes from on-road evaluation, the data available through medical record review did not have any quantifiable measures of cues and assistance to reveal how many times CDRS assistance took place within a session and how extensive each episode was over the course of a driving session. Furthermore, the applied coding scheme lacked the depth to independently link error types to specific risks of involvement/injury in traffic accident scenarios.

The digitization of data from client records involved some lack of clarity on how/when to document assistance. For example, it was not completely clear whether or not to count phrases including “request for cue,” “intervention,” or “orientation” in client records as spoken cues, physical assistance, or neither during the session. The present study limited analysis to the baseline driving evaluation, and did not explore the potential for decreases in CDRS assistance to serve as a measure of progress in driver training. In review of the original four characteristics of error generation, the characteristic labeled reaction was withheld from formal analysis, but the error classes associated to it reflected driver attitude and awareness when driving. These characteristics reflecting a client’s attitude were central to the three failing outcomes from initial driving evaluations, but there is no construct to capture how these errors relate to CDRS-assisted driving.

With respect to the clinical setting, ADP clients presented a limited representation of vehicle modifications, primarily the low-tech range of hand controls and left foot accelerators. The ADP utilizes a standard driving route with deviations to target areas of concern for an individual. In some instances, the driving route was selected in the vicinity of a client’s home. The analysis of client demographics did not include medication use or the context of seasonal variations in road conditions.

2.5 CONCLUSIONS

Increasing demands for driving evaluations among people with medical impairments will challenge professionals to provide a greater level of counseling services when driving restrictions, training, or cessation are recommended. The availability of more evidence to support counseling and client education may promote greater trust and harmony among health care professionals and current or potential drivers. The results of this study illustrate that assistance by an evaluator during on-road evaluation was associated with 90% of the cases where clients did not pass their baseline driving session. While documented assistance mapped to a small percentage of the unique errors recorded within most classes, the simple nature of an error resulting in assistance appeared to turn low-frequency error events into high criticality ones in determination of a client's outcome.

Although the errors cannot be considered of equal weight to the demonstration of driver capability and determination of fitness to drive, driver errors that require assistance could indicate a greater probability of crash involvement. These findings support our current development of in-vehicle technologies to digitally log assistance (steering assistance, braking assistance, driving cues) during on-road assessment. A future study will aim to quantify the frequency and duration of assistance in hopes of identifying a cut-point at which to differentiate assistance among clients who do not pass versus the clients who do pass.

The comparison between CDRS intervention and total errors in relation to outcomes from the driving evaluation was nearly identical for specificity and positive predictive value. The summary of all findings suggest that CDRS assistance might be an ideal marker to reflect when errors of many types are taking place. Using vehicle sensor technologies may be a feasible way to both enhance reports with evidence of CDRS assistance and could facilitate further advancements towards the realization of an intelligent referral system or follow-up screening system. The future practices of physician reporting of medically-impaired driving could be strengthened by allowing referral to driver rehabilitation programs with in-vehicle data recording, whereby quantitative evaluation of driver fitness would reflect probabilities of crash involvement and crash severity to balance the decisions by medical advisory boards of state licensing authorities.

Finally, the concept of driving experience was evident in the error rates committed under the SIP category among the younger drivers and non-passing outcomes with respect to all other drivers. At the same time, errors related to steering and mirror checks were attributable to marginal and failing drivers in the older age groups. Thus, the lack of and decline in driver experience can be seen in the errors committed during on-road evaluation.

3.0 PROPOSAL OF THE NAVISECTION METHODOLOGY

3.1 INTRODUCTION

The basis for driver safety protection is grounded in the Haddon matrix (1973), which categorizes crash risk by its source (person, vehicle, and environment) and the phase of its occurrence (pre, during, and post). Driving incidents can range from near misses or property damage to injury and fatality. With the combined analysis of crash causality and severity, safety experts have been challenged to reduce the burden of injury in society so that independent transportation can thrive. These efforts have led to many improvements for drivers at the levels of post-crash response, in-crash protection, vehicle safety, and environmental (physical or social) reforms. A challenging aspect of safety is to prevent accidents, pre-crash, at the level of the driver. When viewing driver-level factors, the AAA Foundation for Traffic Safety (2010) surveyed societal views on safety regarding errors in the categories of distraction, impairment, and behavior/attitude. The errors made by drivers in the pre-crash scenario present a great challenge for safety experts when addressing active correction or behavioral change. Many passive correction approaches have the advantage of initiating change by enforcement of standards or automation beyond the driver's control.

The topic of driver impairment can introduce a wide variety of concerns. In the broadest view, distractions can be interpreted as external factors motivating impairment through cognitive errors, and unsafe behavior/attitude can be seen as internal impairments to decision making processes. However, the central driver impairment issues studied by the National Highway Traffic Safety Administration (NHTSA) Driving Safety Group (2011) involve alcohol abuse, substance abuse, medication side-effects, and medical-impairment in older drivers. Drowsy driving could also be included in the impairment category. Younger drivers are viewed as inexperienced and punitive measures for reckless/aggressive behavior are enforced. Many drivers become transiently impaired due to the consumption of alcohol/drugs or certain medications, but older adults develop chronic impairment beyond the transient forms caused by lifestyle choices.

Reality on the US roadways greatly burdens older drivers. Janke's literature review (1994) concluded that older driver competency particularly entails dementia, the combined effects of impairment with medications, and the frail elderly with reduced time driving on the road. The study "Older Driver Involvement in Injury Crashes in Texas" by Griffin (2004) reported that drivers over the age of 65 are 1.78 times as likely to die in car crashes as middle-aged drivers between the ages of 55 to 64. Results were attributed to the likelihood of illness, physical ailment, or perceptual lapses. Furthermore, MacLennan *et al*. (2009) showed that 69% of surveyed drivers, age 55 and older used one or more prescriptions known to affect driving. While crash mortality per miles driven was upheld by Eberhard (2008) to be higher for younger and older drivers, older drivers' capability was called into question with evidence that only infrequent drivers are an increased risk and older drivers are more of a risk to themselves than other road user age groups. The RAND Corporation (2007) reported that drivers 65 and older are one-third as likely to cause auto accidents as drivers age 15 to 24. Conversely, the report stated that senior drivers are nearly seven times more likely to be killed in two-car collisions than younger drivers. At the same time, Cooper (1990) found that the average number of accidents was not higher for older driver groups, while the number of accidents per conviction was.

Considering the breadth of driver causes of crashes, the pressing question is then how to definitively assess a driver's safety on the road. To clarify, this can be specified as ability to handle crash risk levels typically encountered by drivers. Brookhuis and de Waard (2003) described the need for a "golden yardstick" to assess driving performance with regards to driver impairment, but the discussion lacked any mention of medically-impaired older drivers. Eby and Molnar (2008) edited the recommendations report of the North American License Policies Workshop, where AAA Foundation President, J. Peter Kissinger, shared a projection that by the year 2025, people aged 65 and older will account for 25 percent of drivers, an increase of 15 percent from 2005. This trend is well noted by Stutts and Wilkins (2003), whose survey and focus group results called for increased involvement of driving schools under the practice of CDRS certification. In addition to our society's impending growth in percentage of people age 65 and above, the rise of chronic disease among middle-aged Americans causes great concern regarding wellness and mobility during a major period of productivity in a person's life.

3.1.1 Screening the Community for Fitness to Drive

Fitness to drive is a context-based concept. Before actual evaluation of on-road driving, driver fitness includes multiple associated issues, including knowledge of driving rules and regulations, the means for owning/maintaining a vehicle, and the basic motivation (volition) to continue driving. Multiple sources provide extensive and/or contemporary views of holistic driving models (Lindstrom-Forneri et al, 2010; Heikkila and Kallanranta, 2005; Beatson and Gianutsos, 2000; and Pellerito, 2006), but there is less information available on how to systematically practice and standardize all aspects of driving into a comprehensive evaluation. Clinical assessment standards have yet to be adopted, although literature is available to help provide a baseline for testing (Eby et al, 2007; Dickerson et al, 2011). The dissertation work of Justiss (2005) provides one example of a systematic approach to on-road evaluation to strengthen the repeatability of assessments and clarity of driver ratings. To complement the sophistication of structured on-road evaluation, Horberry and Inwood (2010) reported the benefits of standardizing evaluation using a static assessment rig (SAR) for its high face validity and potential to build a consensus towards key driver characteristics for safe driving.

To preface the current aims, driving capability is viewed as the principle focus of an on-road driving assessment when providing recommendations and findings related to driver licensing. To clarify, the intent is to focus on capability and not capacity. A driver is expected to be able to independently operate a vehicle and to identify risks/hazards/obstacles. Within this expectation, driver capability reflects overall performance within an exposure of driving as well as competency in detecting road hazards and traffic laws. In essence, driving capability is the product of driving performance and driving competency. Capacity is assessed at the point where driver capability goes to zero if performance lapses in the absence of independent vehicle operation or competency declines due to decreased awareness in rule following. Therefore, a driver's capability must remain above the demands of exposures presented within the natural environment that they travel within. In this way, driving capacity is only involved in assessment as a result of insufficient driving capability, and the true capacity of a capable driver is not of interest.

A topic of wide debate, the responsibility of screening the population for driving is largely placed upon the family doctor or a mandatory age-based review of license renewal. Langford and Koppel (2006) summarized the case for and against mandatory age-based assessment of older drivers by reporting no demonstrable road safety benefits from the age-based approach despite over-representation of older drivers in fatal crashes. Many states' Departments of Motor Vehicles (DMV) control licensing with more routine renewal requirements beginning at a certain age. The challenge is how to assess licensure at time points of interest with respect to medical impairments. The 2003 Stutts and Wilkins study supported the role of medical advisory boards with DMVs to fulfill this role for the rising demand in society. Coughlan *et al*. (2004) surveyed a large number of older drivers who self-selected when to stop or restrict driving without a formal screening processes either independently or through conversations with a family member or trusted friend.

As a supplementary approach, primary care physicians or specialists are expected to report patients who exhibit clinically-measurable impairments to driving related skills in the NHTSA and AMA (2009) guide. Odenheimer (2006) shared strategies for how healthcare providers can maintain a trusting, comfortable relationship with patients. Currently, this practice is only fully mandated in about one-fifth of the states in the US. Even within these localities, retests are ordered by random sampling for drivers beyond a certain age. Research evidence is also in place to help predict crash risk based on older drivers' past driving history (Rothenberg, 2009). The Association for Driver Rehabilitation Specialists (ADED) Best Practices Committee (2009) provides standards of practice and certification for driving evaluators to facilitate licensure decisions by DMV medical advisory boards. The role of the CDRS is to provide a broad range of services that best assess a client's fitness to drive and maximizes their potential to remain safe drivers on the road.

3.1.2 Technologies for Driver Safety

The Research and Innovative Technology Administration (RITA) of the US Department of Transportation released their Intelligent Transportation Systems (ITS) Strategic Research Plan for 2010-2014 to outline the five-year trajectory for anticipated research initiatives. Former RITA Administrator Peter Appel (2010) shared that RITA was created to coordinate multimodal research, advance technology deployment, supply comprehensive transportation statistics, and further education and training opportunities in transportation-related fields. In 1991, the ITS Society (2008) was formed as a federal advisory committee, and has since been a leading advocate for ITS development as well as a thought leader in transportation policy. The current growth of attention towards ITS applications presents great promise for cross-disciplinary exploration and the rapid deployment of effective technologies. Anderson *et al*. (2011) recently reported a list of potential crash reductions by technology modality, and found that monetized crash savings were greatest for forward-collision avoidance, alcohol interlocks, and fatigue management systems.

The more mature market for ITS solutions is commercial transportation with fleets of delivery trucks. For example, the Federal Motor Carrier Safety Administration has sponsored efforts to demonstrate the viability of Lane Departure Warning Systems which has been addressed in the work of Houser *et al*. (2005) for concepts of operations and voluntary requirements for implementation, and Houser *et al*. (2009) for a cost/benefit analysis. When viewing the personal vehicle market, some ITS features have been growing from the perspectives of entertainment (for passengers), comfort/customized settings, and vehicle maintenance support. Now, most of the commercial vehicle safety systems have also been transitioned to personal vehicles in this segment with driver assistance features. Within this segment of technologies, vehicle-based systems allow for event data recorders (EDRs) or in-vehicle data recorders (IVDRs) to log data of interest for use by automobile manufacturers. This type of technology is also available as an aftermarket solution that has been used by researchers in the field of naturalistic driving studies. Gabler and Hinch (2009) demonstrated the application of EDRs in the process of a rear-end crash to consider pre-crash driving behaviors. However, the ITS technologies on the horizon may completely revolutionize the boundaries of driver assistance with direct short range communications. Andreone and Provera (2005) highlighted ways that vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication may help alert drivers to developing hazards beyond the driver's line of sight.

In order for technologies to reliably predict or identify road hazards, engineers, human factors experts, and psychologists have strived to define critical performance measures for rating the safety of a scenario. A special issue of the journal, Applied Ergonomics, presented the latest research on simulation or modeling of driver behaviors and the complexity of driver-vehicle-environment monitoring to support drivers on the road (Casucci et al., 2010; Cacciabue and Carsten, 2010; and Amditis et al., 2010). In considering decision criteria among expert driving evaluators, Jamson *et al*. (2008) previously demonstrated the difficulty and barriers to developing a safety index for driving through a Delphi study. Concluding statements pointed to studies using naturalistic driving data to compare crash and non-crash driving scenarios. The Virginia Tech Transportation Institute (Instrumented-Vehicle Fleet), University of Michigan Transportation Research Institute (Instrumented Test Vehicle Fleet), University of Iowa Division of Neuroergonomics (ARGOS and NIRVANA), and the Massachusetts Institute of Technology AgeLab (AwareCar and Miss Rosie) have produced a wealth of US-based research in this area.

A future in which ITS advancements are embraced does not come without hurdles. Challenges and doubts are visibly present within the Pellerito text (2006) regarding the extent to which ITS solutions are being proven before deployment and the true value to driver safety as opposed to overall road safety. One way to view this concern is by considering the difficulty of developing biomedical technology development in general. In addition to the complexities of designing and testing sound engineering systems, demonstrating real effects of change that correct or stabilize impairments to humans is also burdensome. The haunting question for the future is then: How will new ITS safety features in vehicles affect the decision making processes for assessing driver fitness? While safety features may certainly protect against crashes, ongoing research aims to determine whether the features prompt drivers towards safer behaviors or if the most effective safety features involve active assistance in crash mitigation scenarios. This concern would be best addressed if the ITS and CDRS communities joined to bilaterally strengthen advances within their respective fields. The research to date has not linked data collection of naturalistic driving data to data collection of CDRS intervention during driving evaluations, and studies involving medically-impaired drivers are not collecting data at a rate suitable to inform national policies on driver licensing for people over age 65 and people with disabilities. Although driving simulation and computer-based testing studies have historically tackled the challenge of assessing the performance of drivers with disabilities (Rizzo et al, 1997; Dobbs, 2005), driving evaluation on the road remains as a critically necessary service.

3.2 METHODS

Safe Driving is one of the research thrusts funded by the National Science Foundation under the QoLT ERC. Under the Safe Driving umbrella of projects DriveCap is an effort to extend the reach and service of driver rehabilitation programs. Developed at CMU, DriveCap is a low-cost, portable package of vehicle sensor technologies that can be installed onto most automobiles within an hour. In concert with the primary aim of enhancing driver rehabilitation, the research themes aim to promote a safety philosophy for self-selection of safe driving behaviors. Figure 3-1 illustrates this perspective as a frequency plot of driving activities over the continuum of risk levels. As opposed to attempting intervention during unsafe driving behaviors exceeding an acceptable safety threshold, the Safe Driving philosophy is to apply assistive technology to facilitate an overall shift towards less risky driving behavior exhibited on the road. This figure was adapted from driver safety philosophies already published by Knipling *et al*. (2004) in safety programs for commercial transportation.

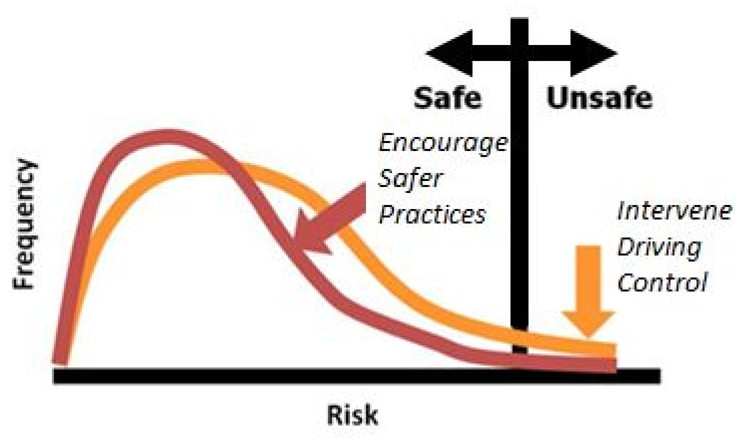


Figure 3-1. Safe Driving Philosophy Adapted from Commercial Driving Risk Models

With the prevailing view of impairment/distraction as an avoidable, transient scenario, it is critical to also consider people with disabilities and the rise of chronic disease as a new paradigm for driving with irreversible impairments. In Table 3-1, crash risk factors are spread out under the three categories of crash causality, while pre-crash risks are further categorized into internal and external risk factors.

Table 3-1. Pre-Crash Scenario of Haddon Matrix Broken into Internal and External Factors

Medical fixed impairment Medical transient impairment Substance-related impairment (drugs, alcohol, medications) Fatigue Behavior/Attitude/Experience	Flat/low tire Steering wheel loss of power assist Gas/brake pedal malfunction Mirror/windshield setup or cracks	Driver Cabin: noise, alarms, glare/light, smell, vibrations Passengers Cargo	***Internal Risk***
Capability Deficit	Vehicle Malfunction	Vehicle Environment	***Crash Risk***
Driver Error Sources →	***Vehicle Error Sources →***	***Environmental Context***	
Distraction/Interference	Vehicle Operational Limits	Driving Environment	
Distraction: Cell, Radio/CD, Food, Make-up Interference: Poor Position, Poor Access	Turning stability Braking distance Traction over slick/compliant roads	Weather condition Road/Traffic condition Road/intersection design Street signs and signals Local traffic laws Fellow motorists	***External Risk***

3.3 RESULTS

A novel method for ITS to complement driver rehabilitation programs in the form of a validation pump was proposed. While driver rehabilitation programs establish and verify clinical standards of driving assessment based on ITS-generated measurements, the technology in turn gains valuable ground truth for systematic evaluation of driving safety and performance. This union of technology and clinical expertise has been termed “NAViSection,” as shown in Figure 3-2.

The definition of NAViSection is the enhancement of supervised driving evaluation by collection of naturalistic driving data for supporting evidence and context-based driver education. Within the driver rehabilitation field, this technique would translate the expertise of a driver rehabilitation specialist into sensor data patterns, which create a standard of evidence-based practice for assessing driver capability. Towards the goal of enhancing driver rehabilitation, the intent is to accommodate measures on all road types, in any weather conditions, and during the entire on-road driving session (an hour or more). Combining the findings across driver rehabilitation programs will facilitate a discussion of which kinds of errors determine driver capability and the proper thresholds for measuring safety. In comparison to past methodologies employed by researchers, NAViSection unites crash risk with the rules of the road in driving assessment by tracking interventions of the driving evaluator or CDRS. This design methodology emphasizes a fundamental principle of the QoLT ERC systems - to be context-aware and person-aware in order for technology to adapt to the demands of the user.

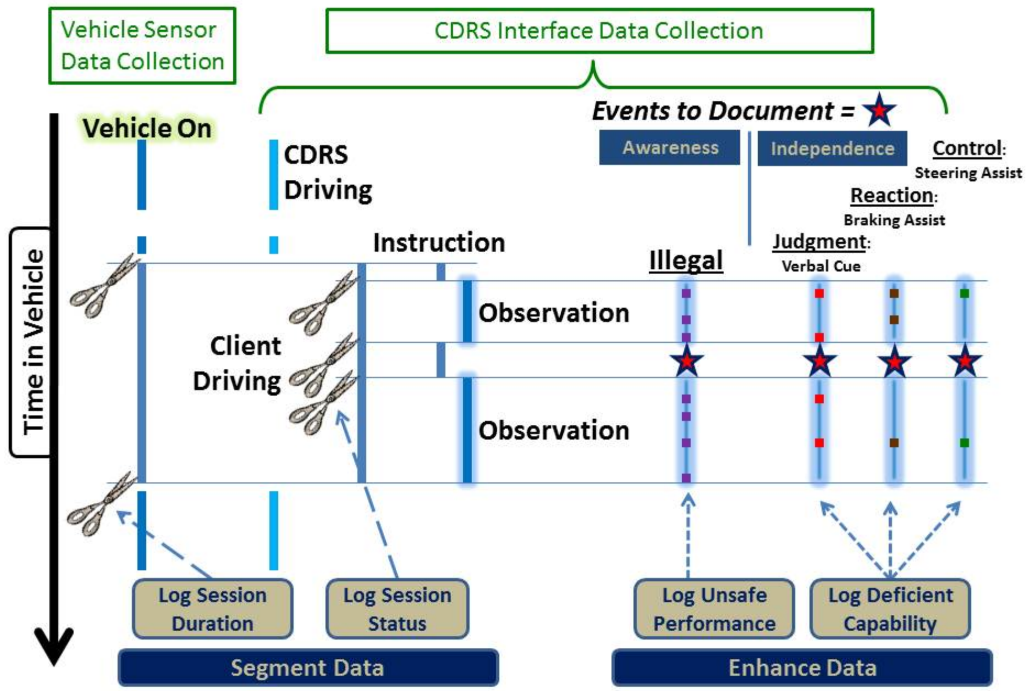


Figure 3-2. NAViSection Scheme for Data Segmentation and Enhancement

ITS in vehicles will be turned on or available at all times, but clinical visits will require more sophistication to identify the data corresponding to specific clients. The first step is to segment data according to times when the client is driving the vehicle. Driving evaluation is not always a testing scenario. Thus, there may also be a need to segment data according to when the client is actually being evaluated and when instructions are being given or training is taking place. The significance of this step of segmentation is to consider the impact to measures of driver safety or performance such that algorithms do not skew estimates of an individual's driving capability.

Besides the segmentation features, there is the possibility to enhance the data for contextual interpretation and categorization of error types due to the presence of a CDRS. The enhancement features rely on two modes of event detection. The event detection of awareness allows for CDRS-witnessed errors to be flagged in time with an illegal event log. For instance, a physical button could be pressed when a client runs a stop sign at an empty intersection. Although there is no risk of harm or collision, the driving maneuver is clearly unsafe and illegal. Conversely, certain events coincide with or lead towards the risk of an accident or collision. In this scenario, the CDRS must first ensure the safety of the client, their own life, and the program vehicle. Automatic event detection is necessary under this scenario to log the occurrence of an uncontrolled event. CDRS-assisted driving events, such as steering, braking, or verbal cues, become the target of this class of event detection, where the vehicle is the witness to any incidents for decision making support. Thus, driving capability is evaluated by CDRS-witnessed driving events to assess a driver's awareness and CDRS-assisted (vehicle-witnessed) driving events to assess independent control.

Finally, the complement of segmentation and enhancement markers with ITS-based naturalistic driving data provides the means to document evidence supporting clinical findings and recommendations within mandatory program reports (See Figure 3-3). Typically, paper-based checklists and narratives are the standard documentation technique for reporting comprehensive evaluations. Beyene and Lane (2011) found few driver rehabilitation specialists that utilize technology to measure driving performance on the road. Given an added CDRS logging interface, the NAViSection technique unlocks the potential of ITS data collection for clinical use. Figure 3-3 uses an image from the DriveCap system to represent the integration of any ITS solution for data collection. With a robust routine for time synchronization, the NAViSection-based markers can direct the display of acquired naturalistic driving data to key points of interest within the navigated path of the driving evaluation session. The CDRS may annotate data plots or tables that support the program findings and recommendations, and the interpretations of naturalistic driving data promote evidence-based practice for driver rehabilitation. While variations among CDRS-witnessed driving events may make comparisons between programs more difficult, the logging of CDRS-assisted driving events will more clearly reflect scenarios in which CDRS engagement is necessary to avoid a collision.

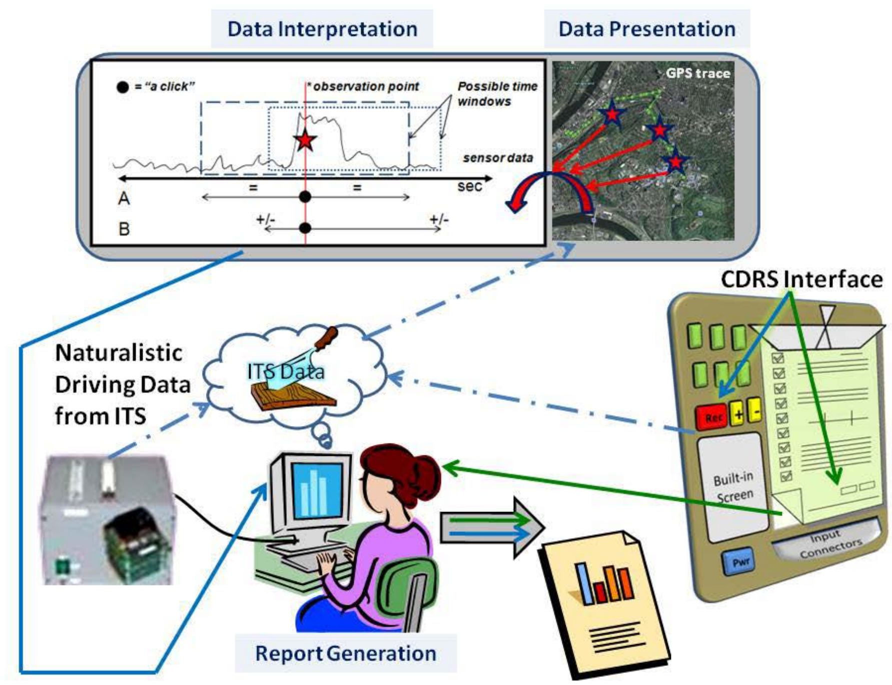


Figure 3-3. NAViSection Model for Data Presentation, Interpretation and Reporting

General algorithms can make use of various data sources in order to generate automatic report data that is consistently required for internal and client records of a driver rehabilitation program. Recommendations for clients should, at a minimum, address driving evaluation exposures, capability, performance, and driver fitness recommendations. The exposure measures could specify the driving maneuvers performed, road types traveled during assessment, and total time spent on the road. Capability and performance reporting can include rates of independent vehicle control and counts of assisted driving events along with quality measures regarding speed control, distance management, and general smoothness of driving maneuvers. Recommendations on driver fitness should relate back to clinical measures indicating functional performance capabilities/impairments and highlight areas of weakness in driving maneuvers based on exposures, plus capability or performance measures. This approach would facilitate the recommendation for a client to resume driving, continue with training/remediation, or transition to alternative transportation modes with driver cessation. When faced with a client's resistance to driver cessation, the driver rehabilitation specialist benefits from having objective data to reinforce their licensing recommendation.

3.3.1 Forecast of Expected Benefits and Limitations

The NAViSection methodology could impact driver rehabilitation programs in additional areas of service delivery. While the intended development of the approach was targeted at on-road driving evaluation, there are a number of ways (see Table 3-2) to assist the administrative and programmatic aspects of driver rehabilitation programs.

Table 3-2. Scope of Applications for NAViSection within Driver Rehabilitation Programs

Administrative	**Program evaluation**	**Enhanced reporting**
Billing – driving time log	Training – client error types	Safety – performance measures
Maintenance – mileage log	Equipment – services requested & client needs	Quality – accuracy/reaction measures
Scheduling – travel time log	Advertising – client volume by region	Capability – independence measures
		Exposures – driving time on different road types

Benefits from NAViSection can extend beyond driver rehabilitation programs to facilitate research as well. Studies can be conducted to identify pure driver capability measures without confounders of in-vehicle distractions (ex. eating, putting on makeup, kids in the back seat, passengers, etc.) or vehicle performance shifts (ex. multiple vehicle types, low tires, poor windshield wipers). At the same time, there would be a large volume of naturalistic driving data available through driver rehabilitation programs nationwide.

For advances in comparative research, data from many clients with cognitive impairments could present gradients for comparison groups based on diagnosis for distracted drivers. In general, NAViSection would provide much cheaper instrumentation costs and faster data collection with a single program vehicle or fleet of evaluation vehicles covering all classes of motor vehicles. Also, the presence of an expert witness (CDRS in the passenger seat or two-person evaluation team) allows for real-time documentation of contextual details during actual driving events of interest that can enhance the interpretation of data. Further, the clinical setting provides the safest strategy to test people on the road for naturalistic driving data while driving with impairment. The NAViSection methodology should produce more effective and efficient collection of impaired-driving, near-misses, or other incidents in driver rehabilitation programs.

With all the benefits of NAViSection for research efforts, there are certain limitations to the scope of driver safety issues due to the setting of data collection. Within a driver rehabilitation program, there would likely be no night-time driving data. While the pure assessment of driver capability is a potential benefit, there would be no cell phone use or texting while driving and limited distracted driving data due to events within the vehicle. The only plausible connection that could be drawn would involve intentional distractions by the evaluator (such as holding a conversation) when testing for divided attention during the sessions.

Overall, efforts to understand crash causality are equally of interest to driver rehabilitation specialists. Their job is to identify crash causality due to the driver by assessing and evaluating driving capability. The on-road portion of a comprehensive evaluation definitively uses naturalistic driving as a strategy. In some cases, driving evaluators are also used prior to heading onto the road. With the proposed methodology, measurement technologies and surrogate measures can be applied in order to generate safety management strategies for medically-impaired drivers. The advancement of ITS technologies should be introduced here in order to properly achieve validation within design cycles regarding safety management and understanding crash causality.

3.4 DISCUSSION

The paths of development for ITS solutions and driver safety screening appear to be seeking the same target with disjointed mapping systems behind their strategic plans. If these two paths were to intersect, NAViSection would be the clear answer towards building a consensus on driving safety measures. NAViSection may lead to a common platform through which to address the more complex issue of driver performance. While the driver rehabilitation community would seek perspective on performance for the advocacy of driving restrictions and gradual progression towards driver cessation, the ITS community would seek an understanding of performance in order to modulate their solutions to fit the varying demands of our roadways or diverse levels of ability among our motorists.

The following two case studies will apply the stated benefits and limitations of NAViSection to prominent research efforts in naturalistic driving data interpretation and driver screening process improvements. Without attempting to exhaust all comparisons of NAViSection with the example case methodologies, these case studies are intended to spark wider discussion and consideration of how driver rehabilitation programs could combine with ITS design and development to mutually enhance the causes of each critical endeavor for promoting driver safety.

3.4.1 100-Car Naturalistic Driving Study

Neale *et al*. (2005) reported an overview of the 100-Car Naturalistic Driving Study stating 10 specific goals. The NAViSection methodology could potentially address all the listed goals except severe fatigue, but with reduced exposure to secondary task performance or traffic violations. With the expectation that a massive repository of data could support future research, the NAViSection methodology poses that data could continually be collected with refinements to instrumentation or supporting documentation completed on the fly as the knowledge base and opinion of the research community change.

In the 100-Car Naturalistic Driving Study, no driving instructions were given and no experimenter was present during the data collection. While video data capture allowed a fair amount of contextual evidence for events that transpired during the study, the NAViSection methodology would ensure a much greater level of descriptive detail for the context of driving errors within a driving session.

Also, seventy-eight percent of the study participants drove their own vehicle. Very few people would drive their own car with the NAViSection methodology, although there is a possibility that instrumentation could one day be installed in personal vehicles for clients of driver rehabilitation programs.

Considering the subjects recruited and vehicles instrumented, the 100-Car Naturalistic Driving Study yielded data on the targeted drivers, an equally large number of family members, and recruited participants based on six different models of car ownership. The NAViSection methodology would generate a similar number of subjects without including family members or the depth of data that continuous monitoring would provide. However, the NAViSection methodology could potentially incorporate many more vehicle models as well as the best possible sample of drivers using adaptive controls or vehicle modifications.

3.4.2 Maryland Model Driver Screening and Evaluation Program

Many states' DMVs have conducted studies on older driver screening, and the Maryland Model Driver Screening and Evaluation Program is among the best recognized studies. The final technical report by Staplin et al. (2003) provided numerous findings based on the use of functional tests as predictors of driving impairment. However, no technology was included for on-road evaluation incorporated with the pilot study. This may be another reflection of the lack of technology use found in the survey study by Beyene and Lane (2011) among driver rehabilitation specialists.

The NAViSection methodology in this case is still too nascent for comparison, particularly concerning the secondary aim to assess the administrative feasibility of delivering the targeted functional tests reviewed for validity. If outcomes of studies based on the NAViSection methodology were to result in an on-road driving screening tool, then it is feasible to pose that ITS solutions enhanced by NAViSection-based research could serve as intelligent referral systems. This futuristic perspective would address the timeliness of screening; whereas the Maryland Model Driver Screening and Evaluation Program does little to explore how drivers can be empowered to screen themselves or how the timing of a screening can be more tightly centered around the onset of impairment or a transient decline in performance.

3.4.3 Implications to Enhanced Driver Rehabilitation and Licensing Policy

As presented earlier, the dissertation work of Justiss (2005) demonstrated the advantages of a structured driving assessment route. However, multiple sources advocate for the need to allow exploratory or familiar routes during assessment for more accurate assessment of drivers with dementia or heightened anxiety during evaluation (Beatson and Gianutsos, 2000; Leung et al., 2009). The NAViSection methodology could result in a more flexible framework for standardized measures of driving safety that support fixed and exploratory assessment routes.

Furthermore, NAViSection could provide a framework to allow more incremental paths to driver cessation and evidence to advocate for restricted driver's licensing practices that demonstrate reduced crash risk or mortality. A number of sources document interests in finding the difference between driving ability and driving skills in response to changes in road settings or local environment (Galski et al., 1997; Freund and Petrakos, 2008; Eby and Molnar, 2008). Although this analysis did not address legal action, Galski *et al*. (2000) covered multiple reasons why excessive trust in non-standardized tests can result in errors in decisions about fitness to drive as well as risks of litigation that may arise due to inappropriate recommendations.

3.4.4 Implications to the Advancement and Adoption of ITS Solutions

The involvement of driver rehabilitation specialists in the discussion of ITS application may minimize the rejection of these emerging technologies. As the advancements benefit standards of practice, a whole field of experts in driving assessment will then be able to advance the design and regulation of ITS products. The introduction of this field into the evaluation of ITS will be more harmonious based on the shared goal of extending how long people can drive safely in society.

Hypothetically, there is a major advantage for automotive companies and technology leaders in ITS development if partnerships were made with driver rehabilitation programs. To overcome the lack of incident (near-miss event) detection, some proprietary technologies could possibly be loaned through donated program vehicles with a cooperative agreement that the data used in evaluation would also be shared with the donor companies. In this way, the fullest mutual benefit would be realized. Driver rehabilitation programs would not need exorbitant amounts of grant funding to acquire the technology and ITS producers would have a steady source of data collection to fuel the evaluation or further research and development of their systems. Furthermore, auto insurance companies would have an opportunity to gather the same data in support of enhanced risk mitigation analyses for at-risk driver populations.

3.4.5 Model Experiments and Initiatives to Guide Future Work

Following RITA's charge to generate transportation statistics, the TrafficSTATS project by Fischbeck et al. (2007) demonstrates an earnest effort to educate drivers in the multi-factorial complexity of managing risk on the road. The web-based, interactive tool provides promise that the sophistication of emerging ITS solutions could be harnessed to inform drivers about the risk scenarios they encounter on the road. Lotan and Toledo (2005) presented a system to provide young drivers with a monthly driving report card using an in-vehicle data recorder to generate risk statistics reflecting the driver's own performance. These examples demonstrate how inherent or experienced risk of driver-vehicle-environment scenarios might be able to modify an individual's driving behavior if the information is properly communicated and provided at appropriate times for consideration and adoption. The NAViSection methodology might be able to further increase the validity of the above mentioned tools by offering a higher order of ground truth as the basis for driver safety rating and trip planning decisions before traveling into the community.

Because of the promise of studies such as these, it is possible to envision a future in which ITS solutions extend the reach of driver rehabilitation specialists to meet the demands for driver screening in our society. In the spirit of universal design, the decision making criteria that help professionals negotiate license restrictions based on driving performance could in turn help individuals better monitor themselves when impairment threatens their safety of the safety of fellow motorists.

3.5 CONCLUSIONS

NAViSection is a driving assessment method with broad applications and a myriad of benefits when viewed as a tool to improve relationships during the decision making process of whether or not to drive. As a witness-dependent methodology, the scope reaches to any setting where a witness evaluates driving capability or performance. The targets for expanding the methodology would be physician-patient relationships, CDRS-client relationships, DMV-driver relationships, parent-child relationships (new drivers), and child-parent relationships (experienced/older drivers).

The products of this methodological advancement may lead towards a CDRS standard for driving assessment if the evidence yields a consensus for vehicle sensor data patterns correlating to capability and performance ratings. Given such a standard in the future, we could potentially pursue automated driver screening that is blind to age, gender, or social status. Standards would imply context-based, longitudinal evaluation of driving capability. Ultimately, the wealth of context-aware naturalistic driving data should also provide a common platform for interdisciplinary researchers and policy/safety experts to generate greater advocacy and policy recommendations.

4.0 DESIGN OF A NAVISECTION DATA COLLECTION SYSTEM

4.1 INTRODUCTION

The automobile industry has a long history of designing and producing stylish new car models, but sleek, intelligent car electronics with information service features have more recently stood out. The wiring connection of electrical components and cost of overall vehicle manufacturing has grown exponentially to produce greater in-vehicle networks for data communications (Leen & Hefferman, 2002).

With this growth trend and these new capabilities, driving data collection has become popular as reflected by naturalistic driving studies such as IVBSS (LeBlanc, 2008) and SHRP-2 (Antin, 2011). These efforts present a new complement of data to prior studies that were only possible using driving simulators. However, continuous video feeds present massive data sets which require many hours of review by researchers to determine causal factors for near crash incidents “in the wild” or on real roads. The NAViSection methodology aims to focus on the scenario of supervised driving evaluation as a means to real-time observation of near crash events and expert annotation related to causality and fault. By bridging the naturalistic nature of on-road driving with a structured component of driving simulation, NAViSection does not fit within the constructs of either research domain.

4.1.1 Incident versus Continuous Data Collection

The most popular data collection system is the EDR, which captures information about events including air bag deployment and seat belt use during a motor vehicle collision. For continuous data collection, many cars have incorporated IVDRs. The promise of the technology has prompted a call for mandating collision avoidance technology (NTSB, 2012). While EDR and IVDR systems collect data within the vehicle, intelligent vehicles have extended their computing power into the surrounding environment. This level of technology involves “connected vehicle” systems known as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-other (V2X) systems (Waite, Walsh, & Garcia, 2012). Based on this classification, NAViSection represents an aspect of event detection to streamline the analysis of continuous data collection like a remote control operates the DVR box for your TV.

4.1.2 Disruptive Roles through Automated Driving

Increasing attention and media coverage on the use of autonomous vehicles in the future has many people intrigued with how such a disruption to transportation options will affect industries within and beyond transportation. The core motivations behind advancing this capability are the level of risk society faces in driving and the sustainability of our infrastructure with the growing number of vehicles on the road. Just from the viewpoint of safety alone, over 30,000 fatal crashes occur in the US each year; teens and older drivers have the greatest risk of involvement in fatal crashes (Williams & Carsten, 1989). Emerging technologies from connected and self-driving vehicles have been said to potentially eliminate 80% of crashes (Jermakian, 2011).

One focus of the NAViSection methodology concerns how these technologies could be controlled and ushered into public use through adoption within driver education and training schools as well as driver rehabilitation programs. In this overview, intelligent vehicle trends have been divided into features of automation and autonomy. This differentiation allows for discussion to include features which do not present any level of autonomy associated with operation and driver interaction (Shladover, 2012).

The following subsections cover prevalent terms under two "lenses" to classify vehicle features according to their qualities of controlling decisions (autonomy) or interacting with people (automation). Advancements in vehicle technology can still simply be summarized as a spectrum of driver alert, driver assist, and driver switch. In the field of driver rehabilitation, these terms may provide stronger connections in the way that the technologies support people with cognitive and/or physical impairments.

4.1.2.1 Classification by Control of Decisions

The transfer of increasing levels of control to an intelligent vehicle results in the following levels of automation. This list is an adaptation to Table 1 in an original manuscript by Parasuraman *et al*. (2000), which extended the principles of human computer interaction to the field of intelligent transportation systems.

- Absence of assistance
- Communication of insight
    - offers options
    - presents top options
    - prompts single action
- Collaborative control management

    - acts upon request
    - takes over when ignored
    - performs unless halted
- Independent driving operation
    - informs driver upon request
    - summons driver if needed
    - disregards driver interaction (for passenger accommodation)

4.1.2.2 Classification by Interaction with People

Various levels of driver disengagement illustrate how the demand on human input to the vehicle is reduced in response to automation of vehicle function. In this classification approach, many terms imply their benefit to avail the driver of operational tasks, although the details relate to what driving tasks occur automatically. A notation presented by Mercedes Benz (DelGrossi, 2012) listed this reduction of driver input as follows: Feet Off, Hands Off, Eyes Off, Body Out. The BASt classification directly discussed automation in terms of driver only, driver assistance, partial automation, high automation, and full automation (Gasser, 2012). A similar hierarchy was presented by Sven Beiker from the Center for Automotive Research at Stanford (Beiker, 2012). The key distinction in his classification was for driver support, which was evident in driver alert systems between the realms of solely driver control and driver assistance. At present, the rule-making definition established by NHTSA has five levels of automation (LOAs): no automation (LOA 0), function-specific automation (LOA 1), combined function automation (LOA 2), limited self-driving automation (LOA 3), and full self-driving automation (LOA 4) (NHTSA, 2013).

4.1.3 Orientation to Goals for a NAViSection Data Collection System

The dissertation work of Justiss (2005) demonstrated the advantages of a structured driving assessment route using evaluator assistance as the core metric for driving assessment. However, multiple sources endorse the need to allow exploratory or familiar routes during assessment for more accurate assessment of drivers with dementia or heightened anxiety during evaluation (Beatson, 00; Leung, 09). The NAViSection methodology could result in a more flexible framework for automatic detection of evaluator assistance to support fixed and exploratory assessment routes.

The following figure (Figure 4-1) illustrates the framework through which the NAViSection data collection system was conceived. To begin with, the scenario of supervised driving is necessary to capture driving assistance from a human evaluator. The model presumes that a person who is fit to drive will be able to independently and safely navigate roadways in the presence of roadway exposures. When the risk of a collision requires intervention by an evaluator or trainer, driver capability is put into question, and an evaluator must determine if driver capacity has been reached. When placed in the context of the driving maneuver and applicable traffic laws, the evaluator can assign fault and make recommendations regarding driver fitness. The framework for NAViSection assumes that driver control of a vehicle can be measured by how much assistance is required (whether by an evaluator or an intelligent vehicle) to avoid a collision. The comparison of vehicle inputs (driver versus evaluator) builds upon this basis for quantifying driver capability.

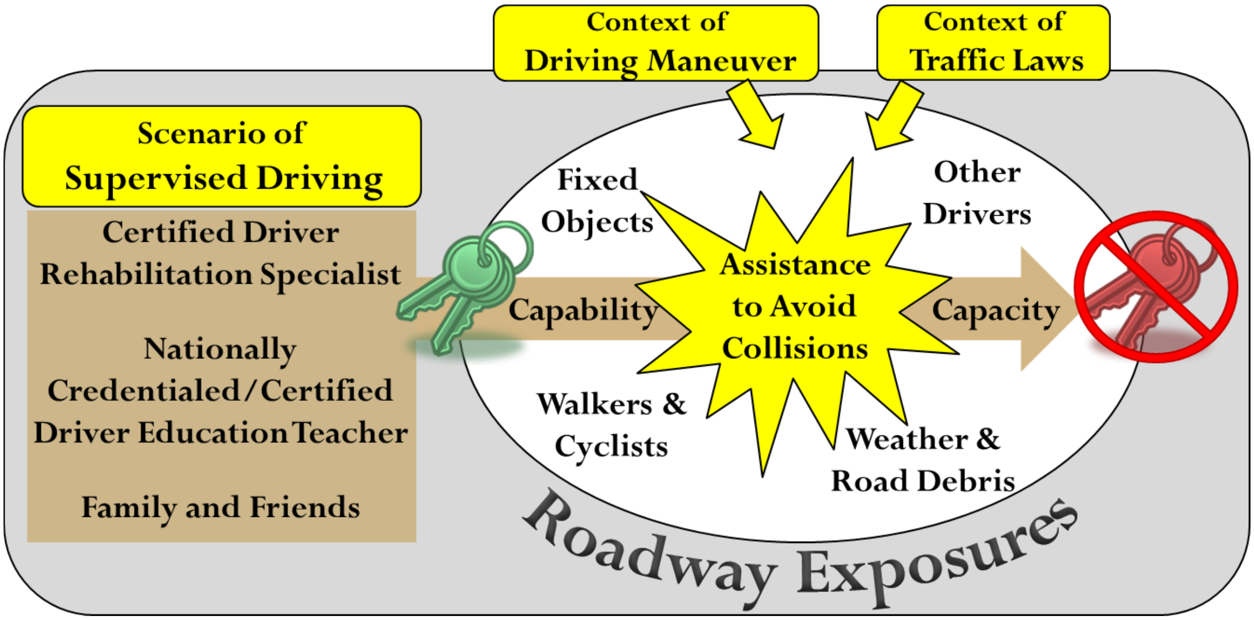


Figure 4-1. NAViSection Framework on the Scenario of Supervised Driving

The framework aims to extend the expertise of CDRSs to meet the needs of people with disabilities, seniors in society with functional declines due to aging, and all individuals with medical impairments affecting their driving capability. The ultimate goal is to promote standardization in reporting of findings from on-road evaluations in driver rehabilitation settings. In achievement of this goal, a data collection testbed could translate CDRS expertise into data patterns captured by in-vehicle data recording technologies, which support the emerging market of Automated Driver Assistance Systems, Collision Avoidance Technologies, Semi-Autonomous Systems, and Autonomous Vehicles.

The present data collection effort quantifies assisted-driving events by a CDRS during supervised/on-road driving sessions among clients of the ADP. These clients arrive at the ADP after consulting with their (primary care or specialist) physician in order to be prescribed the comprehensive driving evaluation service. Data collected in this manner presents a novel paradigm in driving assessment on board the ADP evaluation vehicle. Thus, the design of a

NAViSection data collection system must capture and quantify the intervention of an evaluator while on the road. As a demonstration of the NAViSection methodology, this project measures driver capability, defined by the actions of an evaluator, to measure the frequency and/or duration of errors due to functional performance, vehicular control, awareness, competency, and compliance with rules.

a. <u>Dependent Vehicle Operation</u> – *Assisted-Driving Event: Physical Assistance*
    i. Steering Assistance: heading adjustment for positioning and redirection
    ii. Braking Assistance: speed management for deceleration and stopping
b. <u>Unsafe Driving Decisions</u> – *Assisted-Driving Event: Verbal Cues*
    i. Driving Cues: verbal cues to assist with scanning, identification, and prediction
        1. notifying "right of way" determinations
        2. identifying obstacles and road hazards ahead on the driving path
    ii. Critical Cues: verbal cues to note improper decisions on driving maneuvers
        1. explaining violation of rules of the road
        2. describing deficits of quality/safety in driving maneuver performance

Under this structured collection of on-road driving data, the NAViSection data collection system enables exploration of the potential benefits from intelligent vehicles to inform driver licensing decisions. In relation to the Haddon Matrix view of crash risk, the NAViSection methodology must also integrate with measures on the level of the driver, vehicle and environment seamlessly.

	Pattern Detection	Sensing Technologies	Computer Vision
Environment	Driving Maneuvers	Evaluator Assistance Steer-Brake-Decide	Road Rules
Vehicle	In-Vehicle Data Recorder (IVDR): DriveCap		
Driver	Driver Physiological and Dynamic Health Status		

Figure 4-2. Scope of NAViSection Data Collection System Design Project

The aim of this design project was to demonstrate the possibility of instrumenting driver evaluation vehicles so that assisted-driving events are quantifiably factored into the report informing driver licensing decisions. The background discussion explained that intelligent vehicles may be well suited to ensure accurate documentation through driver assistance technologies and vehicle to infrastructure communication for contextual details. Highlighted within Figure 4-2, the scope of the design effort included sensing technologies applied to detect evaluator assistance, while driving maneuvers and road rules were documented by a driving program observer.

Beyond the scope of the design project, the emergence of health monitoring devices presents the possibility for collecting physiologic data from wearable sensors. While the full framework outlines the detection of driving maneuvers and road rules using additional technologies (i.e., machine learning and computer vision), this project limited design development to automatic detection of evaluator assistance and manual entry of maneuvers and traffic laws by an observer. The main objectives were to

- demonstrate a fully functional installation into the ADP evaluation vehicle, and
- evaluate the dynamic performance of automation detection for assisted-driving events

This chapter outlines the design of a NAViSection data collection system, which used the DriveCap In-Vehicle Data Recording unit for vehicle performance data for use with a secondary observer to capture the contextual details in the environment.

4.2 METHODS

The design process to develop a NAViSection data collection system involved multiple activities. Development phases evolved as a continual cycle such that new insights could be integrated into design decisions and modifications as information/feedback became available. Thus, the activities performed were not incorporated chronologically. Rather, the process followed categories of design development under themes of derivation and synthesis.

Evaluation of our NAViSection data collection system also involved human subject testing, which was approved by PITT and CMU Institutional Review Boards. All vehicle-based testing took place with the support of the ADP within the Center for Assistive Technology in Pittsburgh, PA. As a demonstration project, subject recruitment took place consecutively among all ADP clients during the Fall and Winter of 2012-2013.

4.2.1 Derivation of the NAViSection Deliverable

Derivation activities involved efforts to verify baseline assumptions and the initial concept associated with NAViSection. The concept validation activities found needs and defined problems to form a basis on which to generate design objectives and derive functional requirements. Benchmarking exercises served to enumerate the systems available for use in conjunction with driver evaluation. Additionally, a literature review highlighted wearable systems previously designed to capture use of hand motion or contact for information.

4.2.1.1 Concept Validation

Feedback for the project direction came from three sources. The first was stakeholder interviews, which were held in a focus group format followed by one-on-one interviews using a structured questionnaire. Second, attendees of the annual ADED conference provided feedback by completing a survey on the initial conceptual design. Finally, a review of medical records from the ADP added empirical data to support the premise of the NAViSection framework. A high-level list of design principles consolidated the lessons learned through these sources and built upon the framework for detecting assisted driving events.

4.2.1.2 Benchmarking

Multiple searches for market-ready systems and products were conducted to capture businesses that were promoted under various keywords/buzzwords. Due to the uniqueness of the NAViSection methodology, the outcome of the present design project was not included in the comparison. However, the results of benchmarking have the following characteristics listed for each entry: intended site of use and type of data collection. In conjunction, a literature search of wearable sensors for hand-based functions and activity detection provided insights from prior design solutions that could expand options for the detection of a steering assistance event.

4.2.2 Synthesis of the NAViSection Solution

Activities to promote synthesis of the design solution encompass all steps that molded ideas into fully functional components and an embedded system to enhance on-road driver evaluation. Design and fabrication cycles yielded new capabilities through multiple iterations and refinement of components. Woven in between these cycles were various levels of testing and evaluation, which identified deficiencies when vetted against the derived system requirements.

4.2.2.1 Design and Fabrication

The formulation of component and system level designs required repeated review of the design requirements and revisions based on the outcomes of applied testing. A standard sequence for designing involved desktop or feasibility prototypes, proof of concept prototypes, and high fidelity fabrication for installation into the ADP evaluation vehicle.

4.2.2.2 Testing and Evaluation

In concert with the design cycles, multiple testing scenarios were carried out to ensure that each component within systems was fit for use in the presence of actual ADP clients. Human factor analyses typically began with desktop prototypes and then culminated with mock-trials prior to official data collection. In-lab tests supported all static test conditions to ensure system functionality prior to installation in the ADP vehicle. All testing efforts performed within the lab setting established feasibility of the data collection sub-systems, while also securing that the proof of concept was promoted towards the mock-trial testing phase.

Ultimately, human subject testing allowed for evaluation of the final data collection system and provided pilot data for validation of the assisted-driving event metrics as measures of driver capability. In order to validate the automated event detection and measurement systems, the "Witness Logger" was developed as a laptop-based data entry routine where all witnessed events would be tallied in order to test the true-positive detection from any potential false-positive readings recorded by the NAViSection sensing technologies.

4.3 RESULTS

Derivation of the NAViSection data collection system spanned a period of two and a half years independent of any product design or development. The length of time that transpired was not due to any complexity of conducting interviews, but was simply a characteristic of the project until the implementation site acquired a 2011 Buick Lucerne for use as the evaluation vehicle and the DriveCap data collection system could be transferred into the new vehicle. The additional time was a benefit allowing for better definition of design specifications and to consider fundamental theories across multiple disciplines.

4.3.1 Concept Validation

The findings from stakeholder interviews and surveys of professional care providers and retirees allowed for the design process to begin with end user expectations in mind. Responses in the stakeholder interviews, primarily representing seniors with an interest in driving, provided a perspective from the position of people in society who will ultimately need to decide (or sometimes simply accept) when it is no longer safe or appropriate to continue driving. Among the research groups in our QoLT ERC, the "Person and Society Thrust" conducted the Family of

Engineered Systems (FOES) interviews in August and September of 2008. DriveCap was a core research project discussed loosely as vehicle-based sensors to inform safe driving decisions. The design principles obtained from their comments introduced themes of equality and a broader focus to consider how data collection could also inform teen drivers within the umbrella of at-risk driver classification.

DriveCap team members then developed a survey to explore the needs of driver rehabilitation specialists and their disposition to technology use during on-road driving evaluations. In August of 2010, the survey was administered during the annual ADED conference. Figure 4-3 depicts the initial concept proposed for specialists to integrate vehicle sensor data with the context of a comprehensive evaluation.

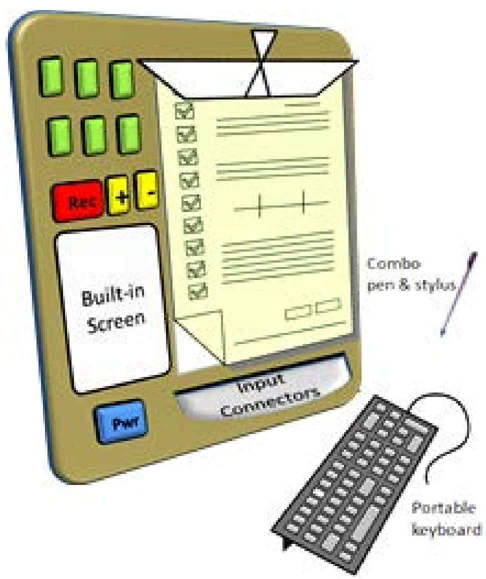


Figure 4-3. Original Concept for On-Road Data Collection

Feedback from the survey participants provided insights regarding which aspects of an evaluation make their clients defensive about their recommendations and which concerns about driving capability are most difficult to capture or document (Beyene & Lane, 2010; Beyene, Cooper, & Lane, 2011). Certain responses revealed that challenging situations can also arise when simply trying to verify that driving errors are causally linked to the medical impairment for which the client was referred rather than factors like anxiety, long-standing bad driving habits, or miscommunication. Table 4-1 presents the core principles to guide design efforts.

Table 4-1. Summary of Design Principles Listed by Stakeholder Perspective Source

Principle #	Description	Stakeholder Perspective
1	Driver capability should be defined with equivalence to standards of new/teen drivers	FOES Stakeholder Interviews: senior drivers
2	Driving data should not be directly displayed to drivers without context or expert interpretation	FOES Stakeholder Interviews: Occupational therapist
3	Data logging tools for evaluators cannot distract or cause anxiety in clients during on-road evaluation	ADED Survey of Needs and Technology Use
4	Data logging tools cannot add complexity or distraction to evaluators who are ultimately responsible for safety in the vehicle	ADED Survey of Needs and Technology Use
5	Interpretation of data must accommodate the clinician's/evaluator's expertise to be a factor at all times	ADED Survey of Needs and Technology Use
6	Driving capability measures should exclude time in the vehicle when in park or pulled-over for instruction	NAViSection Data Collection System Design Team
7	Driving capability measures should be developed with respect to driving maneuvers and as a ratio of good and bad performances	NAViSection Data Collection System Design Team
8	Driving capability measures should incorporate the presence of assistance (whether by human or the vehicle) to consider driver input vs. assistive input to the vehicle	NAViSection Data Collection System Design Team

Evidence from our 2010 ADP medical record review supported the framework presented within the introduction. The main analysis compared committed errors to the documentation of assistance provided to a client while driving.

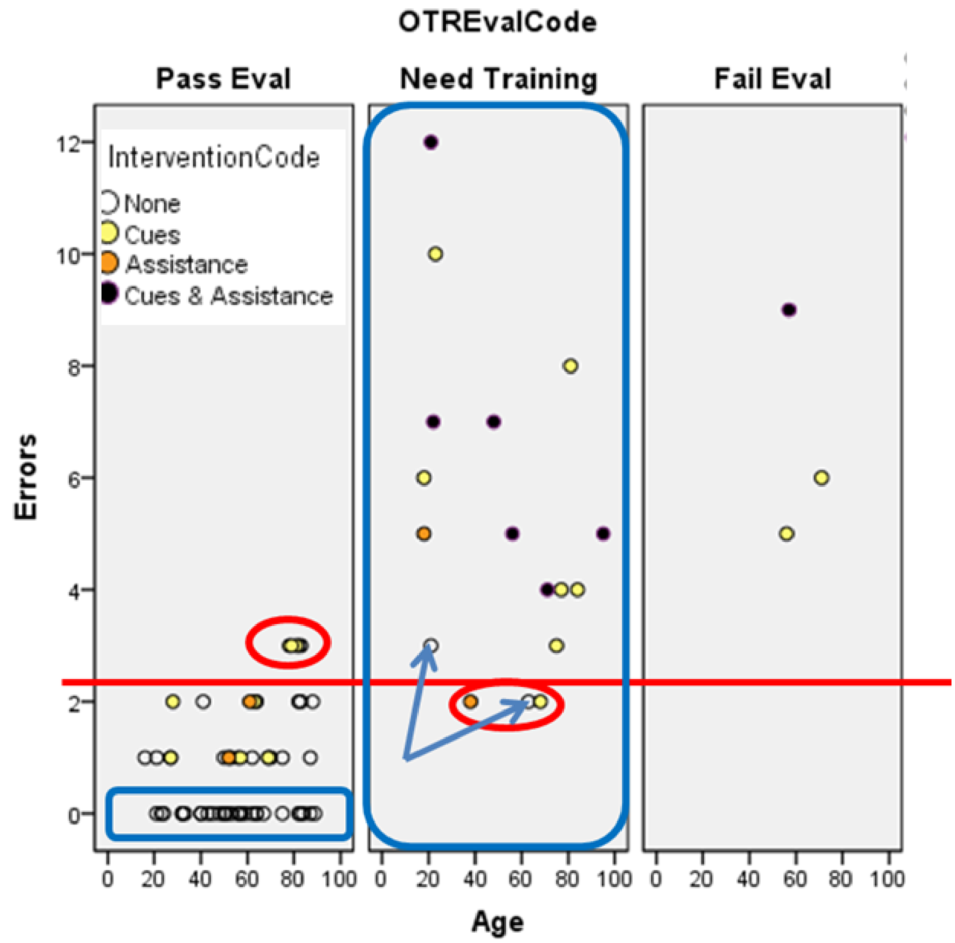


Figure 4-4. Supporting data for *NAViSection* Methodology from Medical Record Review

A main finding was that over 40% passed the baseline evaluation with almost half of those clients committing no errors ("Pass Eval" group bounded by rectangle). This result addresses the growing wait list of clients requesting services from many driver rehabilitation programs. The need for training is still substantial even after excluding the volume of clients who wish to learn how to drive with new vehicle modifications (the "Need Training" group bounded by rectangle). When factoring in the presence of CDRS assistance during the evaluation, only two clients who did not pass were actually unassisted (indicated by arrows in the "Need Training" group). Committing two or less error types clearly differentiated passing clients from non-passing clients except where (indicated by circles above and below the dividing line) three clients passed with more than two errors and three did not pass with just two errors. Based on the results in Figure 4-4, the NAViSection methodology may add value as an intelligent referral system based on advanced driver assistance technologies (crash avoidance steering and braking by intelligent vehicles) to prioritize clients evaluated based on urgency (level of risk).

4.3.2 Benchmarking

The outcome of benchmarking confirmed that data collection technologies have not been designed according to the needs of driver rehabilitation programs in particular and self-guided interpretation of data results in general. However, the findings provide great insight into an early trend in adopting technology from commercial driving applications to personal driving.

Within the realm of driving evaluations, only the Solutions thru Software company provides a commercial product for use in mainstream driving schools and DMV/state licensing authorities. At the core of their service is the conversion of paper-based state test scoring to a digital/e-form format. With their high-end package, GPS data and speed information may be added onto the base scoring sheets. The next closest competitors are fleet management/telematics companies (ex. SmartDrive or DriveCam) with extended capabilities typically for mileage tracking, reduction of fuel consumption, and video capture. The most common aspect for commercial driver facing companies is the use of an On-Board Diagnostic port reader often referred to as OBD II (or OBD 2) scanners and readers. Other companies present similar data for home use by parents in order to guide or council children on driving performance (ex. DriveDiagnostics or AutoHabits). Numerous OBD II-based products are available on the internet for car enthusiasts. Progressive Insurance’s Snapshot operates within this range of technology to use an OBD II reader for exposure-based data to inform safe driver discounts. This trend among the insurance industry also includes products available by State Farm and Allstate to name a few. These and other systems have been enumerated below in a table documenting the type of data collection and field of use for all identified products. The most notable commonality is that no commercially available (or prospective) products provide data related to collision avoidance/driver assistance technologies or connected vehicles (data from car to infrastructure or car to car).

Table 4-2. General Findings from Product Benchmarking Search

Product	Data Collection Category	Field of Use
Vericom Brake Reaction Timer	In Vehicle and In Office Units	Clinical Assessment
Solutions thru Software	Event/Continuous Data Recording	Certified State Test Admins (incl. driving schools)
Advantech Vehicle PC Solutions	Continuous Data Recording	Unassigned
DriveDiagnostics	Continuous Data Recording	Family/Home Use - Teens
AutoHabits	Continuous Data Recording	Family/Home Use - Teens
Automatic (startup product)	Continuous Data Recording	Personal Use – All
SmartDrive	Extended Event Data Recording	Commercial/Fleet Management
DriveCam	Extended Event Data Recording	Commercial/Fleet Management
Mobileye	Driver Alert/No Recording	Unassigned
Progressive Snapshot	Continuous Data Recording	Insured Driver Use – All
StateFarm InDrive	Continuous Data Recording	Insured Driver Use – All
Allstate drivewise	Continuous Data Recording	Insured Driver Use – All

Among the available service models listed in Table 4-2, only Solutions thru Software and the Vericom Brake Reaction Timer offer a way to capture driving performance or safety as witnessed by an expert driving evaluator. Furthermore, our strategy for implementation focuses on existing driver licensing policies that promote the transition of evaluation from a certified driving evaluator to supervising family members or friends. This approach is promising in the way training/tracking is handed over as opposed to expecting that parents will be effective as auditors of driving performance, which is only indicated with dedicated oversight in fleet management of commercial drivers (Li, Simons-Morton, & Hingson, 2013). By integrating telematics solutions (ex. the bottom half of products listed in Table 4-2), critical events during supervised driving sessions may be correlated to continuous data recording by a telematics product and aid in longitudinal tracking of driving performance.

Instead of approaching the existing market players as competitors, our strategy would be to organize the market forces towards a unified effort promoting safe driving. The DriveCap project presents the NAViSection methodology as a means for structuring data sets across all data sources in the realm of intelligent vehicle technologies. Designing the NAViSection data collection system to integrate with the DriveCap in-vehicle data recorder was an effort to consider possibilities beyond present market trends. Contextual data is not bounded by OBD II readers with GPS receivers and bundled video cameras or accelerometers when the promise of self-driving cars is on the horizon. Insights through structured analytics and the power of machine learning could then detect patterns of driver capability shifts for intelligent vehicles to advise their drivers and inform decisions on when to start or stop driving on any occasion.

4.3.3 Design and Fabrication

The first change in design objectives due to concept validation was to update the initial concept to an automated detection system for steering, braking, and verbal cue assistance. The following image (Figure 4-5) illustrates this shift in concept towards a system to completely minimize the number of events requiring an evaluator’s direct attention for operation.

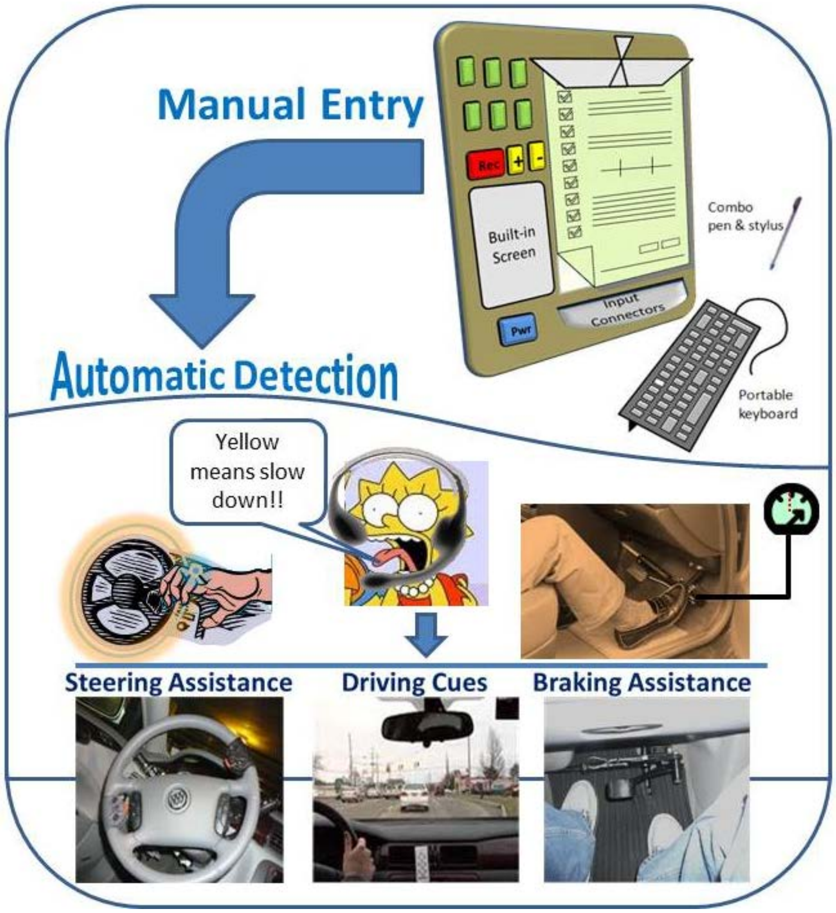


Figure 4-5. Conceptual Change of NAViSection to Automate Detections

In addition to the original design scope limitations for only automatic sensing of assisted events, the verbal cue detection required a simplification to manual entry during full system deployment (see Figure 4-6). Towards the synthesis of a NAViSection data collection system, multiple tests and mock trials took place in order to arrive at the following set of design solutions. All non-commercial components were developed in-house at HERL under the guidance, support, and oversight of machine shop staff.

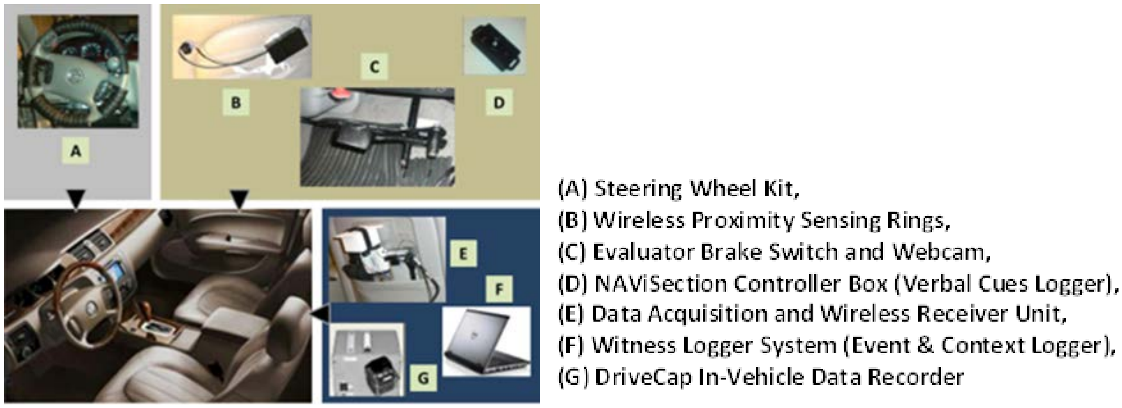


Figure 4-6. NAViSection Sub-System Layout

4.3.3.1 Detection of Steering Assistance

Steering assistance was the main feature requiring considerable design efforts. Basically, the strategy was to envision a trigger field and a detection device split across the steering wheel and the evaluator's hand. As such, the following section presents the development of a steering wheel kit and proximity sensing rings with a wrist-mounted power pack and wireless data transmission unit.

Early product search attempts via did not uncover commercially available solutions to this design challenge. Google Scholar search provided a few leads on comparable research projects using wearable electronics, wireless glove, and activity sensors as keywords. The goal of counting steering-wheel contacts required that only the evaluator's hand (from the passenger seat) would register as a contact while a driver (client or student) maintained one or both hands on the steering wheel. This requirement limited the solutions available for pressure-based sensing technology mounted to the steering wheel. When reviewing prior literature on wearable computing for the hand, a small cluster of findings showed that past development sought to capture more detail than simply the contact between a hand and an object. The objective of using a hand to communicate commands to an object has been demonstrated without touch (Metzger, Anderson, & Starner, 2004; Hernandez-Rebollar, Kyriakopoulos, & Lindeman, 2002) in close proximity of contact (Butler, Izadi, & Hodges, 2008) and by direct contact (Rekimoto, 2001; Hasegawa et al., 2007; Norgia & Svelto, 2007). The implementation by Norgia and Svelto represented the most related design application to this task of steering assistance. Specific differences between their design for safety with dangerous construction tools use and this featured design for steering assistance detection include the need for reduced coverage of the hand and a much lower demand in response frequency.

A choice was made between three detection modalities: computer vision, RF ID-based sensing, or magnetic triggering of a reed switch (or Hall effect sensor). For simplicity and rapid demonstration of a concept, the magnetic triggering approach directed the proximity-sensing ring design to operate as a contact sensor. Commercial applications of this approach have been used in the surveillance/security industry for detecting breached entry at windows/doorways and the fitness industry for capturing treadmill speed. In the following figure (4-7), images of various design phases show how a wired, glove-based prototype evolved into a wireless, ring-based detection unit for in-vehicle use.

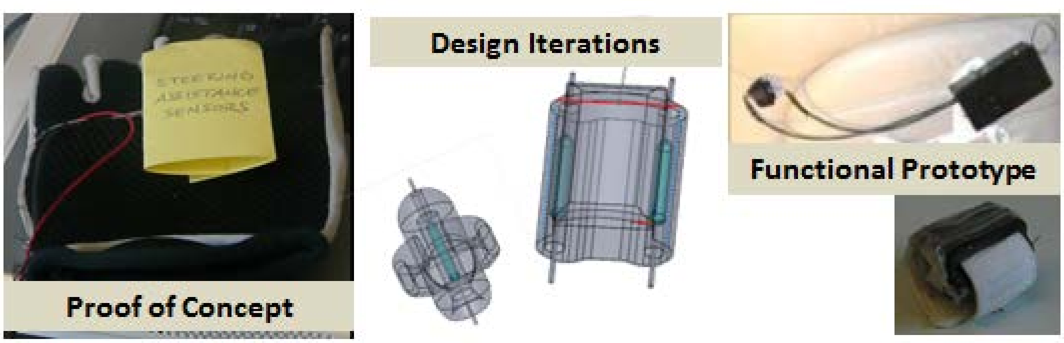


Figure 4-7. Design Progression of the Proximity Sensing Rings

Key characteristics of the reed switch were determined on a breadboard to understand the triggering range and signal response profile. In the glove-based solution, reed switches proved to be extremely fragile, and that prompted a change in positioning from the palmar side of the hand to ring positions outside of the clench of a fist. The ring concept served to provide additional structural support for the reed switch by potting the sensor with a clear adhesive/epoxy material. The sensor housing was fabricated on a rapid prototyping machine with a slot to pass through an elastic band, which was sewn into a finger cuff.

The wrist-mounted wireless data transmission and power pack involved design support from the HERL machine shop staff for design and fabrication of a circuit board. The electronics design allowed for the use of two AAA (rechargeable) batteries via a power switch to power an FM transmitter and up to two proximity-sensing rings. The circuit board enclosure design was also rapid prototyped, and a commercial wrist pouch for runners (Sprigs Bangees Wrist Wallet) contained the battery magazine, circuit board in enclosure, power switch, and connectors to the proximity-sensing rings.

Figure 4-8. Design phases of the Steering Wheel Kit

The steering wheel kit development (see Figure 4-8) presented numerous challenges as the only subsystem that a driver (undergoing evaluation for fitness to driver) interfaces with. In addition, a spinner knob attachment to the steering wheel had to be free for repositioning based on the needs of an ADP client. Using a donated steering wheel, the magnet mounting bracket design solution focused on maintaining smoothness on the outer aspect of the wheel to minimize any potential discomfort with wheel grip. Rare earth magnets held their position within the brackets using a high strength adhesive. For the actual installation, a layer of cushioned fabric provided protection to the original, leather-wrapped steering wheel of the ADP evaluation vehicle. Once the magnet mounting brackets were installed along all open surfaces (excluding the zones for spinner knob mounts) a black leather wrap with Velcro strips sewn on provided a covering for the white brackets and shiny magnets. The final component of the steering wheel kit included a commercial wheel cover to maintain a quality feel and aesthetic of the steering wheel interface to clients during evaluation. To facilitate quick and easy removal, the inner rubber lining was partially removed and elastic bands were sewn on to produce a moderately expandable cover diameter. For storage between uses, a commercial case (with compartmental dividers for separation of magnets) and a pouch were procured.

4.3.3.2 Detection of Braking Assistance

The key to detection of braking assistance was to select a consistent surface on the evaluator's brake pedal that would depress a switch in the default/rest position and disengage upon application of the evaluator's (passenger-side) brake. Two design solutions were unsuccessful during initial installation attempts due to the complex orientation of the evaluator's brake when bolted on the floor board on the passenger's side. We designed a solution using a loaned replica brake model (OS Brakes, Inc.) as shown in Figure 4-9.

The selection of a mounting location specifically targeted a position that would not be at risk of a kick-strike as the evaluator or any passenger enters or exits the evaluation vehicle. A striking plate surface interfaced with the brake cable pulley via the head of a bolt tightened by an Allen wrench. A press-fit sizing on the hex-shaped protrusion provided an adequate grip to secure the striking plate to the pulley fixed to the brake pedal.

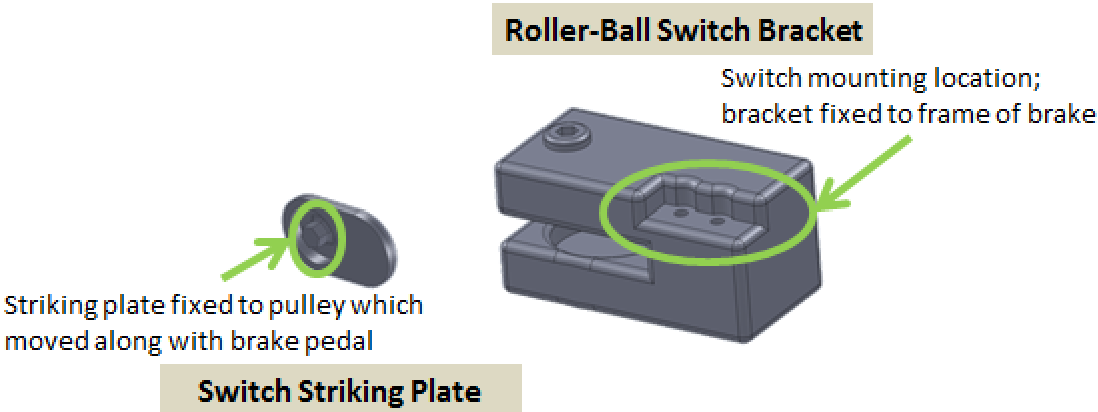


Figure 4-9. Custom Designed Switch Mounting & Interface Brackets

With a striking plate fixed to the moving body (a pulley offset from the brake pedal pivot point), a base bracket attached to the frame of the brake. Despite a design for captive magnets to stabilize the base bracket, double-sided tape was applied to the brake frame for repeatable and reliable switch activation on a secured mounting bracket. A roller-ball switch fastened to the mounting bracket via two screw holes with helicoil inserts. The mounting bracket also accommodated the countersink of the screw heads with two grooves as shown in Figure 4-9 above. A demonstration of the switch installation on a loaner brake presents the exact installation applied in the ADP evaluation vehicle. The final design can be compared to a prosthetic knee replacement when considering the brake pedal as a femur to the striking plate and the roller-ball switch as a bearing surface across the brake pedal (femur) and the brake frame (tibia). Rapid prototyping technology was used to make the base bracket and striking plate, whereas the magnets, double-sided tape, roller-ball switch, helicoils, and screws where commercial products.

The installed solution (see Figure 4-10) included a wired connection to a data acquisition box, which was concealed under floor mats along the floorboard of the ADP evaluation vehicle.

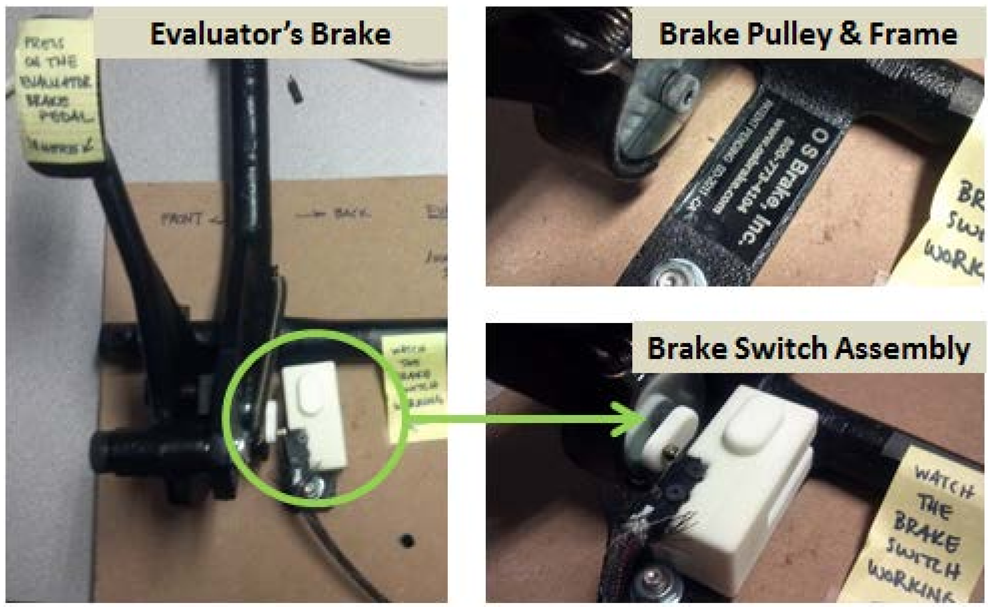


Figure 4-10. View of Brake Assembly with Switch Mounted to Brake Pedal Interface

4.3.3.3 Logging of Verbal Cues

As described previously, the verbal cue feature did not reach the level of automatic detection. However, the NAViSection Controller Box facilitated manual entry of verbal cues by the evaluator. In addition, the use of a sliding switch plus button allowed for key aspects of the NAViSection methodology to occur. The switch indicated when a client was in position and prepared to pull out at the beginning of a driving evaluation. Additionally, the button supported manual entry of spoken verbal cues. Once again, the HERL machine shop staff helped design a circuit board to provide LED feedback of power on and successful button press confirmation. The main start switch position was difficult to manipulate in a recessed location as a measure to prevent accidental shutdown of data recording, while the instantaneous (spring-loaded) button was simple to trigger as the only protruding feature from the front face of the box enclosure.

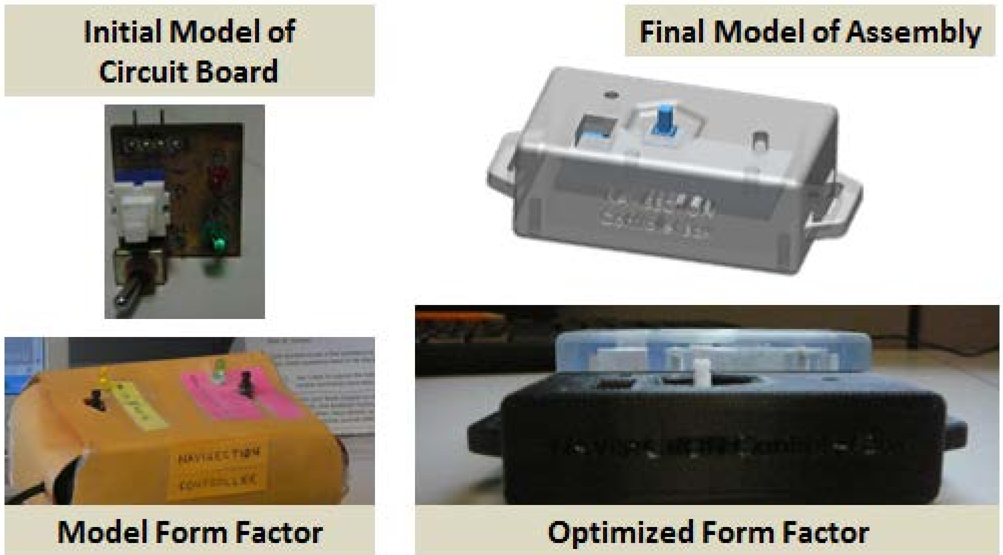


Figure 4-11. NAViSection Controller Box Revisions

The box enclosure was designed to fit the circuit board size as a wired solution. Certain surface features also permitted multiple options for mounting and installation of the box, and are visible in Figure 4-11. On either end of the box, strapping loop ends provided a means to fasten the box to any other in-vehicle objects. Also, a completely smooth lid covering the back of the box accommodated options for adhesion from the box directly to flat in-vehicle surfaces. High-strength Velcro (Dual Lock, 3M) was used on the final installation to apply the box directly onto a clipboard. This location reflected a position that would be repeatedly engaged by the evaluator when noting observations of the driver's performance. Moreover, the clipboard represented an object that would not typically be exposed to outdoor elements (ex. rain, snow) when the vehicle doors were opened.

4.3.3.4 Data Acquisition and Witness Logger

Acquisition of all data streams (steering, braking, and verbal cue assistance) fed into separate channels of an NI-DAQ box (National Instruments, USB-6008 12-Git, 10kS/s Low-Cost Multifunction DAQ) mounted to a flat acrylic board and secured within a pouch on the back of the front passenger seat. The FM receiver and supporting circuit board resided in an enclosure that was also fastened to the acrylic board with leads directed into the DAQ box. As a feature of the NI-DAQ box, a 5V power out channel was available to power all sensors directly wired as inputs. In turn, the NI-DAQ box acquired its power via USB connection to the Witness Logger laptop.

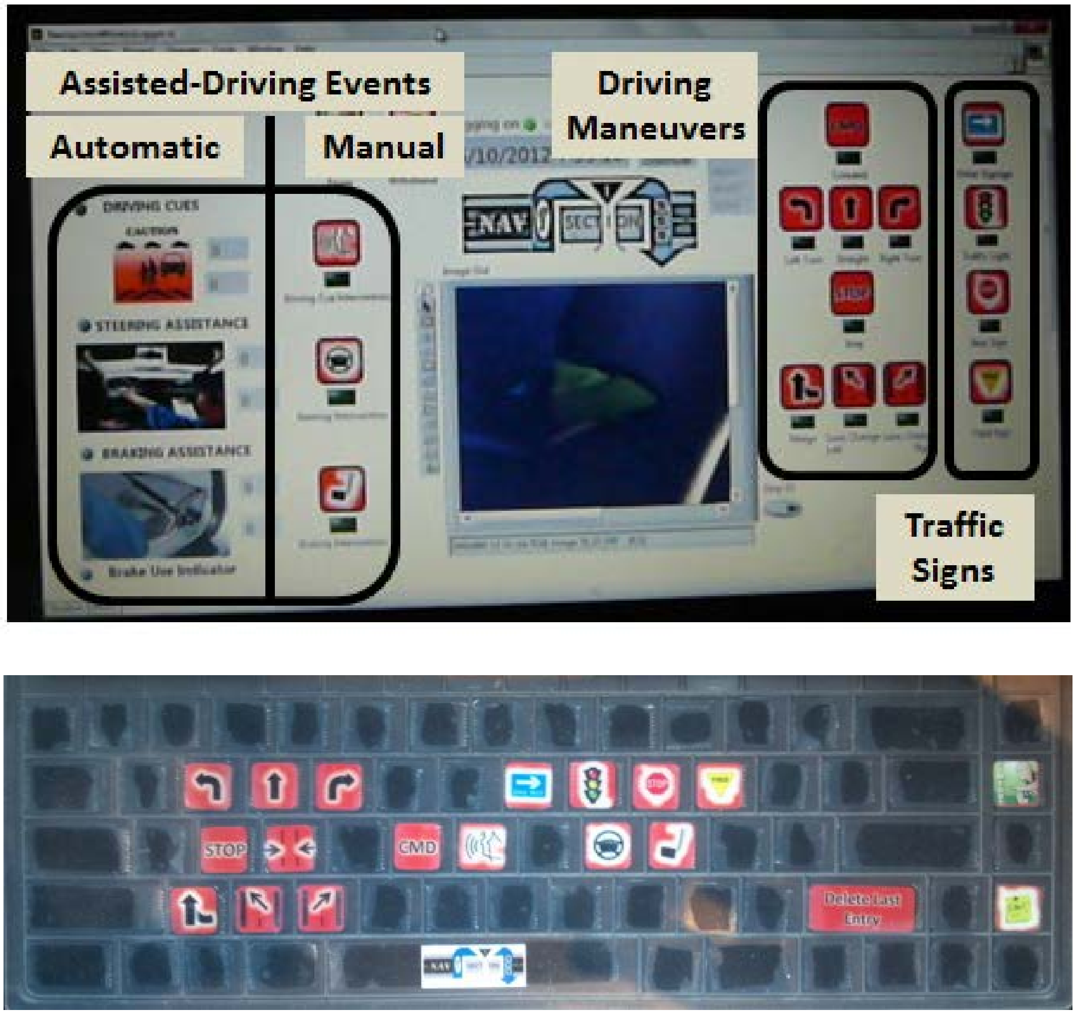


Figure 4-12. On-Screen View with Keyboard Cover Display

The Witness Logger design shown, in Figure 4-12, consisted of a modified personal laptop computer (Dell Vostro 3350) using the NI LabView (student version) environment and a custom keyboard cover to label specific keys for various witnessed events and features within the roadway environment. The screen displayed contextually witnessed items for driving maneuvers (Left Turn, Straight, Right Turn, Stop, Merge, Left Lane Change, and Right Lane Change), traffic laws (Informational Signs, Traffic Lights, Stop Signs, and Yield Signs), and other indications about the state of the driving evaluation (Driving Maneuver Commanded, Evaluation

Paused, Client Withdrew from Study, or Delete Last Keyboard Entry). Assisted-driving events also had dedicated keys for manual entry upon occurrence. On screen, these events were grouped to show the recording of automatic detections and witnessed manual entries to confirm the documentation of assistance during an on-road driving session.

While steering assistance was visible and verbal cues were audible from an observer's position in the rear right passenger seat, braking assistance was not within line of sight. To overcome this limitation, an LED backlit web cam (Kinobo B3) was installed to capture any use of the evaluator brake. The webcam view was initially integrated into the witness logger screen, but later the view was projected over a portable, closed-circuit TV (MON-56TM CCTV Testing Monitor, CCTVCameraPros) mounted via a universal mounting bracket (DBTech Universal Car Headrest Mount, Amazon.com) to the passenger seat headrest. The following figure provides a diagram of where all subsystems interfaced within the interior cabin of the ADP evaluation vehicle.

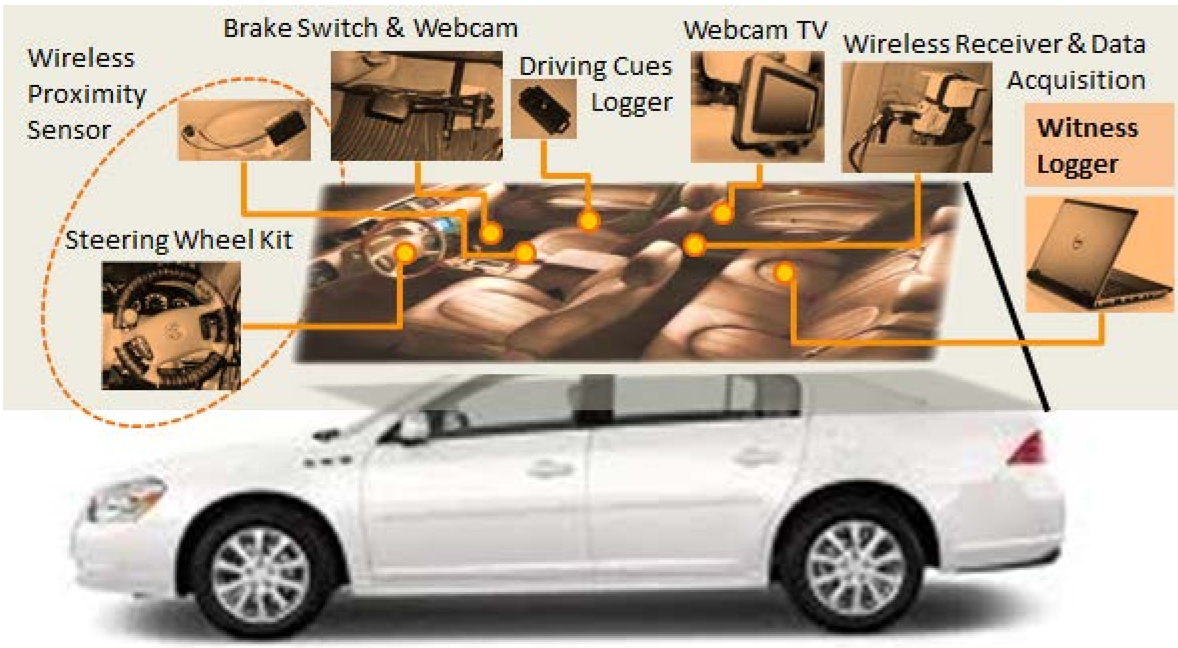


Figure 4-13. System Integration with ADP Evaluation Vehicle

4.3.4 Testing and Evaluation

Testing and evaluation provided the validation needed to advance the development effort towards applied research in human subject testing. Through the following tests, the NAViSection data collection system, presented in the previous figure, was approved to supplement findings and recommendations by the CDRS in the ADP. The mock trial period included a number of component fit checks and "environmental" tests to address the true functional life of designed subsystems. Along with these tests, additional data management considerations were fine tuned to synchronize data across the NAViSection data collection system and the DriveCap IVDR unit. These types of tests occurred between April and September of 2012, and the official data collection demonstration period lasted from October of 2012 to March of 2013.

4.3.4.1 Human Factors and Adaptability

Perceived product functionality largely depends on how a user “feels” when using it to perform tasks or functions for any activity; the product must also exhibit repeatable and accurate performance. For this reason, the first human factors consideration was how a proximity sensing ring would feel if wired into a wrist-mounted, wireless transmission unit and power pack.

In the following figure (4-14), an elastic band and small sticky notes provided a “building blocks” approach to identify the maximum design volume for the proximity sensing ring. Initial concerns with the wiring (cable) focused on variability of cable length over the maximum range of hand motions. Specifically, the necessary cable length varied across full wrist extension and formation of a fist with flexion of the fingers at the first and second joints (knuckles). This issue was dismissed during mock trials in the vehicle based on the feedback of the CDRS. Additional concerns involved the weight of the wrist pack for a risk of fatigue or discomfort when worn for over an hour of evaluation. Again, the CDRS gave final approval for the wrist-mounted solution.

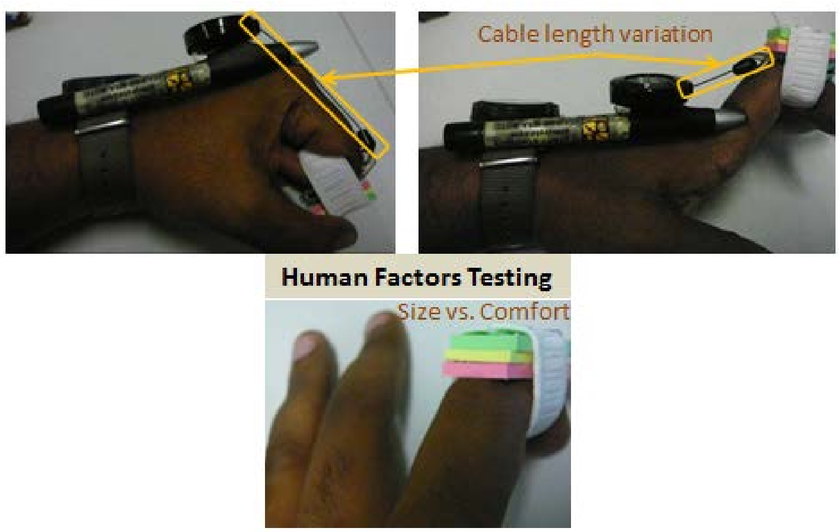


Figure 4-14. Biomechanical and Human Factor Considerations for NAViSection

Secondary to issues with steering assistance detection, there was the question of where the NAViSection Controller Box should be mounted. As shown in the figure below (4-15), multiple installation options were shown to the CDRS with a caution that the device was neither designed to be waterproof nor tested for operation under moisture. The final selection was to mount the box on the clipboard as no issues were raised during the mock-trial period.

Figure 4-15. Usability and Demonstration of NAViSection Controller Box Options

4.3.4.2 System Performance

Benchtop testing provided a baseline on which to assess the relationship with magnetic field strength and the operation of a reed switch. The building block for the trigger field was a one inch diameter, one-eighth inch thick rare earth (neodymium) magnet sourced from K&J Magnetics, and it consistently activated our reed switch at a distance of one inch in all directions.

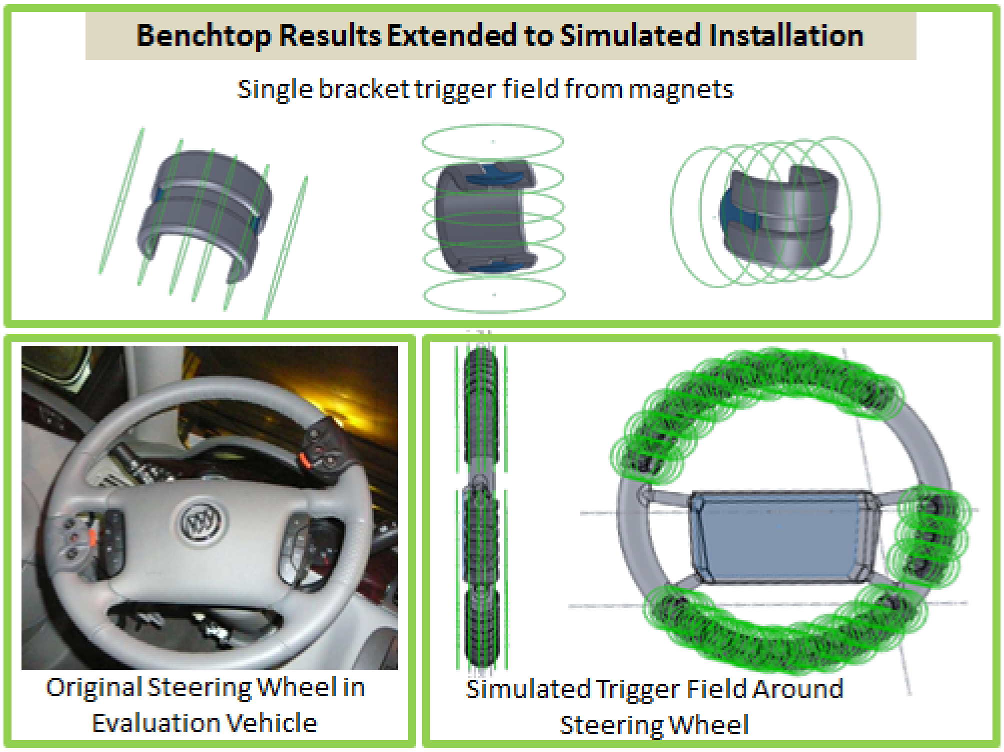


Figure 4-16. Magnetic Field at Trigger Strength for Steering Wheel Kit

Provided with an operational range of the steering wheel kit trigger field, a simple test with the stationary vehicle supported insight on how Type I errors (false steering assistance detection) may naturally occur. The findings from this test showed that only a couple in-vehicle activities within proximity to the steering wheel led to Type I errors. Table 4-3 lists the results from the trials of seven student volunteers, which show that activating turn signals and windshield wipers from the passenger seat (evaluator's position), regardless of the dominant hand, were the only actions to elicit false positive detections of steering assistance.

Table 4-3 Static Test to Identify False Detection Activities

Test Subject	Key Ignition	Turn Signals	Horn	Gear Shift	Wipers	Heat/ AC	Stereo	Dominant Hand
1	✗	✓	✗	✗	✓	✗	✗	Left
2	✗	✓	✗	✗	✗	✗	✗	Right
3	✗	✓	✗	✗	✓	✗	✗	Right
4	✗	✗	✗	✗	✓	✗	✗	Right
5	✗	✓	✗	✗	✗	✗	✗	Right
6	✗	✗	✗	✗	✗	✗	✗	Left
7	✗	✗	✗	✗	✓	✗	✗	Right

4.3.4.3 Mock Trials and On-Road Evaluation

The mock trial testing period added a final assessment of quality across all sub-systems in the fully installed configuration. As a result, every sub-system was upgraded or revised based on issues learned on the road. The CDRS noted that the “power on” LED on the NAViSection Controller Box was too bright when the evaluation vehicle was in the parking garage. A sticker was simply applied over the LED to dull the brightness. Also, the wires leading into the board-mounted connector were severed due to the cyclical bending that occurred as the clip board moved around the forward cabin in the vehicle. This resulted in repair of the cable and a strain relief tie down fastened to the clipboard for reduced hoop stress in the cable.

The braking assistance switch exhibited problems after months of solid functioning. The adjustment in this case was to remove intermediate cable connections in place of a continuous cable from the switch to the NI-DAQ Box. For the steering wheel kit, additional brackets were applied to increase detection over the spoke segments of the steering wheel and the commercial steering wheel cover was added after concerns and comments by ADP clients and the CDRS.

Lastly, a number of decisions were finalized during this period in order to sustain cable management under floor mats, protection of cable connectors secured to the flat acrylic plate, equipment storage between and during driving sessions, and a battery charging station in the ADP office.

Targeted Detections	Sub-System	Totals	Unconfirmed	Captured	Undetected
Steering Assist		6	1	4	1
Verbal Cue Assist		43	12	3	28
Braking Assist		22	8	14	2

Figure 4-17. In-Vehicle Validation Test for True Signals Missed and False Signals Detected

The results of dynamic systems performance tests showed that the automatic data collection system was highly effective in detecting events compared to a witness in the vehicle. With a single steering assistance event missed, the installation still has room for improvement. With respect to steering assistance, the two undetected events appeared to be human error in data entry. Eight events that were not entered by the witness were detected, and the two missed automatic detections occurred in a single driving session with no other system errors throughout the study. Possible causes for the mistaken manual entry by the witness could be a finger spasm, securing control of the laptop during the session, and lapse of attention.

The results of the agreement for verbal cue assistance showed that conceptual definitions for the variable lacked sufficient clarity. Throughout the mock trial period, the evaluator and witness continued to refine the purpose and application of the button on the NAViSection controller. Based on previous studies and the medical record review of the ADP, verbal cues are still a critical component in the licensing recommendation process and may require audio recording to obtain accurate, refined metrics.

4.4 DISCUSSION

The NAViSection data collection system design and implementation project produced promising results towards the ability to capture critical crash events in the context of supervised driving evaluation. Of the three variables for driver capability, steering assistance detection required the most involved design and testing efforts, but the strength in performance outcomes were comparable to the simple brake assistance detection system. The use of a witness in the vehicle to manually enter assisted events served both as a validation tool for the novel engineering design as well as a contingency measure in the event that the system malfunctioned or failed to meet approval of the ADP standard to its clients.

Additional items to consider for continued data collection relate to the limitations of this evaluation. Although a power inverter for in-vehicle use had been procured, the device malfunctioned during the mock trial period and prompted the use of a charging station in the ADP office to keep all systems charged prior to a driving session. The disagreement between the evaluator and witness on verbal cue assisted events indicates that the NAViSection Controller Box button would be of greater use for the evaluator to indicate whether or not an assisted event was "at fault" for their client or other motorists/road users during the incident. Lastly, a more formal training program for the witness might improve the logging accuracy of driving maneuvers such as merges, which often have multiple types of road architectures leading into the driving task (eg. highway entry = lane change + merge point 1 + merge point 2). In retrospect, the data collection software routine provided a "pause" setting to stop the recording of all detection systems, while additional verbal cues were mainly provided during these times in a driving session. Future iterations will need to account for this mode/phase of communication between the evaluator and their client.

Central to the QoLT Center's work on Safe Driving is a focus on the aging population both in the US and globally. Senior citizens' mobility needs lead the focus of the DriveCap test bed, and the effort extends to meet the needs of people with disabilities as well as chronic health conditions that qualify as medical impairments for driving. Anticipated improvements in quality of life include an individual push for "locus of control" on the decision of driving cessation, maximized transportation independence through evidence based practice, and legitimized emphasis on the life role of a driver to friends and family. Driving reflects a deep rooted sense of purpose to family as a transporter for minors, a purchaser of goods for the household, and a free traveler throughout society to socialize and engage in spontaneous or exciting experiences. Targeted domains of human function are succinctly explained in the AMA Physician's Guide to Accessing and Counseling Older Drivers.

The impact of modernizing driving evaluation could transform how society views the management of driving privilege. When people personally request the privilege to drive, they will follow the steps laid out by their state licensing authority to begin driving. The potential of intelligent vehicle systems, with the basis of the NAViSection methodology, is to extend the relationship between the driver and the state through informational assistance to manage driving behavior, while guiding individuals towards the most appropriate time/periods for driving cessation following maximal transportation independence. In turn, healthcare providers may be relieved of a heavy burden with the option of a NAViSection-based approach to mandatory physician reporting using DriveCap-related technologies emerging through intelligent vehicles. On-road evaluation and data collection will support the separation of medical assessment from the quality of everyday living, and the benefits of pervasive computing will inform the decisions made by physician's or the medical advisory board of the State Department of Transportation. Building upon the paradigm of tracking driver capability, this project also presents the opportunity for mainstream driving schools to track accrual of driving experience for certification of driver capability towards Graduated Driver Licensing.

4.5 CONCLUSION

Outcomes from the NAViSection project present a potentially tremendous benefit to the industries of driver training, automotive safety systems, telematics systems, and auto insurance. As standardization in driver education, training, and rehabilitation develops, vehicle-based data patterns may present a capacity to better manage driving privileges by screening for the determinants of driver capability. The scope of these screening algorithms would actually extend beyond the target populations of Safe Driving research, because the impact of driver impairment and driving errors could be documented regardless of the cause of impairment (alcohol, drowsiness, aggressiveness, distraction, medications, or disability) for all at-risk drivers.

Furthermore, the NAViSection methodology could provide a framework for allowing more incremental steps to driver cessation and evidence to advocate for restricted driver's licensing practices that demonstrate reduced crash risk or mortality. This is a capability through the DriveCap project that other studies from the clinical and healthcare fields lack measures for, while transportation safety engineers lack insight into the process for driver licensing recommendations.

4.6 ACKNOWLEDGEMENTS

CMU: Arne Suppe, John Kozar, and Aaron Steinfeld of NavLab (Robotics Institute);

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EXTERNAL: ADED; OS Brake, Inc.

5.0 NAVISECTION PILOT STUDY AND SYSTEM DEMONSTRATION

5.1 INTRODUCTION

People driving on city roads often experience times when another driver is careless or aggressive. On occasion, a confrontational comment may be spoken to question how the inconsiderate driver was able to get a valid driver's license. This scenario speaks to a greater concern about the level of driving capability that must be demonstrated to obtain or retain a driver's license. However, one book counters this frame of logic with a strong claim on the role of state licensing authorities. The book "Power, Policy, and the People" attests that it is a mistake to associate "highway safety" with driver licensing; rather, the goal is "prevention or correction of deviant behavior." (Reese, 1971)

State driving tests involve supervised monitoring of driving over brief periods of time. The test scoring process presents a simplified technique to penalize drivers for errors witnessed on the road. Pen and paper score sheets facilitate this practice only because the standards of state testing do not measure the performance of a driving maneuver on any sub-skill level; all scoring occurs on a pass-fail basis for each maneuver witnessed towards a global performance score. However, road tests, vision tests, and accelerated license renewal cycles have not shown an impact to reduce fatality rates among older drivers (Grabowski, Campbell, & Morrisey, 2004; Morrisey & Grabowski, 2005).

New safety technologies in cars today boast the ability to correct human errors, and our future role as drivers is questioned by the promise that automated driving will be better than humans at the wheel. To compound the situation, an AARP article states that we may be outliving our driving capability by six to 10 years (Ginzler, 2008). While intelligent vehicles may be safer than humans as driver, there is still an opportunity to consider that vehicles could be designed to make humans better drivers. Many automotive manufacturers will be competing to serve the growing population of older drivers, and need research to verify the effectiveness of novel technologies with this driver segment (Coughlin & Reimer, 2006; Reimer, Coughlin, & Mehler, 2009). The alternative perspective views how cars could function as "driver training machines" to improve "driver fitness" on the road. The NAViSection System was designed to relate the expertise of driver rehabilitation specialists to these advanced driver safety technologies, with a goal to establish the ultimate measure of driver capability. In this setting, a driving session occurs over longer periods of time with concerted efforts on determining the root causes (medical impairment versus bad habits) of driving errors performed.

This study served as the final evaluation of the NAViSection System through a pilot demonstration at the ADP, a driver rehabilitation service. The aim was to validate the measures of the NAViSection data collection system by capturing the frequency and duration of assisted-driving events in relation to the driver rehabilitation specialist's recommendations. Three objectives aimed to validate NAViSection.

1. Verify agreement between written case records and automatic detection of assisted driving events
2. Inspect interactions between the tally and duration of any assistance among clients who did not pass baseline, on-road evaluation versus clients who did pass.

3. Determine the predictive value for assistance when comparing clients who did not pass baseline, on-road evaluation versus clients who did pass, and compare to the predictive value of indicators from clinical test results or driver history.

5.2 METHODS

Participants in the pilot study were recruited from the existing customer base of the ADP in Pittsburgh, PA. Formal consenting took place for all clients to permit the data collection protocol and use of NAViSection system during their initial driving session. Clients between the ages of 16 to 92 were invited to participate. Only clients who did not seek an on-road driving evaluation (ex. review of vehicle modification or guidance for car travel as a passenger) were excluded.

The protocol included one option for study volunteers to use or evaluate NAViSection's sub-system for steering assistance detection. A steering wheel kit reflected the only component of NAViSection that interfaced with volunteers for the study during an evaluation. Thus, the volunteer was informed to speak out if the steering wheel kit caused any discomfort or interference with their driving style. As a precaution, the study administrators opted to exclude clients with pacemakers from evaluation of the steering assistance detection system. The reason for this measure was to eliminate the risk of pacemaker interference by rare earth magnets contained in the steering wheel kit. The true risk of pacemaker interference was determined to only pose a threat in the event of a collision if the client was forced into a position within four inches of the magnets in the steering wheel kit.

Every driving session protocol included multiple sets of data collection

- NAViSection System (NAViSection Logger)

- DriveCap In-Vehicle Data Recorder (DriveCap IVDR)*
- Cell Phone Data Collection System (Android Logger)**
- ADP Clinical Records

* In support of the study aims, only data from the NAViSection System and the ADP clinical records provided comparative information for analyses. Support by NavLab and the Ubicomp Lab provided the additional data collection systems through collaboration with CMU under the QoLT ERC.

5.2.1 Vehicle Setup Protocol

The vehicle was instrumented following each client's consent. The DriveCap IVDR and NAViSection components for braking assistance detection remained an embedded installation. The Android data logger system installation took place with other components of the NAViSection system, while study participants completed clinical tests. NAViSection automatic steering assistance detection was installed for participants who gave their consent to test the feature. Next, the NAViSection (logger) laptop connected with a data acquisition box containing all signal leads. Lastly, a closed-circuit TV (CCTV) was mounted to a universal bracket on the back of the passenger headrest, with a web cam connection on the evaluator's brake for the witness to monitor. Once the evaluator brought the study participant to the car, a test of signals took place for all assisted driving events. The recording of data for all three systems started immediately after signal tests.

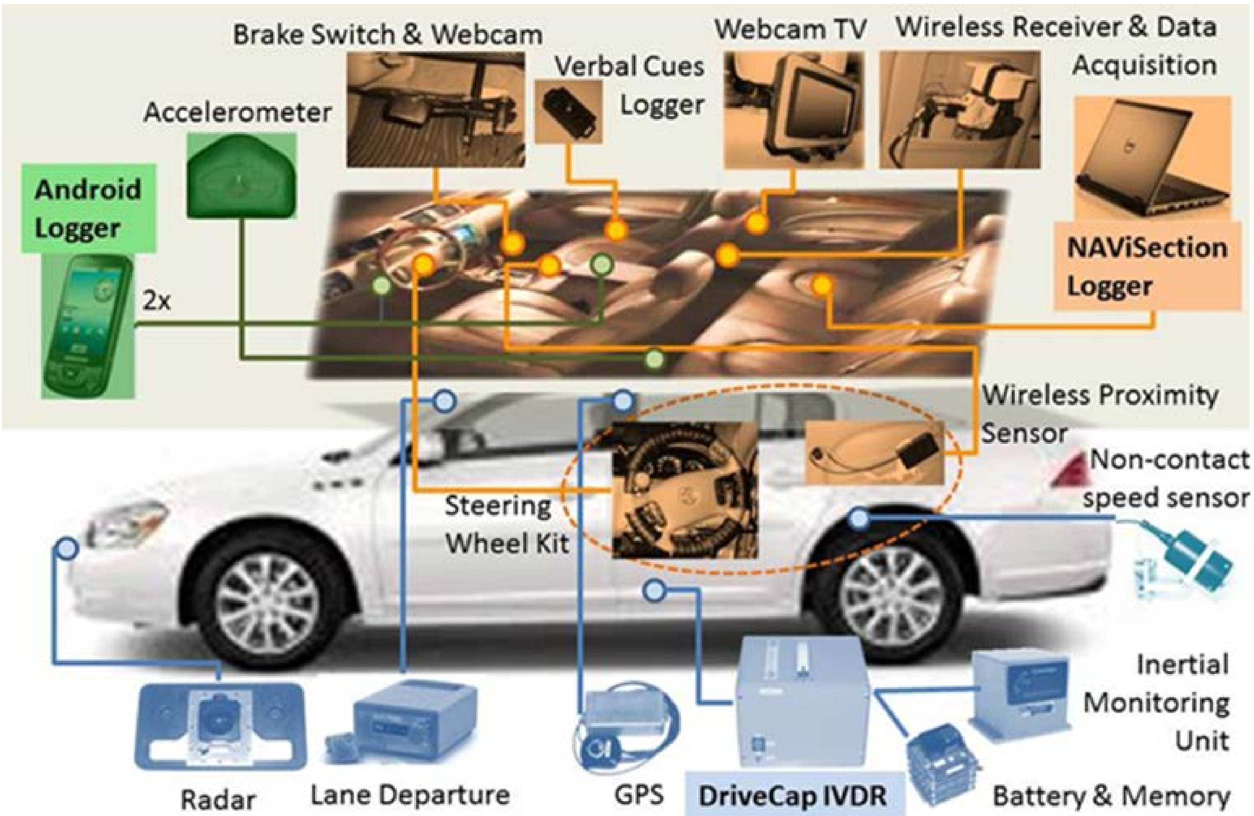


Figure 5-1. Installation Diagram for NAViSection and Supporting Data Collection Systems

5.2.2 Data Analysis Plan

The NAViSection system's data provided two modes of detection: automatic and manual. For every client's driving session, the same driving evaluator and witness participated in data collection. A software routine composed with National Instruments LabView created text files for each driving session in response to inputs from the controller box (Verbal Cues Logger) mounted on the evaluator's clipboard. The witness entered observations using the same laptop that executed the LabView routine. With steering and braking assistance captured automatically with activity monitoring, a manual entry by the evaluator via the verbal cues logger was treated as an automatic detection for comparison to the manual entry of the witness.

Both manual and automatic detections of steering assistance, braking assistance and verbal cues were identified in the data and compared to each other to verify agreement. Agreement between manual and automatic detections provided a list of true assisted-events processed with summary statistics. Then, data from the written report for on-road evaluation supported the verification process and a comparison between assisted driving events and the recommendation for or against driving capability (Pass or No Pass).

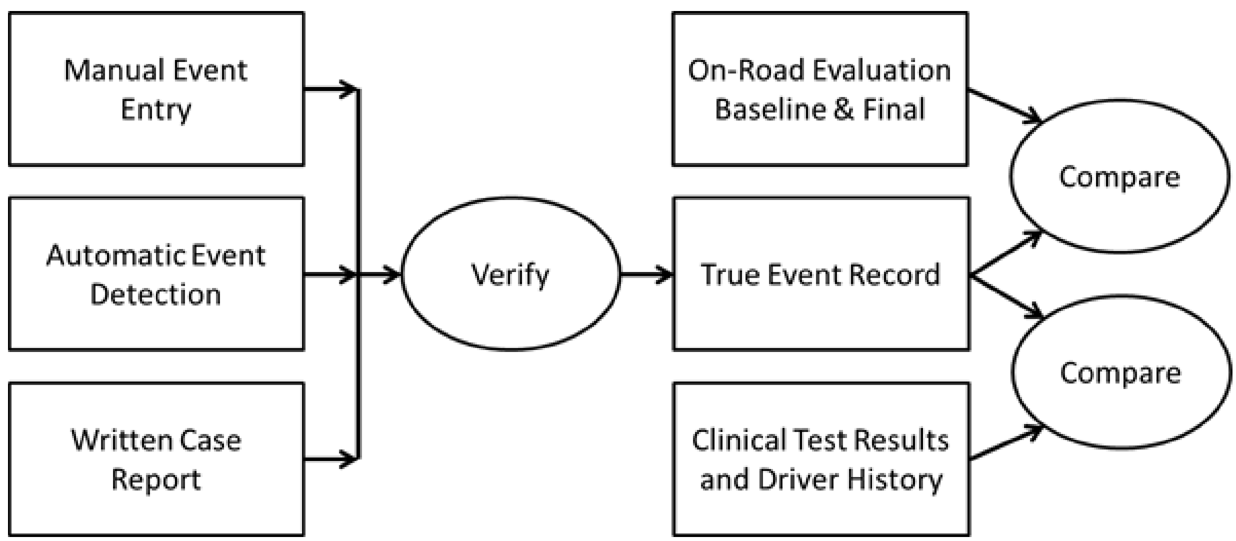


Figure 5-2. Data Analysis Plan for Event Verification and Comparison

With respect to the final objective, clinical test results and driver history were compared. Two measures provided a basis to evaluate the relative effectiveness of NAViSection's predictive values: the AMA ADReS Vol. 2 and the client's self-reported involvement with citations, tickets, or accidents (CTA) in the last five years.

5.2.2.1 AMA Guideline to Addressing Driving Related Skills

The ADP applied clinical tests supported under the AMA guidelines, which were determined to be supported by research literature. The clinical tests documented included range of motion & muscle power (psychomotor domain), Trail Making Part A & B (cognitive domain), and Snellen & Confrontation Testing (sensory domain). The combined representation of the clinical results were summarized as “ADReS” or “Clear” for each study participant based on the thresholds provided in the AMA ADReS. When any of the six clinical tests were below a threshold, the participant was categorized in the ADReS group. All clients with scores within normal limits were grouped as Clear.

5.2.2.2 Citations, Tickets, and Accidents in the Past Five Years

For driver history, self-reported CTA within the past five years posed a secondary consideration for predictive power of a screening test. The CTA predictive measure related to the most common recommendation for people in society to watch for when determining whether or not a decline in driver capability may have already taken place for an older driver within the family.

5.3 RESULTS

In total, 22 clients were invited to participate; 21 volunteers enrolled. Data collection system error caused the omission of data for one driving session.

5.3.1 Demographics of Study Participants

Among the 20 successful trials, 80% of the participants were age 50 and over within a range between 22 and 87 (avg. 65.9, std. dev. 17.9). Genders were represented evenly with 11 male and 9 female study volunteers. Participant's medical impairments spanned mainly cognitive and motor skill functions, while one-fourth of the participants had experienced stroke in their medical history. Alternatively, three participants were evaluated for procedural reasons. Two were required to be evaluated since their occupational roles involved driving. The other participant received a random sample selection from the state licensing authority (PennDOT), which required on-road evaluation.

To begin the comparisons, four data sets were excluded from analysis because the clients were training to use a modified vehicle interface. The value for correlating assisted driving events to the evaluator's recommendations was only meaningful when the default expectation was for the client to be capable of driving with a standard vehicle interface. Thus, all analyses focused on clients who drove without adaptive equipment (N=16). The average driving session took over 40 minutes. A total of 71 assisted events were logged, including 28 steering and braking events. Due to limitations and poor agreement with detection/verification of verbal cue assistance, the analyses focused on physical assistance with steering and braking.

5.3.2 Written versus Detected Driver Assistance

Among the 16 study participants using a standard vehicle interface, nine did not pass the baseline evaluation during their initial visit to the ADP. By the time of case resolution, three of the participants "passed" with a recommendation of fitness to drive, while participant 20 was advised to continue supervised training with parents. Participant 6 made a personal decision to retire their driving privilege during the baseline evaluation, and four others (#7, 14, 21, and 22) received recommendations to stop driving.

The following figure shows that all except one study participant (#20) required assistance with steering or braking during their driving session. The NAViSection System indicated that the evaluator registered two verbal cue assists and the witness indicated five other unique verbal cues during the session. There was no indication of physical assistance among the participants who passed their baseline, on-road evaluation.

Table 5-1. Written Record vs. Detection of Assisted Driving Among Failing Clients

Assistance:	Steering	Braking	Case Decision
Participant 5	☒	☒	Training Passed
Participant 6	N/A	☒	Retired
Participant 7	N/A	☒	Failed Baseline
Participant 8	N/A	✓	Training Passed
Participant 14	N/A	✓	Failed Baseline
Participant 18	?	☒	Training Passed
Participant 20	N/A	N/A	Parent Supervised Training
Participant 21	✓	☒	Failed Baseline
Participant 22	☒	✓	Failed Baseline

✓ – documented with auto detection; 4 of 18 True Positive
? – documented without auto detection; 1 of 18 False Negative
☒ – undocumented with auto detection; 7 of 18 False Positive
N/A – undocumented without auto detection; 6 of 18 True Negative

When analyzing the written report from client files, the summary recommendations often excluded mention of assistance provided to the client. The steering assistance provided for participant 21 was not documented, while the braking assistance for participant 22 did not appear in the report. These cases involved both forms of physical assistance with only one form documented, but neither form of assistance was explicitly mentioned for participant five. Braking assistance was not documented in the final recommendations of three other participants even though no other form of physical assistance took place.

5.3.3 Tally versus Duration of Assisted Events

Assistance during on-road evaluation involved two forms of measurement. The tally or count of all assisted events provided an overall picture of a client's dependency on the evaluator. Alternatively, the duration of assistance presented a measure of severity in the driving error performed. The total duration of assistance could only provide a value for physical assistance (steering and braking), so there was no measure to reflect the criticality of verbal cue assistance. The following figure illustrates the relationship of each form of measurement with respect to the outcome (Pass/No Pass) of a baseline, on-road evaluation.

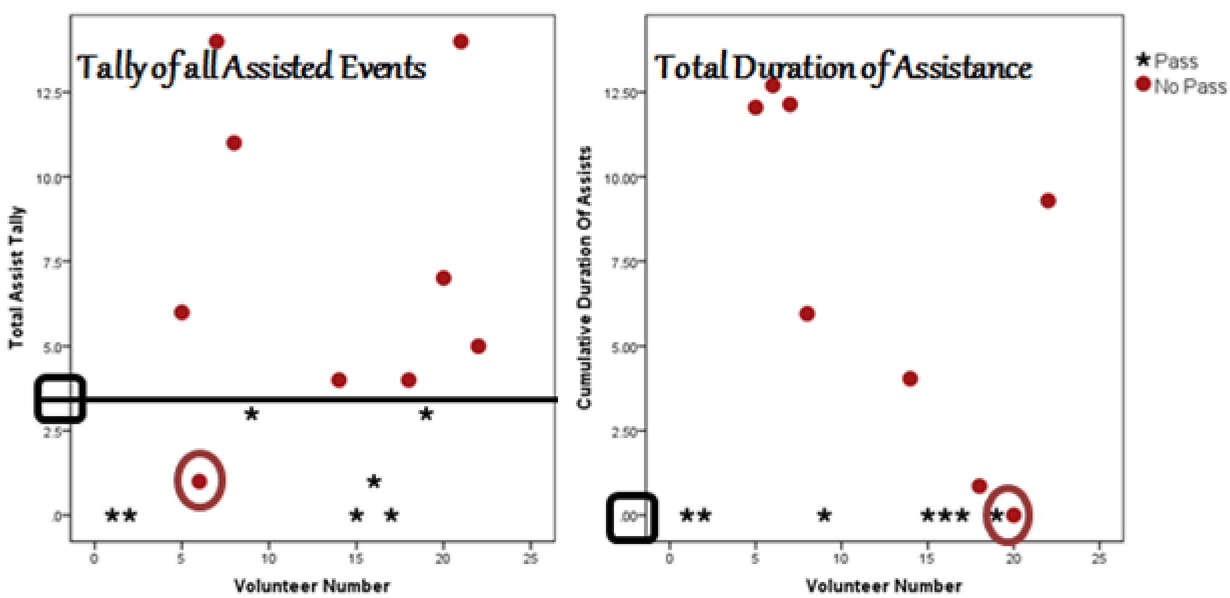


Figure 5-3. Assisted Driving Events by Study Participants for Pass and No Pass Groups

In isolation, the tally of assisted events produced an error (participant 6) for Pass/No Pass classification at a threshold of three tallied events. The same was true when observing only the total duration of assistance from physical interventions, except the error was with classification of participant 20. This classification error showed again that verbal cues assistance alone could be critical in the evaluator's formulation of a recommendation.

However, when combining classification rules under both measures, a perfect classification scheme existed within the data. A model for classification (Model P-NP) was derived such that no physical assistance may occur OR the assistance by verbal cues cannot surpass three events during a session. More specifically, the No Pass classification applied when the cumulative duration of assistance was greater than zero OR the total assist tally was greater than three.

5.3.4 Screening Criteria versus On-Road Assistance

Following the definition of Model P-NP, a comparison to clinical test result and driving history predictors of driving performance was possible.

Table 5-2. Contingency Tables and Predictive Values for ADReS, CTA, and Model NP

Baseline On-Road Evaluation N=16

	No Pass	Pass
ADReS	6	3
Clear	3	4

	No Pass	Pass
CTA	4	2
No CTA	5	5

	No Pass	Pass
Model NP	9	0
Model P	0	7

Comparative Predictive Value of NAViSection-Based Model P-NP

	ADReS	CTA	Model NP
Sensitivity	66.7	44.4	100.0
Specificity	57.1	71.4	100.0
Total Error	30.0	35.0	0.0
+ Pred. Value	66.7	66.7	100.0
- Pred. Value	57.1	50.0	100.0

Participants Flagged (Categorized) by:

ADReS – A Clinical Result Not Within Normal Limits

CTA – Self-Report of Involvement With Citations/Tickets/Accidents In Past 5 Years

Model NP – Cumulative Duration of Assistance Greater Than Zero OR Total Assist Tally Greater Than Three

As seen in the tables, the ADReS criterion has greater specificity than CTA, while sensitivity is higher under the CTA criterion. Model P-NP was clearly the best of all measures with absolute correlation with the evaluator's Pass/No Pass recommendation for all 16 study participants.

5.4 DISCUSSION

The NAViSection system pilot study results illustrate that assisted-drivnig events are neither rare nor simple to document by pen and paper. Crash events are very difficult to capture in naturalistic driving studies, so near crash events are the frequently used measures for crash risk (Guo et al., 2010). Physical assistance by an evaluator provides a near crash type of detection during routine driver evaluations on the road, and the events took place in 50% of the on-road driving sessions among ADP clients evaluated with a standard vehicle interface.

During these events, the evaluator must immediately stop writing notes and fully commit to the intervention. In this way, it is possible that assisted-driving events may often be left out of the written record of a baseline, on-road evaluation. The NAViSection system presents a systematic tool for reinforcing licensing recommendations by driver rehabiltiation specialists, while also capturing crash critical driving errors committed during routine driving sessions.

The detection of verbal cue assistance was critical for the accuracy of driver capability measures in relation to on-road outcomes. A tally of physical assistance alone did not provide any unique insight on driving capability compared to the cumulative duration of assistance, and would still require the consideration of verbal cues. The cumulative duration of assistance as a measure providing a simple visualization to determine if the total tally of assistance consisted of verbal cues only or additional assistance with steering or braking.

Limitations of the present study reflect the reduction in scope to analyze physical assistance with driving since the agreement between “auto” and manual entry of verbal cues assistance was not achieved. The analyses did not include any clients needing training for vehicle modifications. Without incorporating the other data sets, the study could not provide further consideration of severity in detected events based on real-time speed and the driving maneuver performed at the moment.

The strong predictive values of NAViSection using the Model P-NP criterion provide an opportunity to look at the additional data sets from DriveCap IVDR and Android Logger. The ability to link driver capability measures to vehicle performance data would present a number of benefits for driver safety screening, but the greatest would involve enhanced predictive ability in determining who should be evaluated by a driver rehabilitation program. Too often, the view on older drivers is that they are primarily dependent on mass transportation (Wachs, 1988). The burden to physicians and cost to family members is excessive (Bedard et al., 2013) when one in three drivers may be advised incorrectly based on the predictive values of the AMA ADReS guidelines and self-reported driver history records.

The NAViSection system performance supports further capabilities of the methodology as a reliable basis for comparison across driver impairments (ex. medical, substance abuse, aggressive, drowsy, and distracted driving). To achieve these broader ranges of driver screening, the measures of NAViSection must be correlated to data from in-vehicle data recorders for application in the personal vehicles of drivers without an evaluator in the passenger seat. Then, the NAViSection methodology would integrate the best of naturalistic driving with driving simulation using vehicle based sensors to play back critical events.

Based on the data from the 16 study participants in the pilot study, NAViSection presented crash critical driving events at a rate 10 times greater than documented in the 100-car study by the Virginia Tech Transportation Institute (Neale et al., 2005). The adjusted rate of event detection is still over eight times greater when modified to reflect the relative percentages of clients served annually by the ADP. In the pilot study, the number of clients who failed the evaluation was slightly overrepresented for the small sample size.

5.5 CONCLUSION

The NAViSection pilot study, in the ADP yielded results which confirm assisted-driving events as the most valid measure of driving capability. The correlation of measures from NAViSection to the evaluator's recommendation upholds that supervised driver observation is the gold standard for determining a person's driving ability. In future work, advanced analysis of in-vehicle conversation and speech by the evaluator should enhance the detection accuracy and insights towards counseling or education of clients. Also, automated report generation tools would enhance the evidence behind an evaluator's pen and paper recommendations while increasing efficiency of a driver rehabilitation program's report writing procedures.

Beyond the setting of the driving program, data recorders in vehicles may be able to extend the evaluation of driving capability for certain populations. People living in rural communities often lack access to the expertise of driver rehabilitation specialists, while follow-up monitoring post evaluation could help others with medical conditions associated with poor prognosis.

5.6 ACKNOWLEDGEMENTS

Special thanks to Amy Lane of the ADP and the staff of the Center for Assistive Technology

6.0 FUTURE DIRECTIONS TO ADVANCE NAVISECTION

Naturalistic driving studies have grown tremendously in the past decade with the 100-Car Naturalistic Driving Study, SHRP-2, and the Connected Vehicle Safety Pilot. A wealth of driving simulator studies has also been conducted. Overall, relatively few studies can unite the results of simulation with the naturalistic findings of on-road data collection, unless the on-road portion occurred at an instrumented road segment. Intelligent vehicle technologies, including self-driving cars, will transform this scenario such that the driving experience could be recorded and converted into a driving “replay” simulation. Using the NAViSection methodology, there may be greater focus on what issues should be given priority for investigation as high crash risk scenarios evidenced by steering and braking assistance during supervised driving sessions. The following image, Figure 6-1, illustrates how NAViSection may assist and inform crash causality models as an extension of the paradigm for naturalistic driving and surrogate measures.

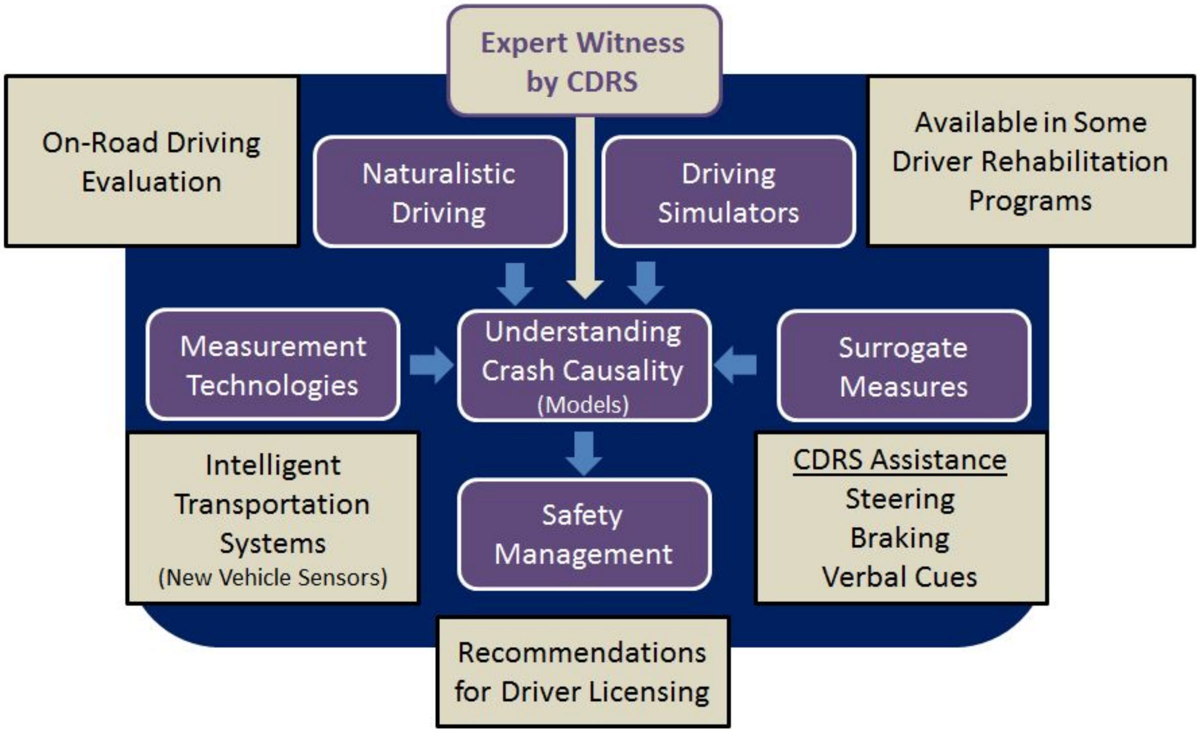


Figure 6-1. The Scenario for NAViSection to Build Upon Existing Research Methodologies

The previous chapters have outlined a vision and an efficacious solution to achieve modernized driver evaluation that encompasses the use of intelligent vehicle technology. Steps towards realizing effective and efficient use of NAViSection require broader engagement and input based on the findings laid out here. To achieve validation and acceptance among the many users and stakeholders, NAViSection will need to pursue generalizability (without compromise to individualized care and attention) and operationalization (without removing the potential for customizability). The users and stakeholders will include, but will not be limited to, driver rehabilitation specialists, driver trainers, driver safety educators/instructors, physicians, therapists, medical advisory boards, state licensing authorities, police/law enforcement, and existing/potential drivers in society.

Research models for crash safety promote measures of risk exposure, which have not been adopted in the field of driving assessment. The scoring of driving performance is a strong desire in clinical settings (Horberry & Inwood, 2010), but the focus must remain on driving capability rather than capacity. Without an on-road assessment, there is no gauge to assess how well the driver dynamically compensates for known functional limitations that are witnessed on static assessment equipment. On-Road evaluation can be rated on the level of individual driving maneuvers by indicating when independence with vehicular control or decision making is lost (Justiss et al., 2006). However, the scoring of the session must also reflect the amplification of risk and severity associated with speed and other environmental factors (Jamson et al., 2007). The application of measurement technologies should be applied to well defined scenarios of functional performance (Naito et al., 2009; Kowalski & Tuokko, 2007), so that scoring considerations (or performance “cut offs”) are tightly linked to rule-based performance guidelines (Michon, 1989). Through this approach, vehicle data can address a lack of ability to adhere to the rules, while the evaluator can address attitudes behind decisions to ignore rules.

6.1 OWNING THE DECISION TO STOP DRIVING

The personal decision to give up driving privilege depends on our awareness of changes in our functional abilities over time. Vehicle-based data should empower us all to acknowledge when our experience as drivers is no longer reflected in our performance. The ability to detect and internalize this change or variability in performance could promote better awareness regarding our driving capability and greater locus of control in our decision to stop driving.

As shown in Figure 6-2, medically-impaired drivers are on a common plane with law enforcement, physicians, and driver rehabilitation specialists with respect to licensing decisions. In situations where concern with driver capability is elevated, the state licensing authority must take action (e.g., through case decisions by the medical advisory board) and the locus of control has moved away from the licensed driver. The current model for managing driving privileges is to equip informed professionals with tools to help drivers realize individual self-awareness of driver capability prior to reporting to the medical advisory board. The combined perspectives of drivers, driver rehabilitation specialists, physicians, and law enforcement should steer an individual's decisions towards a healthy balance between independent mobility and public safety. The medical advisory board should be necessary only in cases where a driver disengages from the council of trained professionals serving to protect the driver in conjunction with society. Maintaining the locus of control with the driver is the ultimate goal, so long as self-awareness can be achieved in a reasonable time period and cost.

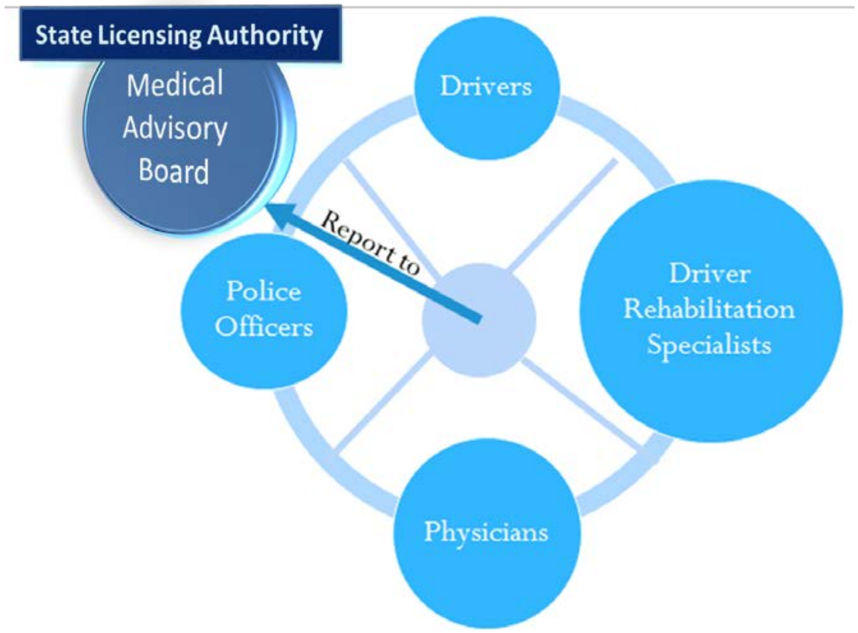


Figure 6-2. Model for Managing Driving Privileges in the US

Considering the nature of state-based legislation and authority over driver licensing, all discussions and recommendations have been limited to the context of driving in the US. However, the natural expansion for NAViSection encompasses the global volume of drivers and road safety concerns worldwide. All recommendations in this dissertation represent a perspective that the growth and prevalence of intelligent vehicle technologies will continue to advance towards the realization of autonomous vehicles (fully automated cars). In light of the disruption this technology presents to the culture and standards of driving, the fields and professions associated with driver safety (determination of fitness to drive) must be equipped to master the technology and educate the public on how to be fully capable drivers in the era of intelligent vehicles. Forecasts have already been made to predict a day when driver's licenses will no longer be necessary with intelligent vehicles demonstrating greater safety when driving than people. (Newcomb, 2012) This call to attention appears to focus on road safety, but the studies within this dissertation focus on ways that the intelligent vehicle technologies could assist with documentation and reporting. The key is to realize benefits for all stakeholders in the future of safe driving.

The NAViSection System is designed as an improvement to driver evaluation and is intended for purchase by driving programs. Vehicle-based sensors and data collection are a fast-growing trend, and will likely become part of standard features in future cars. Presently, older drivers face the cost of evaluation as an out of pocket expense. Thus, the potential for older drivers to lead in the decision making process could be enhanced if the cost of evaluation is imposed after evidence from driving is in place.

6.2 ADVANCING THE DESIGN OF NAVISECTION

Chapters 4 and 5 discussed the design and performance of the NAViSection system in great detail with some discussion on the limitations with the prototype and capabilities. Here, the discussion expands to share how the design may be advanced in response to safety, performance, and usability. With further exposure and interaction with stakeholder groups, the NAViSection system may be refined in order to promote operationalization, generalizability, and commercialization.

6.2.1 Remaining Design Improvements for Steering Assistance Detection

For acceptance by most CDRSs, the steering assistance detection feature should undergo a design revision. A concern regarding rare earth magnets is their potential interference to the function of pacemakers. By reversing the placement of magnets and reed switches, the design could be modified as a small transmitter pack mounted to the rotating base of the horn/airbag unit on a steering wheel, with connections to a wired array of reed switches across the steering wheel surface. The evaluator would then wear a magnetic ring(s) to trigger the reed switch array. To facilitate ease of use, the installation of the steering wheel kit should focus on minimizing the time to install or adjust the kit so that adjustment of a spinner knob is still possible without requiring more time than other adaptive equipment requires for installation or removal.

Advancements to detection accuracy should first target known false trigger zones. Assistance to turn on/off the turn signals can falsely trigger steering assistance detection when the evaluator reaches through or across the steering wheel. General strategies would be to train users how to operate a “time out” signal to the detection routine prior to reaching for the turn signal or to create additional triggers on the turn signal lever for the software to filter out the falsely detected events.

With market research, it will be possible to test if there are any interface and usability concerns with the proximity sensing rings. There were no complaints from the ADP evaluator or clients when the system was in use. The steering wheel kit was acceptable to all who participated in the evaluation of steering assistance detection during the study. Approximately half of the participants commented how the steering wheel was notably larger, yet the CDRS’s overall impression was that a larger diameter grip to the steering wheel only appeared to be helpful to clients with reduced grip strength. The risk of clients blaming their performance on steering wheel thickness of was a serious concern in the study, so our CDRS used personal judgment during the mock trial phase to exclude clients who already showed signs of irritability. During the formal study period, no clients were excluded by the investigators for this reason. One participant declined use of the steering wheel kit during consenting without viewing installation or complaining of discomfort during the driving session.

6.2.2 Additions to Promote Commercial Value

In the current configuration, the NAViSection data collection system requires a software operator in the back seat of the evaluation vehicle. Software and embedded processing advancements can direct the entire process to be in the hands of a driving evaluator. In the vehicle, data monitoring software should present a test of all data channels to view if the system is functioning nominally. The software would also allow the driving evaluator to start and stop recording of data from all channels. With this improvement to data collection, a driving evaluator could run the system independently. Upon return to the office, the driving evaluator would then need data visualization capabilities to facilitate documentation and report generation.

Moving beyond the DriveCap in-vehicle data recorder, the NAViSection methodology allows for any vehicle-based sensor system to capture driving performance data. In order to facilitate the time sync between NAViSection data and commercial sensor data, the NAViSection data collection system should adopt a GPS receiver into the design and possibly cellular connectivity. This would allow for time sync through GPS location or triangulation off of cell towers to match up with in-vehicle data recorders over the duration of a driving session. Strategies for data transfer should securely send data to a server for data viewing following the evaluation, with low-level processing on board the vehicle to support data for basic feedback. The final solution should consider whether the data resides with the driving program or with the company supplying NAViSection data collection equipment. At the same time, the Witness

Logger laptop can be replaced with a simple computer (e.g. microcontroller) and memory for an embedded data acquisition unit.

Design improvements of the NAViSection data collection system are also needed for commercial use for compatibility with various vehicle interfaces. One improvement needed is to address the variability among steering wheels with respect to overall size (standard sizes A, B, and C) as well as the differing number and location of spokes between the horn/airbag and the steering wheel perimeter. Along with the steering wheel kit design, the switch mounting unit for the passenger/evaluator brake must be reviewed for the possibility of other brake manufacturer designs aside from OS Brake, Inc.

Ultimately, the redesign process should seek a goal for single-evaluator operation with timely installation/reconfiguration in the presence of adaptive equipment. In place of the two AAA batteries that power the proximity sensing rings, a rechargeable battery with charging dock station would simplify battery life concerns. During the redesign process, driving evaluators' interaction and feedback will be necessary to identify the order/criticality of features to implement for widest adoption of the NAViSection data collection system.

6.2.3 Exploring the Data Analysis

This chapter opened with the mention of users and stakeholders, which raises the question: Who is the end user of NAViSection data analysis? The intent is for data to simplify and harmonize interactions from all perspectives regarding driving decisions. The NAViSection methodology builds off of the natural progression and structure of driver rehabilitation programs. In doing so, the data structure reflects the same framework.

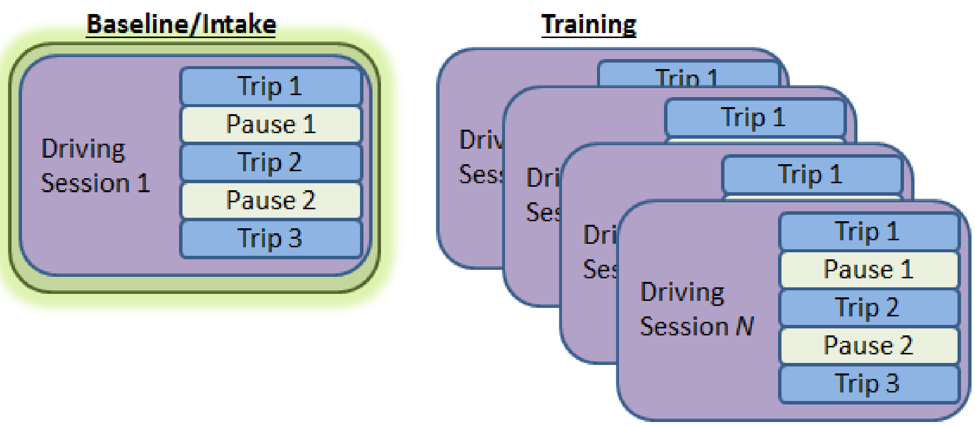


Figure 6-3. Schematic of the Data Structure and Usage Beyond a Baseline Driving Session

All collected data fits into bands that are pertinent to the evaluation/training or bands to be segmented and discarded. As shown above (Figure 6-3), the structure indicates bands to be saved or discarded with respect to the dynamics of a driving session. The driving session essentially represents any visit to the ADP, except for pre-driver assessment for new clients or clients who are only seeking consultation/vehicle check-out to verify proper installation of adaptive equipment in their personal vehicle. Within the course of a driving session, data can be categorized into trips and pauses. Trips reflect continuous periods of driving evaluation, while pauses reflect moments when the car is parked or turned off to allow for coaching and communication between the CDRS and the client. In the end, "trip chaining" is necessary to create the summary statistics for a single driving session with data from the paused periods extracted.

With this data structure applied, a number of potential data comparisons can help inform a CDRS' reported findings and recommendations. Individual clients will have data to enhance considerations of driving capability within a single (baseline) session or across all of their sessions when participating in training interventions. Data reviewed within the baseline session would include comparisons across trips or simply the aggregate results for the entire session. The data collected via NAViSection along with associated vehicle-based sensor technologies could quantify road exposures during driving, independence, safety, endurance/vigilance, and acceptance of advice and coaching offered by the CDRS. With comparisons across training sessions, the same data tracks improvement with added emphasis on the acceptance of advice and coaching.

Other considerations for analysis would inform researchers about the differing needs and capabilities across clients. The analysis of driving capability and performance across clients would enable a global performance map to track group and overall program outcomes among the clients. The groups formed could match clients by gender, age group, years of driving experience, disability classifications, use of medications, use of vehicle modifications, prior involvement in accidents, or any other factor believed to influence the determination of driving capability.

Table 6-1. Proposed File Types for Routine Data Reports

Data Sets	Action	Files		
A	Processing	Maneuvers & Assisted-Events		Continuous Driver Input
B	Summarize: Trip	Maneuvers	Assisted-Events	Independence & Safety Stats
C	Summarize: Session	Maneuvers	Assisted-Events	Independence & Safety Stats
D	Summarize: Case	Change in Maneuvers	Change in Events	Change in Safety & Independence

Any products or services built upon the NAViSection methodology should consider reporting results according to Table 6-1 above. The raw NAViSection data should be processed to present all events with respect to the driving maneuver taking place at the time of assistance. In conjunction with this processed list, a continuous data file should couple driver inputs to the vehicle (steering or braking) with the assisted-events captured through NAViSection data collection equipment. The files for each data set represent the layers of data comparisons shown in Figure 6-3 and the team design principle (see Table 4-1) to compare driver input to the assistance input.

Future work should assemble all stakeholder feedback to decide how this level of quantified driving performance could advance their goals and objectives. The needs of a CDRS will closely relate to the reporting needs of physicians/specialists and the medical advisory board of state departments of transportation. Alternatively, the findings and recommendations by CDRSs could be aggregated via ADED in order to test for convergence around a set of CDRS standards in determination of driver capability and fitness to drive. Any determinations among these stakeholder groups would also be of interest to safety researchers among a multitude of disciplines.

6.3 MODERNIZING DRIVING PROGRAMS WITH NAVISECTION

The original intent of NAViSection was to facilitate the entry and application of intelligent vehicle technologies into driver evaluations. With so many technology options available, this framework opens the door to many improvement opportunities beyond the key reporting tasks of CDRSs as well as driving instructors or driver safety trainers and educators. The clients, customers, and students of driving (school and rehabilitation) programs are in need of clear metrics that can inform their recommendations on driver capability. To counteract the "above-average driver" bias, people should know and embrace perspectives to recalibrate one's awareness of their driving capability. The provision for data collection by the NAViSection methodology and formulation of CDRS standards will be able to generate novel training and educational experiences for new and medically-impaired drivers. NAViSection's future promise is illustrated in Figure 6-4.

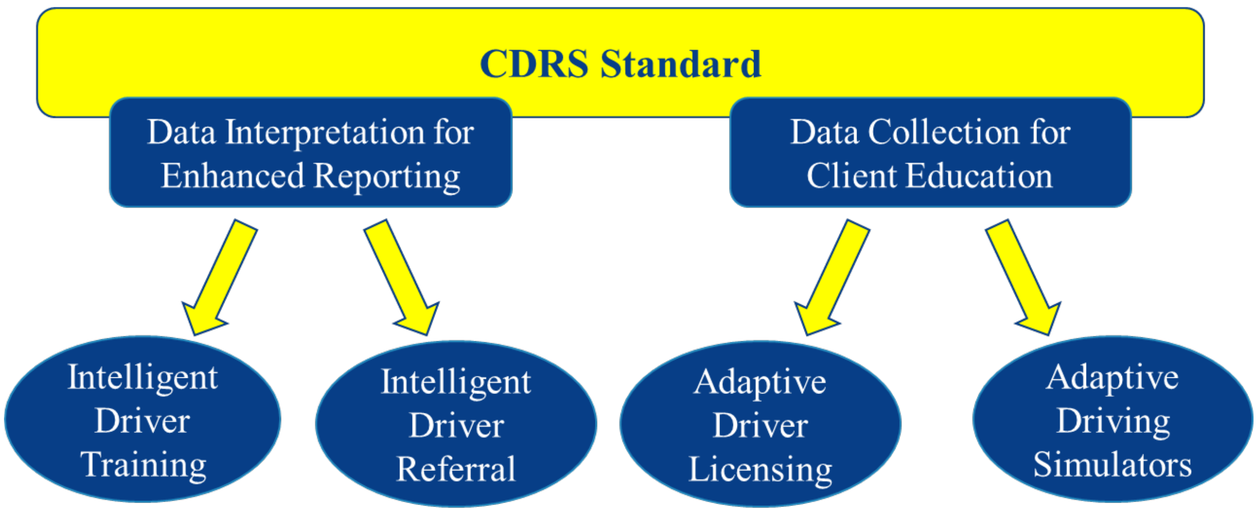


Figure 6-4. Novel Training and Education Possibilities through Data and Standardization

The proposed possibilities present intelligent systems as a reflection of automated or data-based decision support. Intelligent driver training opportunities would fortify the static learning resources published in text and video formats by integrating data that could animate the concepts presented in driver safety education. Intelligent driver referral is a concept in which at-risk drivers would be encouraged to seek professional assistance as data collected through in-vehicle data recorders presents correlations to risky driving as recorded during supervised driving sessions through driving programs. In combination, the data would positively influence a driver to be more aware of their areas of weakness as an experienced driver, while also providing a triage effect that prioritizes who should be assessed by a professional more urgently. The triage capacity would assist many driver rehabilitation programs that have built up substantial wait lists to take on new clients.

Adaptive systems are also proposed with the intent to make policies or provisions more flexible to the case by case needs of individuals in society. Adaptive Driver Licensing would serve as a continuum of licensing restrictions until revocation. Where new drivers undergo graduated driver licensing, there might be an opportunity to apply the reverse strategy as a more gradual route to retirement of driving privileges. Additionally, driving simulations/animations would present a future possibility of recording driving sessions on the road and recreating them "on the fly" as an instant replay for additional time to reflect on and learn from a driver's own errors on the road. The adaptive quality of this approach would customize educational content and resources to the specific needs of each client.

6.3.1 Advancement for Education

A major advancement in client education would be an in-vehicle tutor, such as a GPS-based game, for real-time guidance on rules of the road for an observer or passenger in a car. Driving programs can use this in states where hours of education as an observer are credited towards licensure. In the home/personal setting, parents can adopt such systems for their children to learn about driving through active observation. The opportunities to promote discussion about driving safety among family members will also enhance the awareness of all members involved in discussions about driving privilege.

In addition to the simulation of driver safety training in the vehicle, in-classroom simulators could prove useful for acceptance of driving errors in prior driving sessions involving near crash events. As data collection capabilities increase, cars will be able to eventually capture all of the features already designed into fixed base driving simulators. Under these conditions, it is reasonable to expect that any near crash event could be replayed to the driver following a driving session. The objective of the replay would then be to identify (in most cases) where human error was involved and to accept that the event was avoidable rather than an "accident." Also, with an intent to educate a client about how the event under review was avoidable, the in-office driving simulator may not need to be more advanced than a desktop computer display system in order to achieve the learning effects desired.

6.3.2 Advancements for Driver Capability Tracking

Considering the relationships between driving evaluators and the state licensing authority, there is a potential to improve how licensing decisions are made. New drivers without medical impairments are subject to greater regulations through Graduated Driver Licensing policies. Alternatively, drivers with medical impairments or disabilities (including older drivers) receive guidance from other health professionals under Mandatory Physician Reporting policies. This group of prospective or existing drivers may also experience health conditions with increasing impairment (poor prognosis) over time.

The case for new drivers would be that capability tracking could expedite or customize the period for supervised driver training under Graduated Driver Licensing policies. New standards built off of NAViSection data collection would open up the possibility for naturalistic driving data to be linked with decisions from many prior evaluations. The correlation of expert decision making with statistical significance of continuous data collection could then indicate whether or not a new driver has built up enough driving experience for issuance of an unrestricted driver license. Such a process could replace mandatory time periods (such as the six month period mandated in Pennsylvania) and allow for review of performance per vehicle miles traveled.

Drivers with medical impairments would include new drivers as well as experienced drivers who experience health complications across the age spectrum. To protect the physician-patient relationship, driver rehabilitation programs could offer an intelligent driver referral system in order to avoid or delay reporting to the medical advisory board of the state licensing authority. An intelligent driver referral system would apply naturalistic driving data via a commercially available vehicle-based sensor technology to track driver capability over a longer evaluation period. This opportunity allows for individuals to reflect on their ability to drive before facing the state licensing authority, which issues judgments on the client's/patient's future as a driver. Driver rehabilitation programs could further advance their standards of practice to follow up with their clients longitudinally using vehicle-based sensors. Certain clients come in with unstable medical histories or unidentified etiology/pathologies, affecting their functional impairments. These situations should be resourced with tools that allow a program to call a client back in for reevaluation due to the insight of naturalistic driving data.

6.4 HARMONIZATION OF DRIVER SAFETY COMMUNITIES

The ultimate potential of the NAViSection methodology is to unite the champions of driver safety and build partnerships among road safety stakeholders. From the perspective of driver safety, discussions need to converge upon solutions that unite strategies to keep drivers safe while ensuring that it is the safe drivers who maintain privilege.

License holders will need to understand the leverage that exists across family/friends, law enforcement, physicians/specialists, and driving evaluators. Prior to the emergence of telematics and naturalistic driving data, the conversation has focused on what can be seen or observed as driving errors. The dynamics of this discovery pattern promotes reactionary involvement from personal and professional advocates available to the license holder. Thus, any attempt to breech the topic is often met with a defensive attitude, because the weight placed upon a recent error is used to question the very core of driver capability. The promise of the NAViSection methodology is to promote preventative engagement when global driving performance factors indicate a fixed or progressive decline in driving capability. This foresight would allow discussions to focus on what to do if a (at fault) collision does occur. Without the NAViSection methodology, discussion is typically triggered because a decision must be made urgently because the collision/error has already occurred.

Among professionals who promote safe driving, more collaborative research work between driving instructors/CDRSs and road safety engineers are needed. To simplify the paradigms of each side, driving instructors'/CDRSs' work on strategies would illustrate that the driver is safe, while road safety engineers' work on features would prevent the driver from exposure to a dangerous/fatal situation in the first place.

Driving instructors actually represent many titles from driver rehabilitation specialists to driver safety educators, with terms and definitions still under debate. The limitation of their recommendations is that the determination is regarding an individual's fitness to drive rather than their on-road safety. This is because they do not apply surrogate measures for crash risk. In other words, they do not relate driver capability to driver safety on the road.

Road safety engineers include another broad segment of disciplines from traffic safety and automotive engineers to human factors and injury prevention experts. The focus from these professionals is to determine that exposure to risk factors of motor vehicle collisions has been mitigated in all ways possible, despite the actions of the human driver.

The NAViSection methodology works as a binding agent to unite the activities on both sides of the effort to promote safe driving. Events detected by NAViSection capture the errors related to crash risk. From there, the error may be classified to the domains of human function (cognitive, vision, motor & somatosensory) and the causality of the error may be mapped to clinical assessments, prior history, and self-perceptions regarding medical impairments or impairments due to distractions. At the same time, errors captured under the NAViSection methodology may be categorized as operational or decision-based errors, such that the likelihood and severity of those errors can be associated with the risk of crash involvement using vehicle-based sensors.

The underlying concern with this disjointed effort in the promotion of safe driving is that advancements in automated driving demonstrate a reliance on the ability of machines to be safer than humans. Despite the fact that an overwhelming majority of collisions are attributable to human error, the number of collisions per person is not highly frequent. Much work remains to enhance human perception and awareness with machine interaction. Prior work in machine learning has already shown the potential to train a technology based on observation of human activity (Ziebart et al., 2008; Sofman et al., 2006). That is the essence of the NAViSection methodology. Automated driving must traverse a path of technological advances including collision avoidance technology, and NAViSection uniquely presents the “mirror function” that will allow intelligent vehicles to “learn” by observing driver rehabilitation specialists and driving instructors.

Finally, there is much room for improvement in order to bring harmony WITHIN the two paradigms for safe driving respectively. The harmonization of naturalistic driving studies with driving simulator studies reflects a major challenge within the traffic safety engineering community. At the same time, there are synergies yet to be realized among the occupational therapists and driving trainers within the driver rehabilitation specialist field.

Occupational therapy practitioners have championed the call for evidence-based practice in driver rehabilitation within the ADED organization, while driver training professionals have maintained a presence only in the formation of credentialing examinations. The NAViSection methodology explicitly used the SIPDE driving strategy presented by driver training professionals in order to synthesize the values of driver rehabilitation practice. Additional inclusion and participation by driver training professionals in research will greatly enhance the role and influence of the driver rehabilitation field for safe driving.

APPENDIX A

SURVEY OF DRIVER REHABILITATION SPECIALISTS

The “Survey on Technology for On-The-Road Evaluation in Driver Rehabilitation” was administered during the 34th Annual ADED conference and Exhibits in Kansas City, MO from July 31st-August 2nd, 2010. The following pages contain the entire survey, and the results were presented in the ADED *News Brake* publication (Vol. 3 No. 1 – Winter 2011 Edition) as well as the 3rd International Symposium on Quality of Life Technologies in Toronto, Canada from June 5th-8th, 2011.

Survey on Technology for On-The-Road Evaluation in Driver Rehabilitation

Service Delivery Demographics

1. What roles do you play in driver rehabilitation? (check all that apply)

☐ Occupational Therapist
☐ Driver Educator
☐ Physician – Primary Care (General Practice)
☐ Vocational Rehab. Representative
☐ Mobility Equipment Supplier/Installer
☐ Therapist – other, type:__________________
☐ Researcher/Policy Expert, type:_______________
☐ Physician – specialist, type:__________________
☐ Other Funding Rep., type:__________________
☐ Unlisted, type:__________________

2. Are you a Certified Driver Rehabilitation Specialist? ☐ Yes ☐ No

3. How long have you been working in your current position related to driver rehabilitation

_______ yrs. ________mos. Comments: ____
____

4. Where do you work? ________________country ________________ state/province

5. Do you conduct pre-driving assessments? (ex. clinical tests for driver fitness)

☐ Yes ☐ No

6. Do you use any technologies (*anything more than pen & paper*) to produce client records/reports?

Comments: ____
____
____

7. Do you conduct on-the-road evaluations?

☐ Yes ☐ No

8. Do you use any technologies (*anything more than pen & paper or adaptive equipment*) to enhance your assessment during on-the-road evaluation?

Comments: ____
____
____

Client Demographics & Experiences

9. What type of medical conditions do you most often work with? (check all that apply)

☐ Spinal Cord Injury	☐ Amputee	☐ Multiple Sclerosis
☐ Head/Brain Injury	☐ Stroke/CVA	☐ Diabetes
☐ New Drivers (with disabilities)	☐ Older Citizens	☐ Mental/Emotional Conditions
☐ Learning Disabilities	☐ Vision deficits	☐ Hearing/Speech deficits
☐ Dementia	☐ Neuropathy	☐ Cerebral palsy

Comments: ____

____

____

10. When do your clients become defensive about your findings and recommendations?

...for which driving tasks or capability assessments do clients disagree with your assessment?

Comments:____

____

____

11. Do these challenges occur for your most frequently seen medical conditions or the infrequent ones?

Comments: ____

____

____

12. Would you be able to provide better client education if you had sensor-based measures of their driving performance?

Comments: ____

____

____

13. Which driving tasks do you feel are most challenging to observe or assess?

Comments: ____

____

____

Proposed Novel Device Description

Motivation:

The automotive industry is exhibiting a rise of vehicle sensor instrumentation to monitor and inform many aspects of driving performance. The focus has been on the driving environment (positions/default settings), vehicle status (tire pressure sensors), or crash risk detection/avoidance (distance sensors/traction control). Implementation of driver safety, capability, and performance monitors should also benefit from the emerging market of vehicle sensor technologies.

Investment and research needs to target key challenges in driving evaluation, such as the difference between poor vehicular control and an intelligent evasive maneuver avoiding road hazards. The knowledge base behind interpretation of sensor data has significant challenges that can best be addressed by the work of Certified Driver Rehabilitation Specialists and the field of driver rehabilitation.

Goals:

A. Identify combinations of <u>key driving tasks</u> and <u>clinical tests</u> that best flag <u>driving capability/safety</u> issues with common medical conditions documented for medically-impaired drivers.

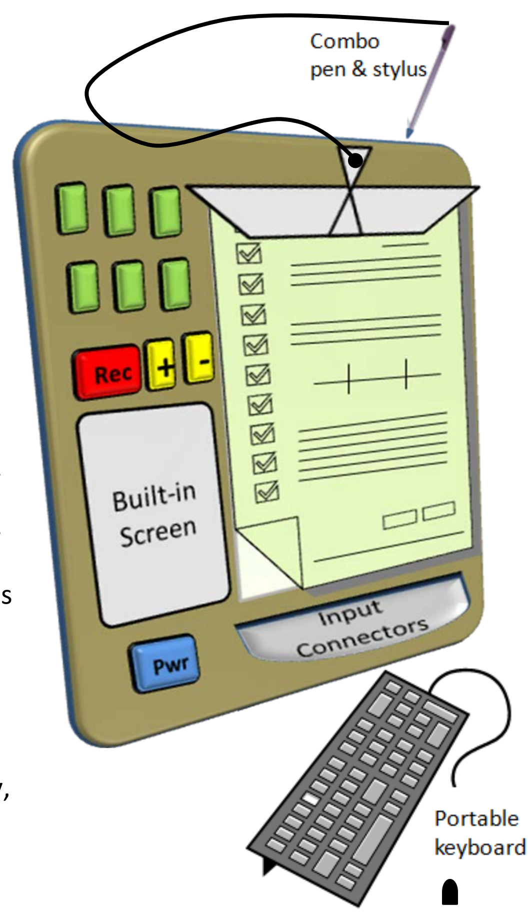
B. Develop a tool to allow a CDRS interface for

1. Logging time stamps where a driving task is observed,
2. Labeling of the time stamp windows by the observed task, and
3. Rating of the driving safety/capability/performance criteria evaluated

Concept:

Think about using a driver rehabilitation evaluation vehicle fully instrumented with sensors that can measure data about the driver, the vehicle, and the environment.

- Imagine a "clipboard" for your on-the-road test form with multiple methods for data input or selection.
- Envision the simplicity of selecting time points or ranges of time where a driving task is performed and you have the ability to "tag" the event observed.
- Picture "rating" criteria to document observations of driver safety, capability, and performance by a CDRS.
- Consider the ability of this device to apply your inputs to process the data, from any vehicle sensor technology, collected during a driving evaluation.
- Extend the data processing outcomes to annotated, graphical representations of driving safety, capability, and performance for reporting as well as client education purposes.



General Comments:

14. Do you have any concerns about…

safety,

ease of use,

application of technology,

value of technology to your practice,

…or other issues having considered the design description presented above?

____

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15. Do you think some automated screening of driver capability with vehicle sensors can support…

triage of client volume in backlogged driver rehabilitation programs,

follow-up of clients with questionable medical prognosis,

training supervision for marginal driving evaluation findings,

performance feedback for clients to self-monitor their driving,

due process appeals for clients resisting recommendations for cessation,

…or other opportunities?

____

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---Design Factors for the Proposed Device---

Think about a driving task, operation or capability that you would like to observe with vehicle sensors.
16. What is your *<u>envisioned driving task/capability</u>* to be observed with vehicle sensors?

Task/capability: ______________________________

****Please answer all the following questions with this task/capability in mind.****

<u>Technology Platforms & Interfaces</u>

17. What would you like to use for the platform of the proposed device? (check all that apply)

☐ Cell phone/Smartphone

☐ Clipboard

☐ Tablet computer (with keyboard connectivity)

☐ Other, *write response in blank space*:

18. How would you like to enter information into the device? (check all that apply)

☐ Touch screen

☐ Stylus/pen (stylus: a pen for screens/electronics)

☐ Buttons/keys and mouse

☐ Voice

☐ Other, *write response in blank space*:

19. How would you want data entry spaces presented?

☐ Checklist with expanding/hiding sections
(like a set of tabs that open up like a drop-down box/menu)

☐ Full view of electronic form
(like a web page)

☐ Prompted Sequence of Sections
(like a PowerPoint presentation)

☐ Other, *write response in blank space*:

Comments: ____
____
____
____
____
____
____

Driving Data of interest

20. What should a sensor record for the "*envisioned driving task/capability*" in terms of the…?

Driver: ____

____

____

Vehicle: ____

____

____

Environment: ____

____

____

21. How would you group sensor data to compare performance within or across clients & scenarios? (check all that apply)

- ☐ Training Session
- ☐ Years of Driving Experience
- ☐ Client's Age
- ☐ Medical Diagnosis
- ☐ Onset of Diagnosis
- ☐ Medications Taken
- ☐ Referral Source
- ☐ Funding Source
- ☐ Clinical Test Results
- ☐ Vehicle Modifications
- ☐ Date of Eval/Time of Year
- ☐ Other? ________________

Comments: ____

____

____

22. Would you want to complete your documentation on this proposed device?

☐ Yes ☐ No

23. Which forms would you like to be integrated into this proposed device? (check all that apply)

- ☐ Clinical/Pre-Drivers Forms
- ☐ On-Road Evaluation Form(s)
- ☐ Training Progress Forms
- ☐ Funding/State Forms
- ☐ Reporting Forms
- ☐ Schedules/Billing Forms

Other: ____

____

____

Capturing/Recording Sensor Data

24. How specific do you need recorded data to be for the "*envisioned driving task/capability*"?

☐ Single Driving Task (ex. speed regulation)

☐ Sub-Events for a Single Driving Task (ex. parallel parking)

25. How do you want to capture or record the data within a time window? (check all that apply)

☐ A. Single-click + default time window centered on time of click

☐ B. Single-click + adjustable time window centered on time of click

☐ C. Two-click (record and stop) to select the end points of the time window

☐ D. Press and hold recording to select the duration of the time window

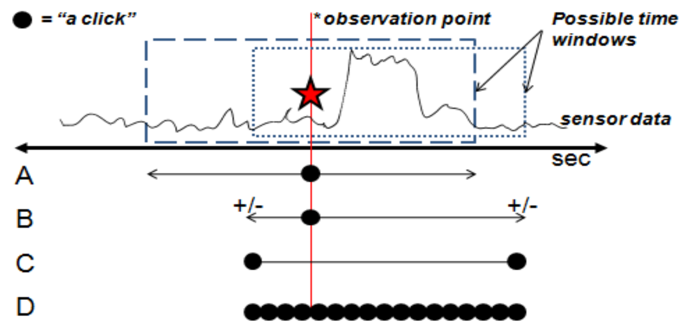
Time Window Explanation

A. centered on click

B. variable off of click

C. click to start, click to stop

D. hold click while recording



Rating Driving Performance

26. How would you assess or rate your client's driving performance based on the following capability concepts?

Concept: Perception (Vision /Cognitive Domains OR Human factors: Input) –
Criteria: Hazards/Obstacle identification, Proper checks/Monitoring

Comments: ____

____

____

Concept: Judgment (Cognitive/Motor Domains OR Human factors: Processing) –
Criteria: Decision making/Reaction time, Problem solving/Adjustment

Comments: ____

____

____

Concept: Operation (Motor/Vision Domains OR Human factors: Output) –
Criteria: Skill/Control, Task performance sequence/methodology, Ease/Difficulty/Fatigue

Comments: ____

____

____

Concept: Compliance – (Behavioral Domain) –
Criteria: Adherence to laws, Acceptance of cautions from CDRS, Driving attitude

Comments: ____

____

____

Evidence Reporting & Client Education

27. How frequently would you want to access data selected using this device? (check all that apply)

☐ Real time for in-vehicle client education

☐ After each client's evaluation

☐ Two or three times a day

☐ At the end of every day

Comments: ____

____

____

28. How would you want data presented and formatted?

Graphs, Charts, Tables: ____

____

____

System notes/Statistics/Annotations: ____

____

____

Pre-drivers result/Client intake: ____

____

____

29. When appropriate, how much additional time is reasonable to enhance reports with sensor-based evidence?

☐ 5 min/client ☐ 10 min/client

☐ 15 min/client ☐ 20 min/client

☐ 25 min/client ☐ 30 min/client

30. Have you participated in any research efforts related to driving assessment in the past or present?

☐ Yes ☐ No

Comments: ____

____

____

APPENDIX B

PROJECT NAVISECTION REQUIREMENTS DOCUMENT

The contents of Appendix B reflect the original project design requirements developed shortly after approval of the NAViSection project proposal on October 27, 2010.

Project Navisection

Design: (Certified) Driver rehabilitation specialist (DRS) interface to DriveCap. The interface will be termed, "**Navisection Device**" for the remainder of this document to reflect the overall system.

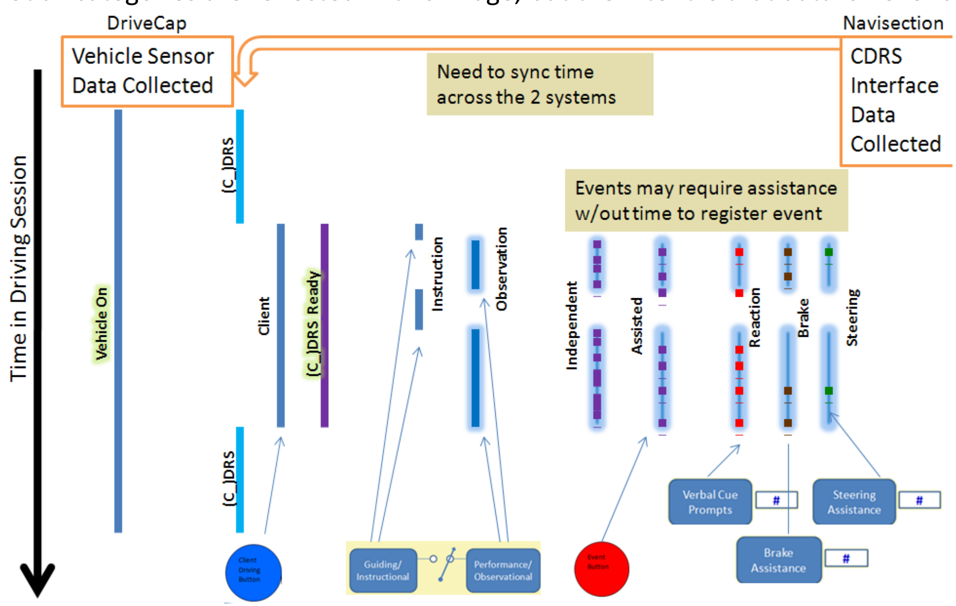
Scope: In future studies, there may be data access and interface design modifications to evaluate other emerging vehicle sensor technologies for In-Vehicle Intelligent Transportation Systems. Modifications to the base design of an interface can be made to accommodate specific needs of driver rehabilitation specialists in the field or for driving evaluators within the context of a DMV site. However, <u>the initial design must prove viable and beneficial to the practice of Amy Lane, OTR/L, CDRS within the Adaptive Driving Program (ADP) in the Center for Assistive Technology (CAT) at Forbes Tower</u>. The primary focus of the present design effort is to detect and log up to three ways that CDRS*-aided driving takes place during evaluation:

- steering assistance,
- braking assistance, and
- verbal cues for guidance in judgment.

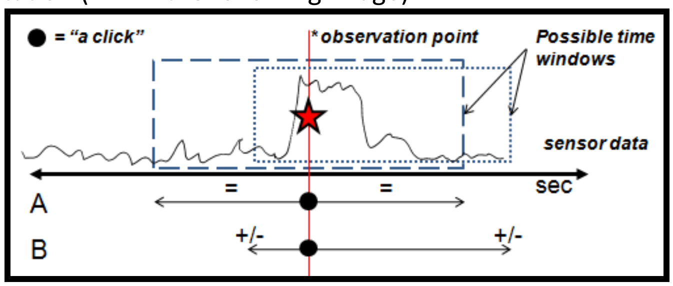
*CDRS – Certified Driver Rehabilitation Specialist

Goal: to segment collected naturalistic driving data based upon event detection or notification during Behind-the-Wheel evaluations (on-road) of medically-impaired drivers. By defining data cut points based on relevance to events of interest in driving assessment, there is an opportunity to enhance documentation and reporting of driving capability (independence) and driving performance (safety) as part of the findings and recommendations reported by driver rehabilitation programs. With a focus on detecting driver capability, data can be categorized by its value for assessing driver performance or evaluating program outcomes.

Data Management: The following image illustrates the categorical value of data based on event logging categories. Not all categories are reflected in this image, but the intent is that data is never discarded.



Data Segmentation: The basic treatment for segmentation will simply apply the following modes of event logging by a driver rehabilitation specialist. An observed event will produce a corresponding "time window" of data associated to the event ("A" in the image below). The time duration of the windows may be preset according to the type of event that is logged, but the driver rehabilitation specialist will be able to expand the left and right end points of a time window as necessary (within reasonable limits) to support data interpretation ("B" in the following image).



Listing of Major Sub-Systems to the Navisection Device

1. DRS event logger

The event logger sub-system must:

a. Accommodate state selection of an evaluation by

1. session status – client driving (active evaluation), CDRS driving (transition), and miscellaneous driving (not associated with client sessions) either real-time or retroactively via DRS data interpretation and documentation tool (see below)

2. phase of session – "off-road"/instructional OR "on-road"/assessment in real-time

NOTE: *the active evaluation includes both instructional and/or assessment phases, but does not include CDRS driving or miscellaneous driving*

b. Support assignment of data collection periods to both a client ID and client session number in real-time or retroactively via DRS data interpretation and documentation tool (see below)

c. Facilitate the CDRS for logging the occurrence of a significant event

d. Maintain communication access to the Witness event logger and classification tool (see below) over the duration of "active evaluation"

2. DRS brake application alert

The brake application alert sub-system must:

a. Identify the action of braking through the displacement or force applied to the evaluator brake mechanism.

b. Provide an appropriate signal to indicate the application of the brake

c. Sustain a signal to indicate the duration of brake application

d. Maintain communication access to the Witness event logger and classification tool (see below) over the duration of "active evaluation"

3. DRS steering assistance alert

The steering assistance alert sub-system must:

a. Capture appropriate features of grasping between the hand of the CDRS and the vehicle's steering wheel

1. Capture some characteristic from the hand of the CDRS (covered or bare) to determine activity within sufficient proximity to the steering wheel.

2. Capture some characteristic from the hand-vehicle interface to discriminate against (some, none or all) false signals associated with assistance with controls (touching/manipulating) other than the steering wheel of the vehicle, such as:

i. turning the key in the ignition,

ii. changing gears from the shifter mounted on the steering column,

iii. adjusting the steering wheel position,

iv. honking the horn,

v. activating headlights/turn signals/windshield wipers, or

vi. accessing secondary controls related to A/C and car stereo features.

b. Provide all necessary data through a combination of 3.a.1 and 3.a.2 to provide evidence for a steering wheel assist event

e. Sustain all necessary data streams sufficient to discern the duration of steering assistance

f. Maintain communication access to the Witness event logger and classification tool (see below) over the duration of "active evaluation"

4. DRS verbal cues recording channel (alert)

The DRS verbal cues recording sub-system must:

*****under discussion, not yet adopted as requirement*****

a. continuously collect voice and speech recordings of the Certified Driver Rehabilitation Specialist

5. Witness event logger and classification tool

The witness event logger and classification tool must:

a. Provide general comment entry by witness for overall issues relating to change in evaluation technique, configuration changes/interference, and any other issues that alter the data collection capability of the Navisection Device

b. Maintain a viewable table of logged events and sub routines listing all information related to EVENTS and NAVIGATION.

EVENTS

a. Display all events due to detection from brake application alert or steering assistance alert and allow witness generated events in response to them

b. Document a log of all events involving CDRS-assisted driving as a tallying system for

1. braking assistance

2. steering assistance

3. verbal cue decision assistance

and also document the source of the event as CDRS generated or witness generated

c. Generate an event description window for all tallied events of CDRS-assisted driving along with an event ID number in order to enter categorization of events into any/all of the following applicable error classification schemes

1. Speed management

2. Steering control (out of lane)
3. Distance maintenance
4. Position stability (within lane)
5. Safe decision making

NAVIGATION

d. Display GPS path traveled during session

e. Tag driving time as a continuum between driving tasks with the following maneuvers

1. Driving/Staying in Lane
2. Going Straight
3. Lane Changes (Left & Right)
4. Turns (Left & Right)
5. Stops

And apply the tagged status retroactively to cover all time points back to the immediately previous entry.

f. Plot/Display sequential chain of driving maneuvers

6. DRS data interpretation and documentation tool

The data interpretation and documentation tool must:

a. Accommodate retroactive data assignment from Section 1.a. and 1.b.

b. Allow for "no consent" check box to omit the use of data that does not receive approval for use by client.

c. Allow sequencing tag to identify the baseline session or how far from baseline the session is within the series of training/remediation sessions.

d. Automatically generate the session length for time elapsed calculations for Client driving, Transition travel and Miscellaneous travel

e. Develop format uniqueness of GPS plot for tags of driving continuum in maneuvers (ex. Color)

f. Develop format uniqueness of GPS plot for tags of event type (ex. Marker size)

g. Develop format uniqueness of GPS plot for tags of error type (ex. Annotated flags)

h. Allow for GPS driven-mapping of event/featured data on CDRS's office computer

i. Provide Google street view augmented video in conjunction with GPS plot driven graphing for performance data in the context of the road traveled during assessment

j. Generate measures of exposure such as risky events, driving maneuvers, and different types of roads

k. Generate measures of capability such as independence rates & counts as an assistance log

l. Generate measures of performance such as speed control, distance management, smoothness of driving

m. Provide annotated plot image export to enhance standard documentation procedures.

6. DriveCap – a system of sub components. Will be used as is with modifications only for data access and time sync needs in the study.

System List with Operational Ranges of Use in Navisection Device [Incomplete]

Functional Ranges for External Communication
Functional Ranges for Internal Processing
Functional Ranges for Reporting

Hardware:

Witness computer,
DRS event logger,
Evaluator brake usage switch,
DRS glove with detection features,
Steering wheel monitoring device,
DRS voice/speech capture device,
Data acquisition device,
ADP computer

Software:

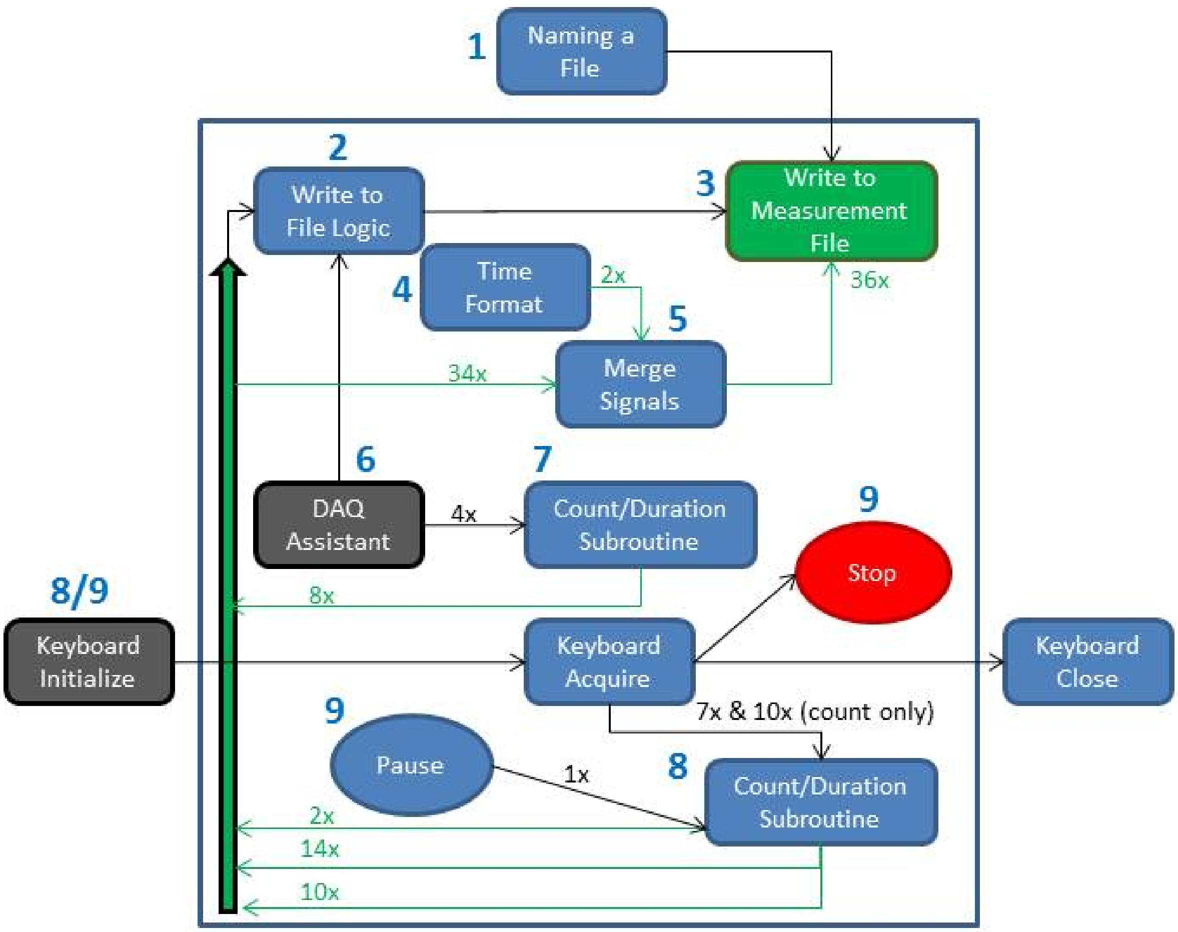
DRS event logging routine,
Witness User Interface (WUI),
Event logging data acquisition routine with display window for WUI,
Event-based data processing sub-routine and window for WUI,
Data interpretation tool for documentation,
other?

APPENDIX C

ILLUSTRATIONS AND DESCRIPTIONS OF KEY ELEMENTS FOR THE NAVISECTION WITNESS LOGGER CODE IN LABVIEW

The following map of lab view virtual instruments explains how data was collected using National Instruments' equipment and software. Following the breakdown of graphical code elements, the full page map of the routine illustrates how all elements build up the data collection routine with a list of all data channels recorded into text files. Additional pages explain the data analysis capabilities envisioned through the segmentation and data enhancement properties of the NAViSection methodology.

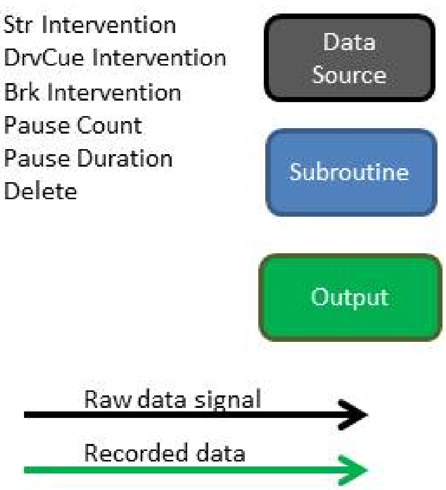
NAViSection Logger System Schematic of LabView Routine

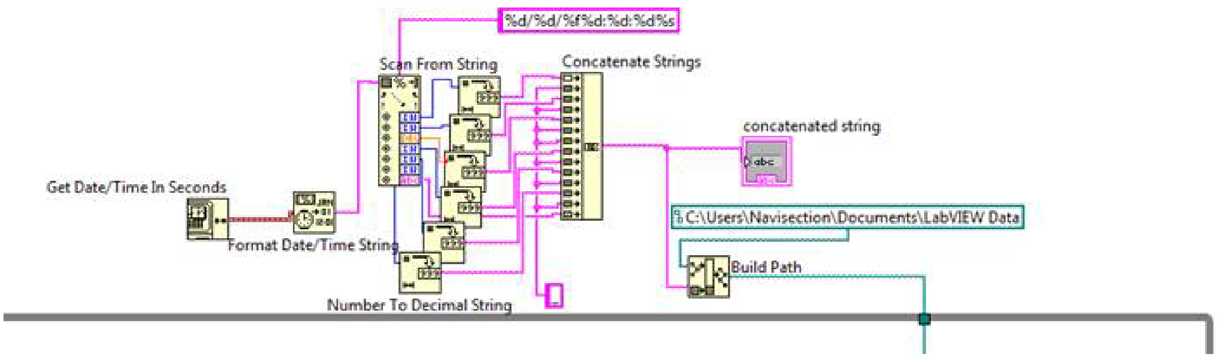


Recorded Data Set (36x)

U=Untitled Column in Text File

U Epochs
U1 LabViewTime
U2 DrvCues Count
U3 DrvCues Duration
U4 StrAsst Count
U5 StrAsst Duration
U6 BrkAsst Count
U7 BrkAsst Duration
U8 Brake Use Count
U9 Brake Use Duration
U10 Comand
U11 Left Count
U12 Left Duration
U13 Straight Count
U14 Straight Duration
U15 Right Count
U16 Right Duration
U17 Stop Count
U18 Stop Duration
U19 Lane Keeping
U20 Merge Count
U21 Merge Duration
U22 LnChg Left Count
U23 LnChg Left Duration
U24 LnChg Right Count
U25 LnChg Right Duration
U26 Info Sign
U27 Traffic Signal
U28 Stop Sign
U29 Yield/Caution Sign
U30 Str Intervention
U31 DrvCue Intervention
U32 Brk Intervention
U33 Pause Count
U34 Pause Duration
U35 Delete





1. Get Date/Time in Seconds reads the computer's clock time and system date

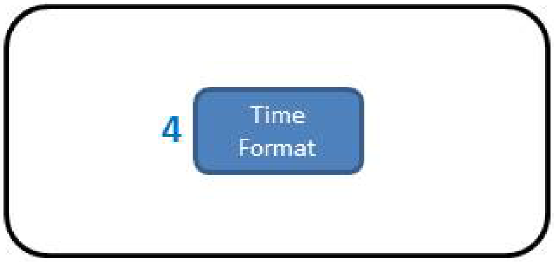
2. Format Date/Time String turns the information into a string result

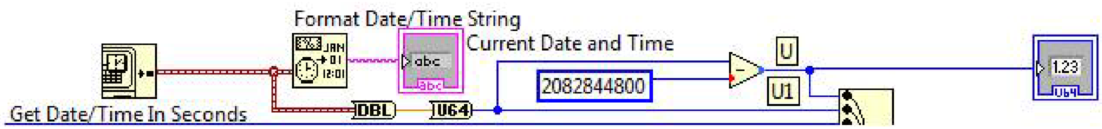
3. Scan from string reads each character into segments based on the formatting specified over the number of characters specified
   ***This step allows the date and time to be broken up for spacing**

4. Number to Decimal String reformats each segment into a string result

5. Concatenate Strings links a series of string results into a single string result
   ***This step inserts an underscore string between each string segment**

6. Build Path takes an assigned directory and a specified string to name a file for the Write to Measurement File subroutine within the main case structure





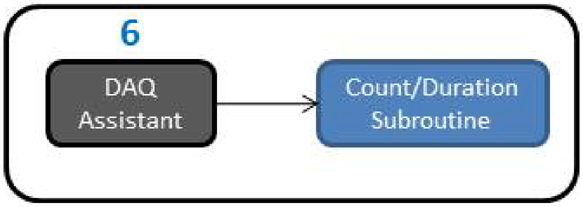
1. Get Date/Time in Seconds reads the computer's clock time and system date

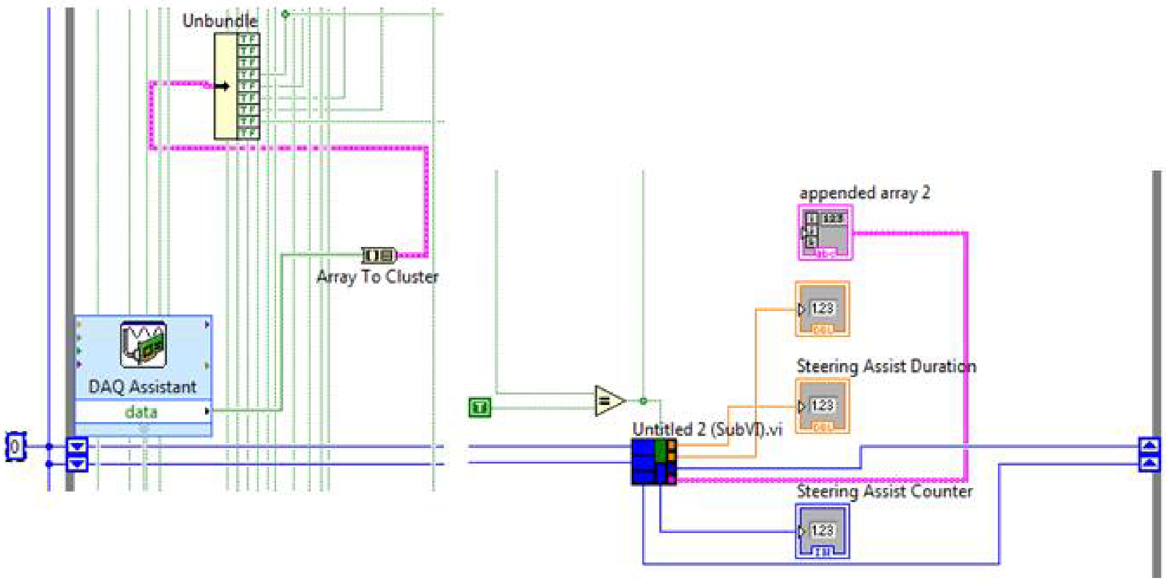
2. Format Date/Time String turns the information into a string result and then displays the result on the Front Panel [Current Date and Time]

3. The DBL (Double Precision Float) & U64 (Unsigned Quad Integer) operators format the source information into a simple number format to enter into Merge Signals in preparation for the Write to Measurement File subroutine.

4. The subtraction operator allows for reduction of the time in seconds to match the unit of Epochs (seconds since January 1, 1900), while the formatted source information maintains the time in seconds according to LabView Time (seconds since January 1, 1904)

5. The Epochs are passed through for display on the Front Panel, while both time series are wired into Merge Signals





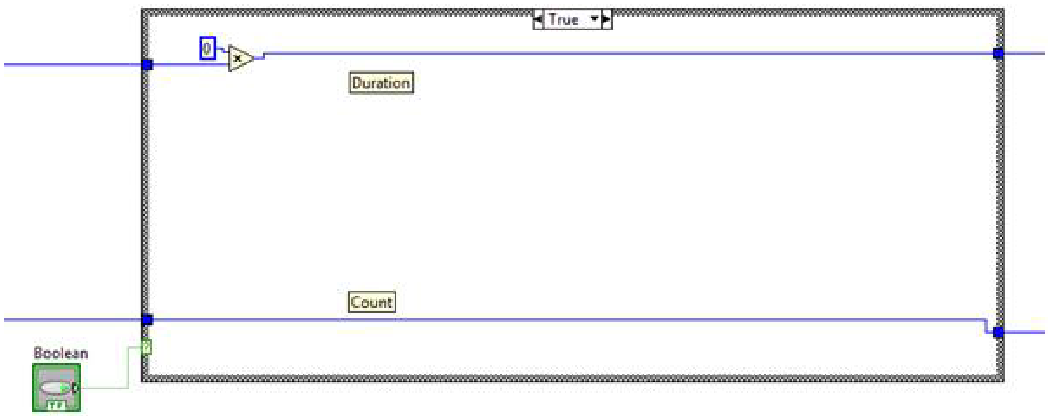
1. DAQ Assistant reads signal sources from a National Instruments Data Acquisition Box (NI connected via USB to the computer

2. An Array to Cluster operator creates a string of boolean values for digital signals

3. The Unbundle separates the cluster of boolean values as entries to other subroutines such as the Count/Duration Subroutine shown here as Untitled 2 ***This image shows the subroutine for Steering Assistance Detection and reflects the data channels for U4 and U5**

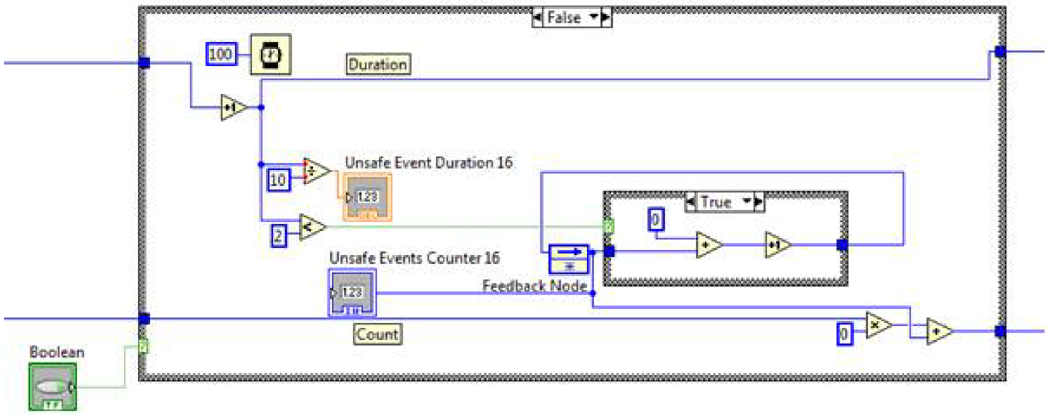
4. The subtraction operator allows for reduction of the time in seconds to match the unit of Epochs (seconds since January 1, 1900), while the formatted source information maintains the time in seconds according to LabView Time (seconds since January 1, 1904)

5. The Epochs are passed through for display on the Front Panel, while both time series are wired into Merge Signals



1. The count and duration lines pass through a True/False case structure, where the boolean control is linked to a digital source from the DAQ Assistant, Keyboard Acquisition, or Pause subroutine.

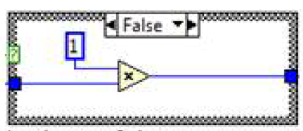
2. The duration is multiplied by zero to initialize a new timing value from zero when the case structure reverts to the false condition



1. Under the false condition, the duration undergoes a +1 operator in 100 millisecond intervals

2. The value is displayed on the Front Panel after division by 10, which presents ten/hundredths of a second in the format of seconds with accuracy to a tenth of a second

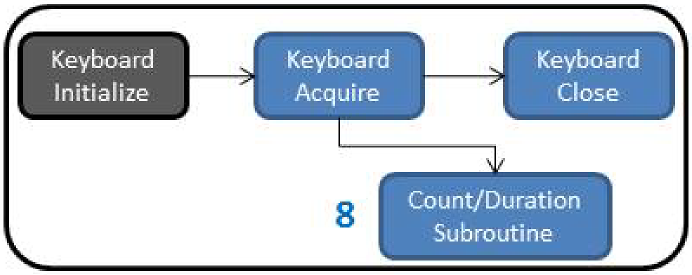
3. A nested true/false case structure operates based on the "less than" logic operator to index the count channel (+1) while the duration is less than 2 milliseconds.

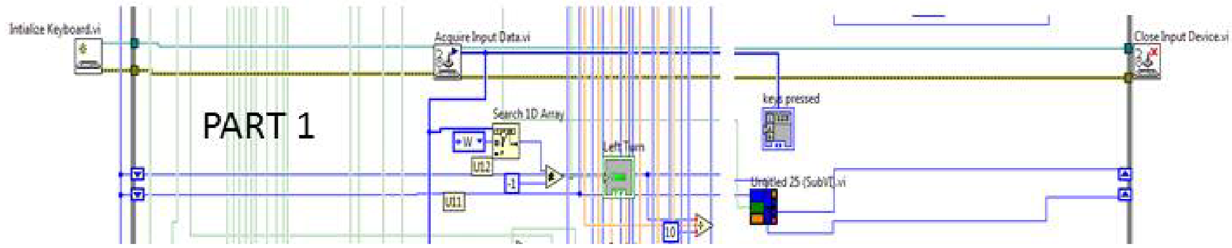


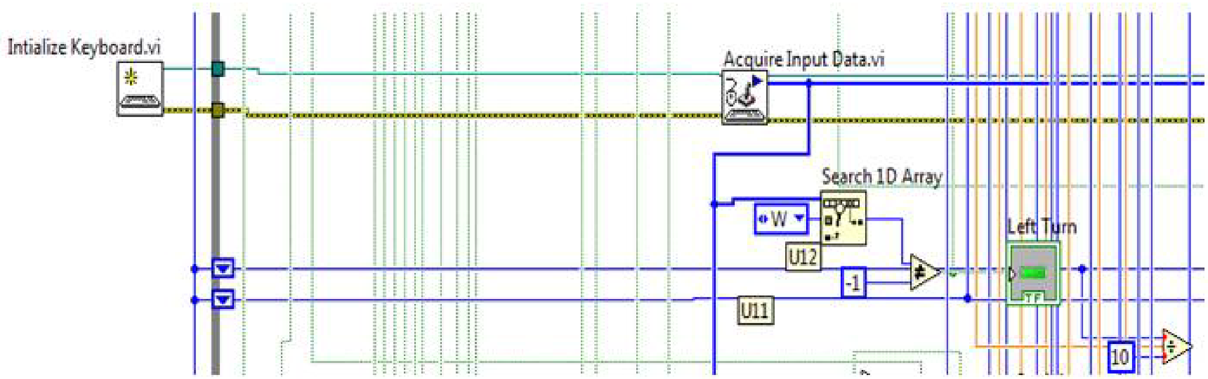
4. In the next cycle of the larger false case structure, the nested condition switches to a false condition that maintains the count value as a constant (x1) for the duration of the surrounding false case structure.

5. The Feedback Node retains the value within this true/false case structure, while the departing channel is "zeroed out" (x0) and added to the value of the nested function's data channel

6. The count value is displayed on the Front Panel also





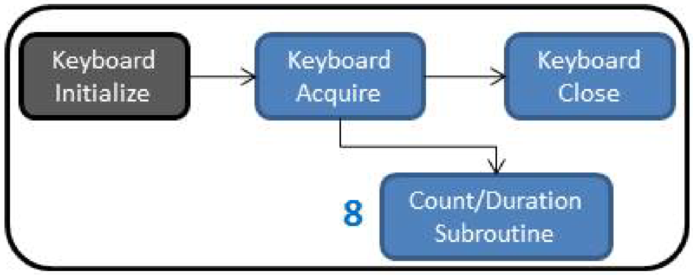


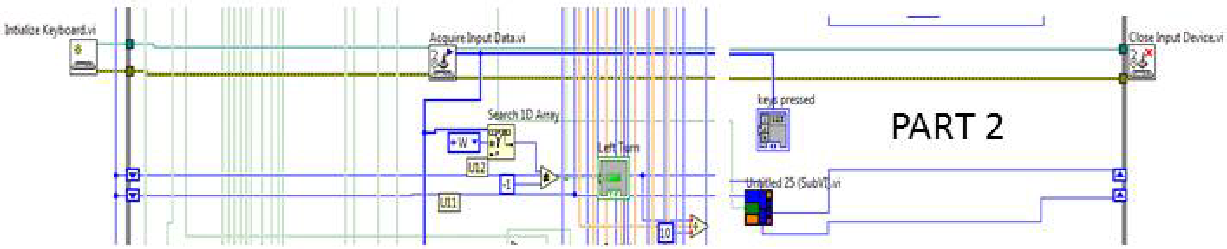
1. The Initialize Keyboard routine prepares LabView to monitor key entries

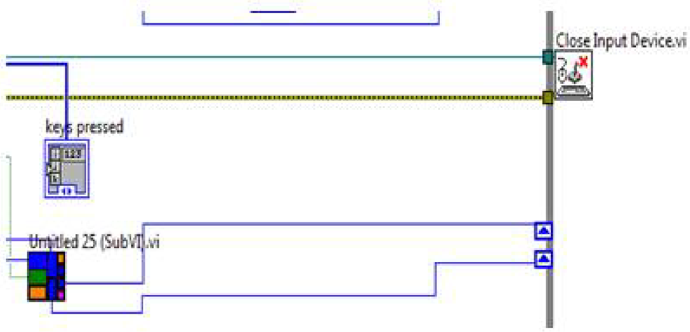
2. Acquire Input Data is a routine similar to the DAQ Assistant that continually monitors the status of key entries via the keyboard

3. The Search 1D Array subroutine scans for a specified key entry among the values of all key entries provided by the Acquire Input Data subroutine in a single array . The result is a value of "-1" if the specified key entry is not present within the array. Otherwise it is the value of the array position where the specified key entry is found

4. The "not equal" logic operator allows for the value of the key entry to be displayed on the front panel with a logo reflecting the event associated with the key entry

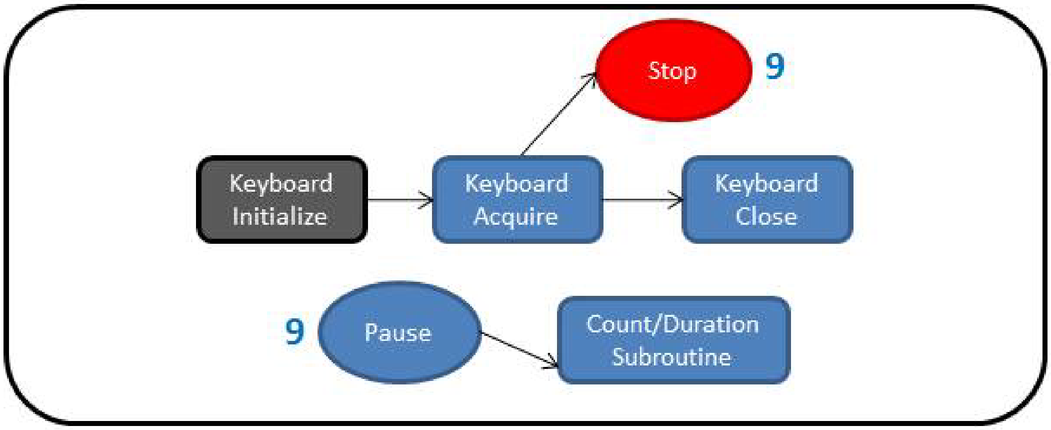


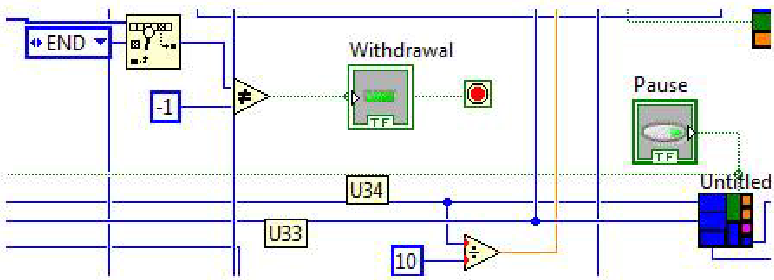




1. A front panel display is available for debugging to see what values of key entries are successfully acquired by the subroutine

2. Upon completion of the routine, the Lab View routine ends the monitoring of key entries via the keyboard



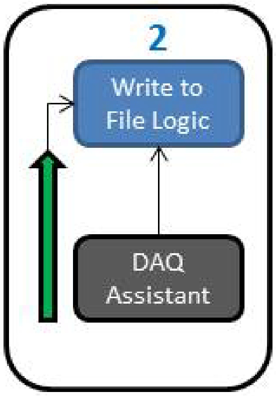


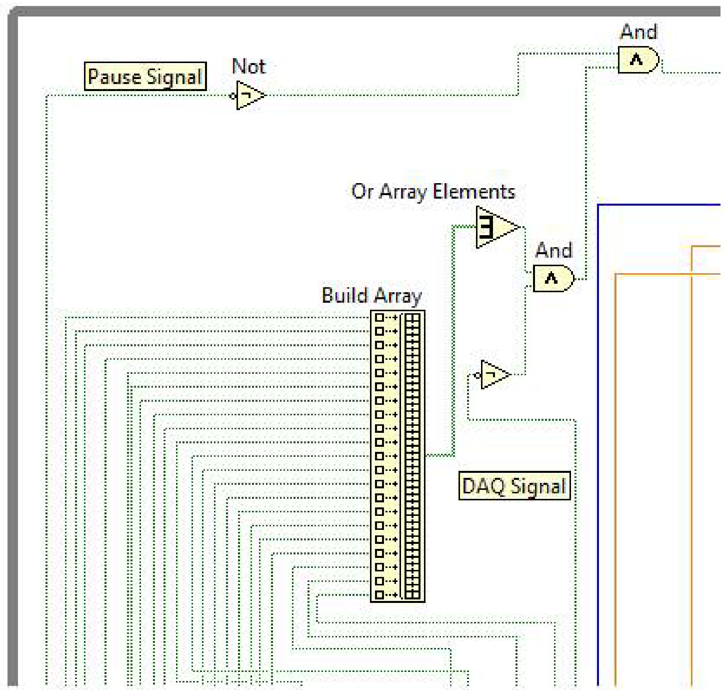
1. The same subroutine (Search 1D Array) scans for a specified key entry for the data collection to stop (ex. study participant withdraws)

2. The "not equal" logic operator returns a boolean value so that when the search routine returns a value of -1 (key entry not found), the routine continues to run (logic operator returns false value for "not equal")

3. The Pause routine is an embedded control feature in the LabView routine that achieves the same function as the Search 1D Array subroutine without using the source of the keyboard initialization subroutine

4. Both values, withdraw and pause, are displayed on the Front Panel





1. DAQ signal specifies when the recording switch is off and leads to a "not" logic operator. The result is true when the recording switch is turned on.

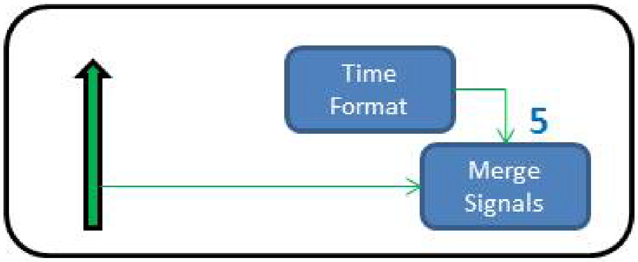
2. The Build Array subroutine collects all logic signals from the subroutines of DAQ and keyboard source signals. When necessary, a "not" operator connects to the signal prior to entry into the Build Array subroutine.

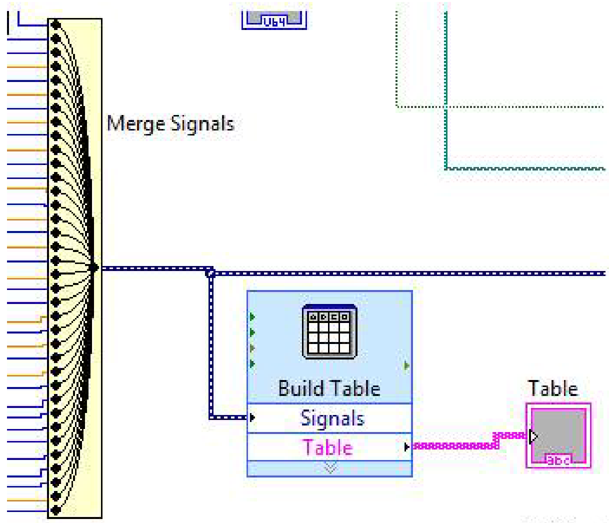
3. The "Or Array Elements" logic operator returns a true value if any of the individual elements provides a true value. The 21 elements include 6 assisted driving events (auto & manual) , 8 driving maneuvers, 4 traffic signals, the pause button, commanded maneuver button, and driver-side brake use signal

4. Comparison of the "Or Array Elements" operator and the "not" operator from the DAQ recording switch signal passes forward a true signal if both arguments are also true entering the "and" logic operator

5. The Pause signal value connects to a separate "not" logic operator which is true if the pause signal is not on

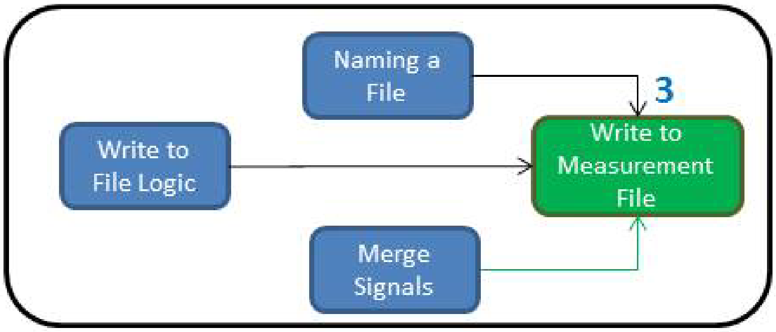
6. The second comparison between the "not" operator from the Pause signal and the first comparison using the "and" logic operator passes forward a true value to the Write to Measurement File subroutine if both arguments entered are also true

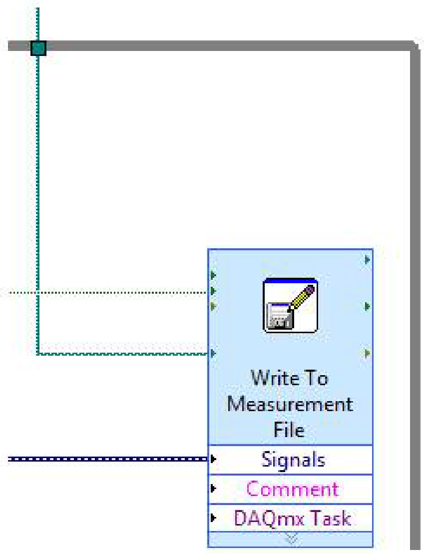




1. Merge Signals is the subroutine that prepares all recorded data for entry into the Write to Measurement File subroutine.

2. The output also leads into a build table subroutine that allows for a table to be viewed on the Front Panel for debugging purposes





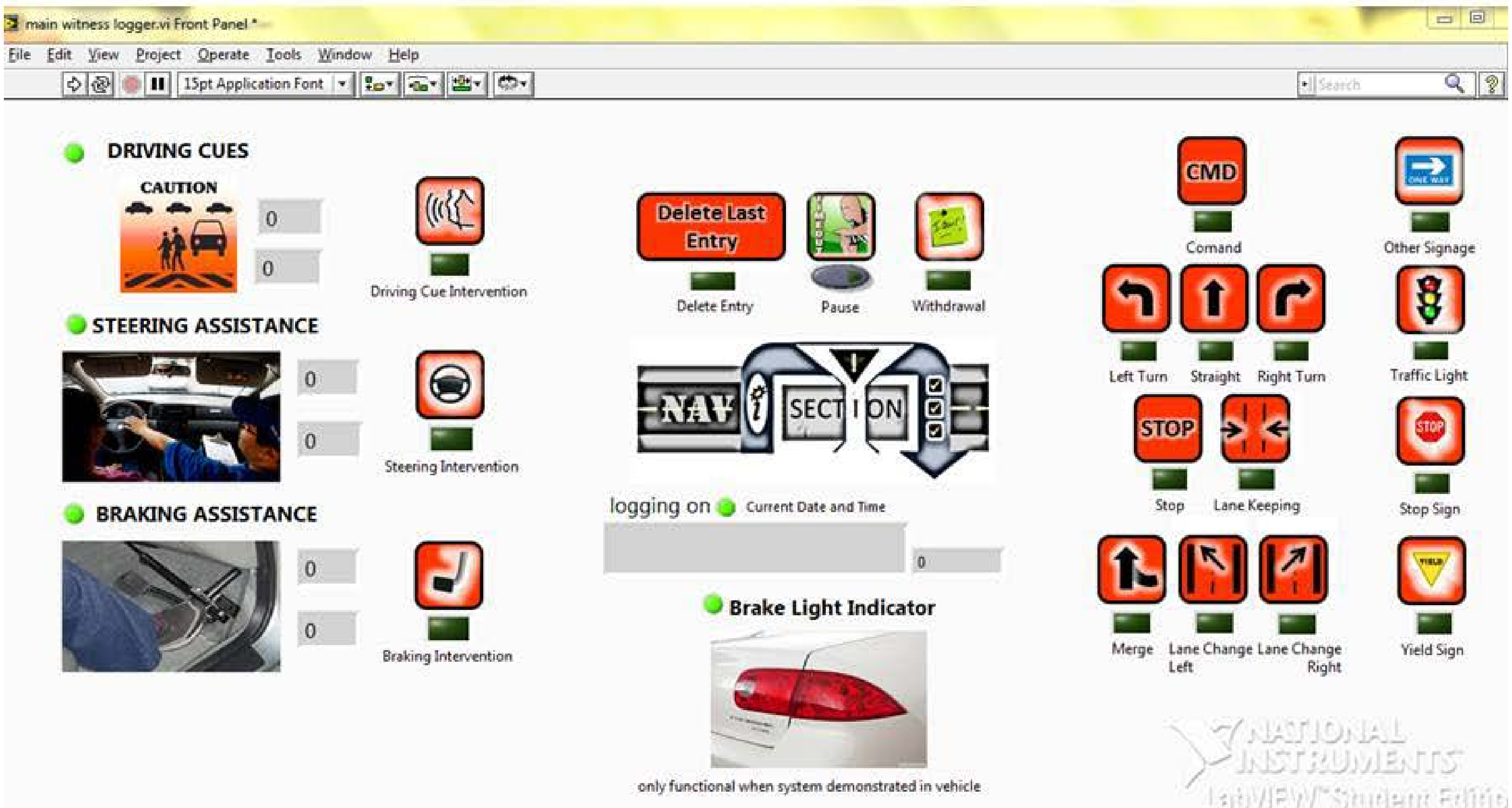
1. Write to Measurement File is a standard LabView subroutine (VI) that crates text files from measurement signals read into a routine

2. The naming a file routine is an input from above to specify the date and time of the recorded driving session

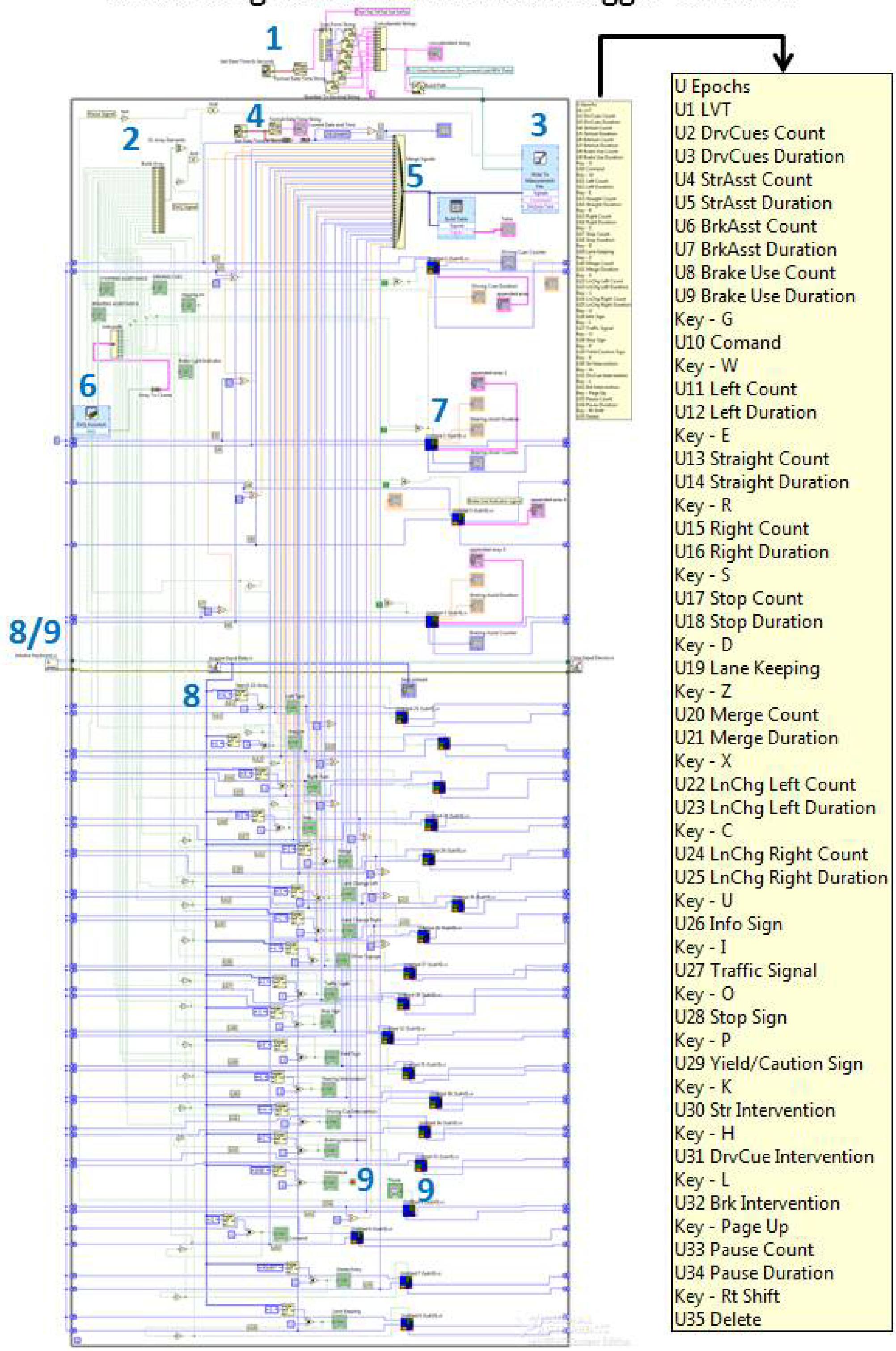
3. The write to file logic enters a single boolean value on when to write the signal values into the file

4. The Merge Signals subroutine provides continuously updated values according to the read frequency of the routine

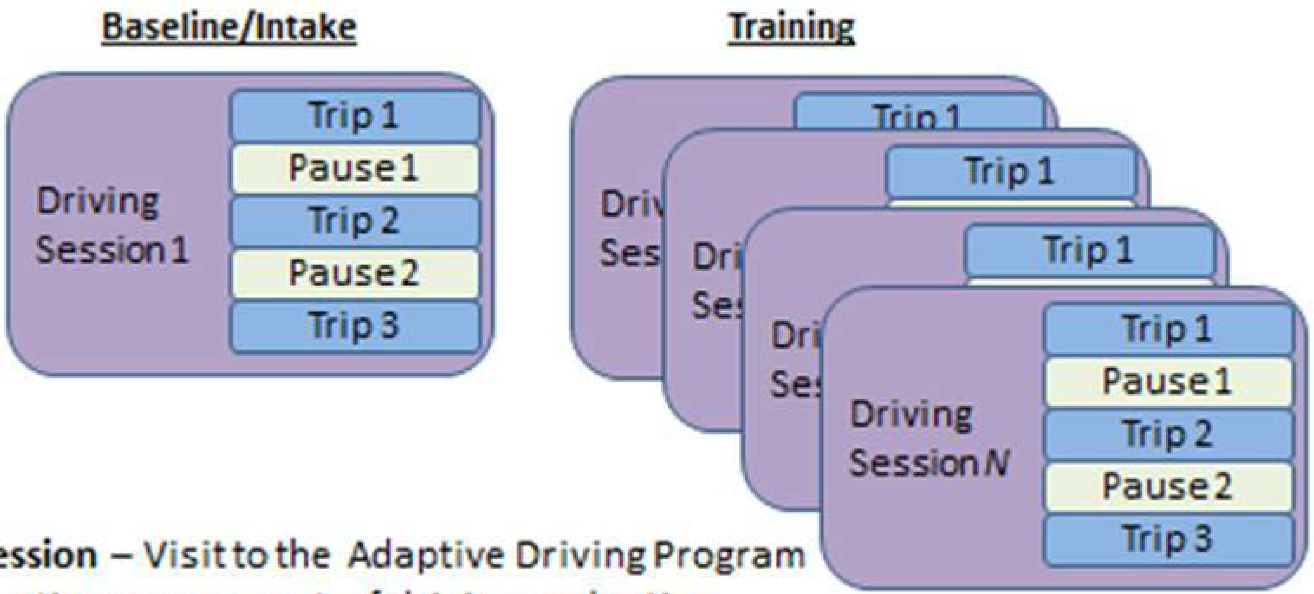
Display on Front Panel of LabView Environment



Block Diagram of NAViSection Logger Routine



Data Analysis – "Big Picture"

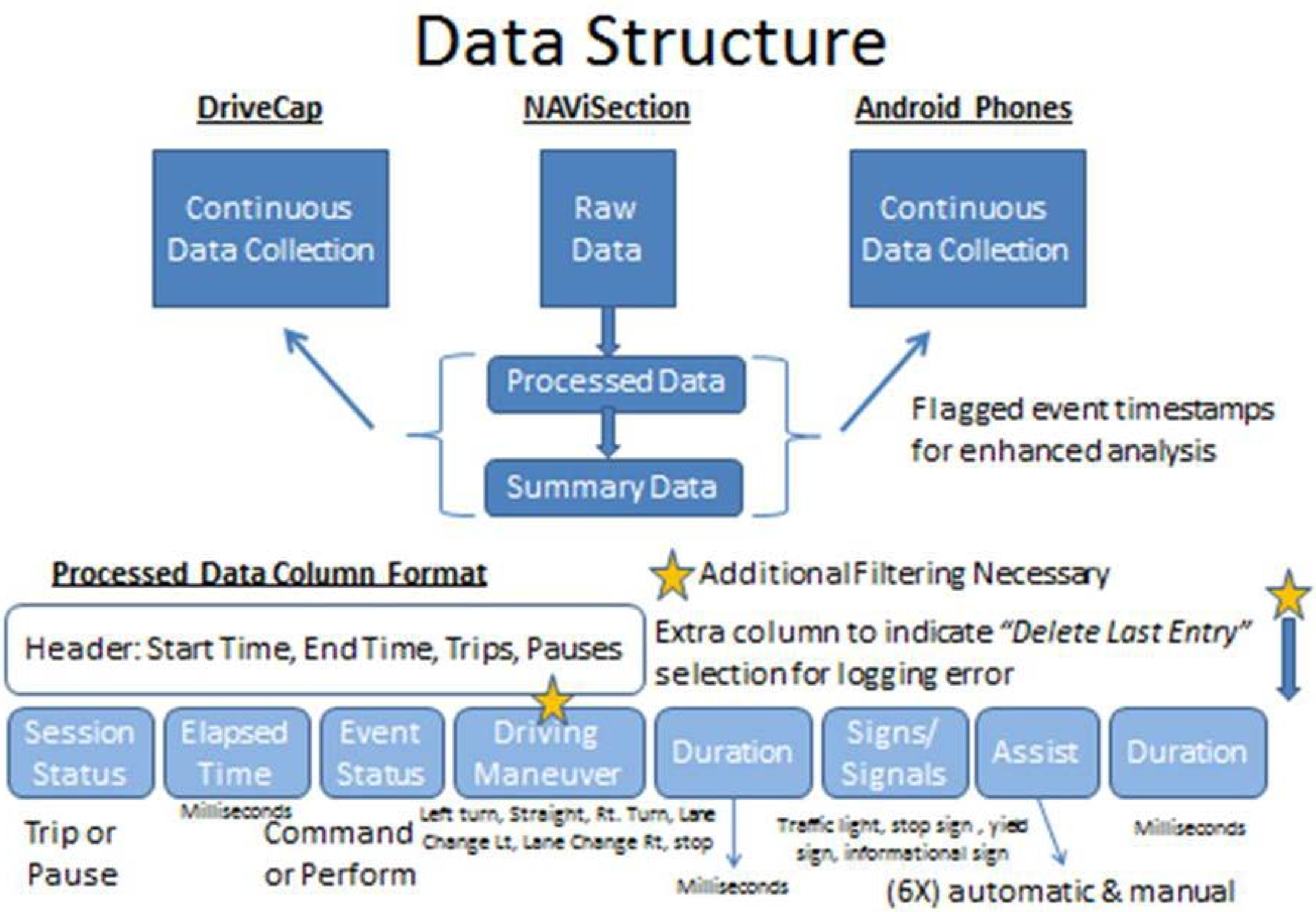


Driving Session – Visit to the Adaptive Driving Program
Trip – A continuous segment of driving evaluation
Pause – Moments when the car is in park or turned off

Trip chaining will be necessary to create a full session

Possible Data Comparisons:

Individual – across trips of a single session (fatiguing, vigilant, receptive to advice)
Clients – matched (age, disability, yrs of driving exp.) or global performance maps

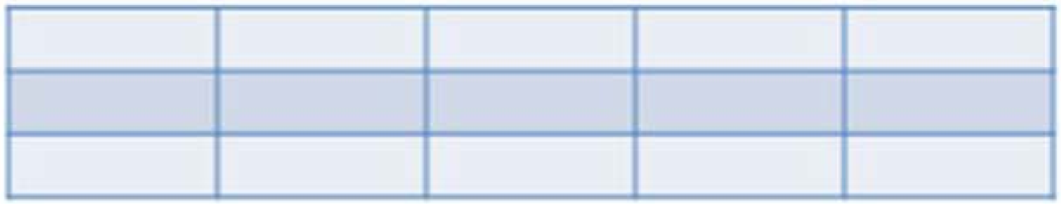

Data Structure
DriveCap
NAViSection
Android Phones
Continuous Data Collection
Raw Data
Continuous Data Collection
Processed Data
Summary Data
Flagged event timestamps for enhanced analysis
Processed Data Column Format
Additional Filtering Necessary
Header: Start Time, End Time, Trips, Pauses
Extra column to indicate *"Delete Last Entry"* selection for logging error
Session Status
Elapsed Time
Event Status
Driving Maneuver
Duration
Signs/ Signals
Assist
Duration
Trip or Pause
Milliseconds
Command or Perform
Left turn, Straight, Rt. Turn, Lane Change Lt, Lane Change Rt, stop
Milliseconds
Traffic light, stop sign , yield sign, informational sign
(6X) automatic & manual
Milliseconds

Sample of aggregated event data for a driving session from a single client

Date	11/12/2012			sec	nominal	sec	Y	Y	Y	Y	Info/Yield	sec	Y	sec	Y	Y	Y	Y	nominal
Trip Status	List ID	Entry Time		Elap. Time	Maneuver	Duration	Delete?	Command?	Stop Light?	Stop Sign?	Other Sign	Auto SA	Manual SA	Auto BA	Manual BA	Auto VC	Manual DC	Manual CC	Crit. Target
Start	0	2:24:54 PM	51894.0000	0.0000															
Trip	1	2:26:48 PM	52007.5454	113.5454	Left Turn			Y											
Trip	2	2:26:53 PM	52013.4399	119.4399	Left Turn	4.3125				Y									
Trip	3	2:27:00 PM	52019.8366	125.8366	Left Turn			Y											
Trip	4	2:27:08 PM	52027.9154	133.9154	Left Turn	6.4696													
Trip	5	2:27:33 PM	52053.4239	159.4239	Straight	6.3967				Y									
Trip	6	2:27:55 PM	52075.4031	181.4031	Straight	5.2106				Y									
Trip	7	2:28:04 PM	52083.6500	189.6500	Right Turn			Y											
Trip	8	2:28:19 PM	52098.5114	204.5114	Right Turn	3.6634				Y									
Trip	9	2:28:27 PM	52107.3413	213.3413	Left Turn			Y											
Trip	10	2:28:44 PM	52123.6530	229.6530	Left Turn	3.2033				Y									
Trip	11	2:29:08 PM	52147.6704	253.6704	Straight	3.9854			Y										
Trip	12	2:29:21 PM	52160.7927	266.7927	Straight	3.0263			Y										
Trip	13	2:30:12 PM	52211.7238	317.7238	Left Turn			Y											
Trip	14	2:30:33 PM	52232.7819	338.7819	ooooo							1.1811	Y	5.4465					
Trip	15	2:30:40 PM	52240.4106	346.4106	Left Turn	3.5814				Y									
Trip	16	2:32:15 PM	52335.3721	441.3721	Straight			Y											
Trip	17	2:32:19 PM	52339.3405	445.3405	Straight	1.6672				Y						Y			
Trip	18	2:32:33 PM	52352.6419	458.6419	Straight	1.9722				Y									
Trip	19	2:33:12 PM	52392.3128	498.3128	Left Turn			Y											
Trip	20	2:33:45 PM	52425.1651	531.1651	Left Turn	5.0035			Y										
Trip	21	2:34:12 PM	52452.1968	558.1968	Straight	3.7154													
Trip	22	2:34:28 PM	52467.9294	573.9294	Straight	2.0712			Y										
Trip	23	2:34:40 PM	52480.0776	586.0776	ooooo									5.4215	Y				
Trip	24	2:35:35 PM	52534.5400	640.5400	Right Turn	2.7383													
Trip	25	2:36:13 PM	52573.1659	679.1659	Straight	6.5357			Y										
Trip	26	2:37:31 PM	52651.4027	757.4027	Straight	4.1034													
Trip	27	2:37:45 PM	52665.1671	771.1671	Left Turn			Y											
Trip	28	2:38:04 PM	52684.3330	790.3330	Left Turn	3.7444			Y										
Trip	29	2:38:30 PM	52709.8766	815.8766	ooooo												Y		
Trip	30	2:38:35 PM	52715.1511	821.1511	ooooo													Y	Stop
Trip	31	2:39:03 PM	52743.1649	849.1649	Stop			Y											
Trip	32	2:39:09 PM	52749.1265	855.1265	Stop	10.8531													
Pause	33	2:39:32 PM	52772.3538	878.3538	xxxxx	115.6176													
Trip	34	2:41:30 PM	52889.9836	995.9836	Lane Chg Left			Y											
Trip	35	2:41:37 PM	52897.4060	1003.4060	Lane Chg Left	9.2703													
Trip	36	2:42:03 PM	52923.3000	1029.3000	Right Turn			Y											
Trip	37	2:43:19 PM	52999.0710	1105.0710	Right Turn	3.2078			Y										
Trip	38	2:43:33 PM	53012.8030	1118.8030	Lane Chg Left	6.0375													
Trip	39	2:43:52 PM	53031.6310	1137.6310	Left Turn			Y											
Trip	40	2:45:14 PM	53114.2980	1220.2980	Left Turn		Y												
Trip	41	2:45:38 PM	53137.5120	1243.5120	Left Turn	5.8229			Y										
Trip	42	2:45:58 PM	53158.0150	1264.0150	Right Turn			Y											
Trip	43	2:46:32 PM	53191.7890	1297.7890	Right Turn	5.5533													

Summary Data Representation

Trip Summary



Session Summary

7-Row sections present all driving maneuvers performed
(Lft Turn, Straight, Rt Turn, Merge, "Stop", Lft Lane Chg, Rt Lane Chg)

Include columns for:

- number of "Commanded Maneuvers"
- average duration (std dev) for maneuvers
- number of signalized/signed intersection crossings
- number of assist/cue events (x3),
- number of critical cues
- average duration (std dev) for events (x3),

APPENDIX D

NAVISECTION DATA COLLECTION SYSTEM BREAKDOWN BY SUB-SYSTEMS

Assembly maps illustrate how each component builds the sub-systems of the NAViSection data collection system. The sub-systems include Steering Assistance Detection, Braking Assistance Detection, and Verbal Cues Assistance Logger. Following each assembly map is a parts list with source of design file or procurement. All itemized components are priced according to purchase order records, and estimated pricing is indicated by "*" marking.

1. Steering Assistance Detection:

A – Steering Wheel Kit

QTY	ITEM
7	Leather Bracket Covers with Velcro Strips
60	Rare Earth Magnets as Triggers
30	Trigger Brackets
7	Steering Wheel Protector Wraps
1	Customized Commercial Steering Wheel Cover

Bracket Cover

A

Magnet Trigger *

2x

B

Trigger Bracket

C

Steering Wheel Protector

C

Customized Commercial Steering Wheel Cover

D

Original Steering Wheel of Evaluation Vehicle

A. Velcro straps
B. "Superglue" adhesive
C. Pinch/Friction grip
D. Sewn-in Elastic Band
E. Screw &Helicoil Insert
F. Magnets/2-sided tape
G. Solder/Wired cable

* Magnetic field permeates across perimeter of steering wheel

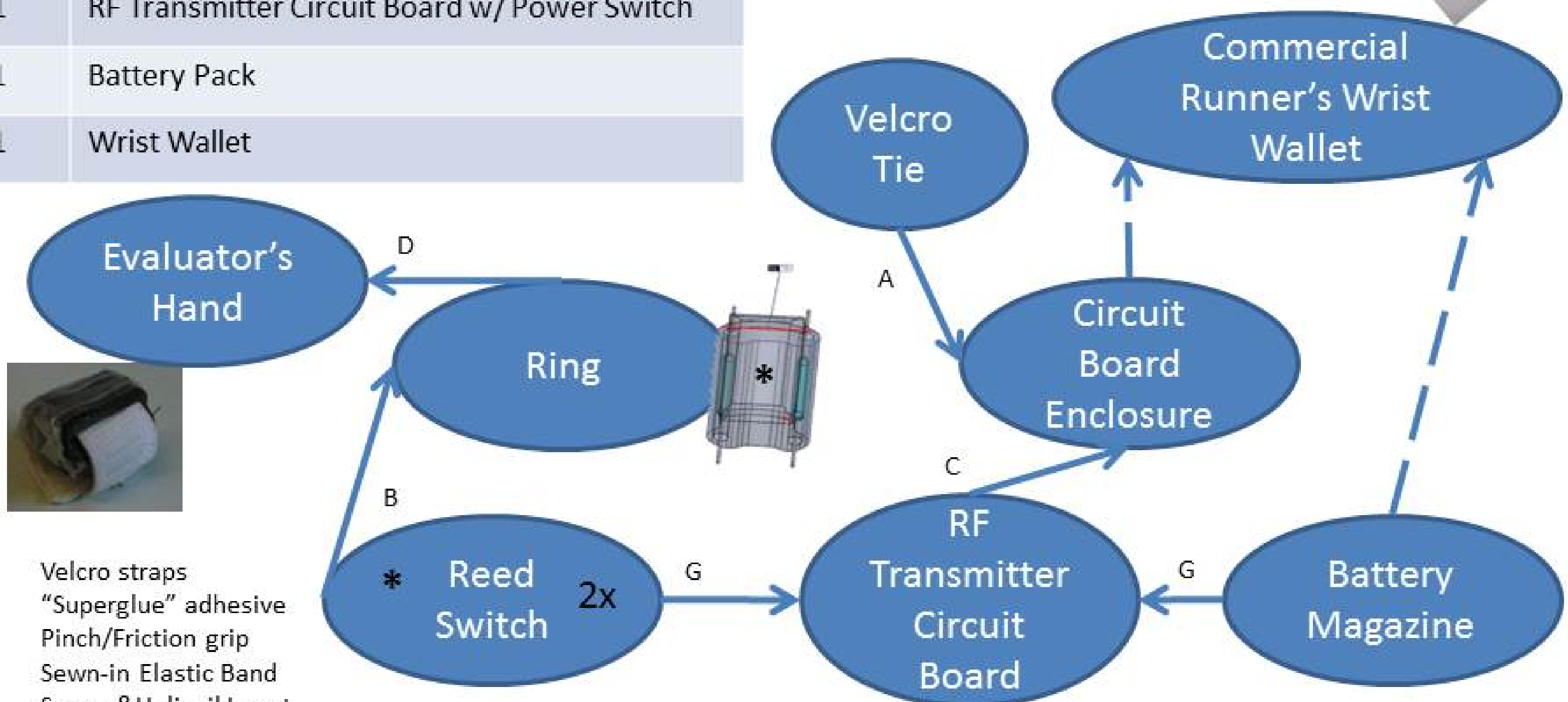
Steering Wheel Kit Assembly in Storage

Contribution	Component Name	Source/FileName	Unit Cost	Cost in Assembly
System	Bracket Cover – Leather	O&P Department Stock	N/A	$10*
System	Bracket Cover – Velcro	O&P Department Stock	N/A	$10*
System	Sewing Operations	O&P Sewing Machine	N/A	N/A
System	Magnet Trigger	P.O./20120521-DriveCap_KJ Magnetics-Beyene	$3.92	$180.32
System	Trigger Bracket	Original Design/magnet clamp V2.SLDPRT	N/A – Rapid Prototyping	$40*
System	Steering Wheel Protector	O&P Department Stock	N/A	$10*
System	Customized Commercial Steering Wheel Cover	P.O./20120530-DriveCap_Bell Automotive Products-Beyene	$9.99	$19.98
System	CCSWC – elastic band	P.O./20110914-DriveCap-Joann-Beyene	$2.99	$0.30
Storage	Storage Case	P.O./20120510-DriveCap-MCM Electronics-Beyene	$24.99	24.99
Storage	Storage Pouch	P.O./20120328-DriveCap-MCM Electronics-Beyene_Revised	$12.41	12.41
Storage	Dual Lock (for Storage Pouch)	Machine Shop Stock	N/A	$3*
Testing	N/A	N/A	N/A	N/A

1. Steering Assistance Detection:

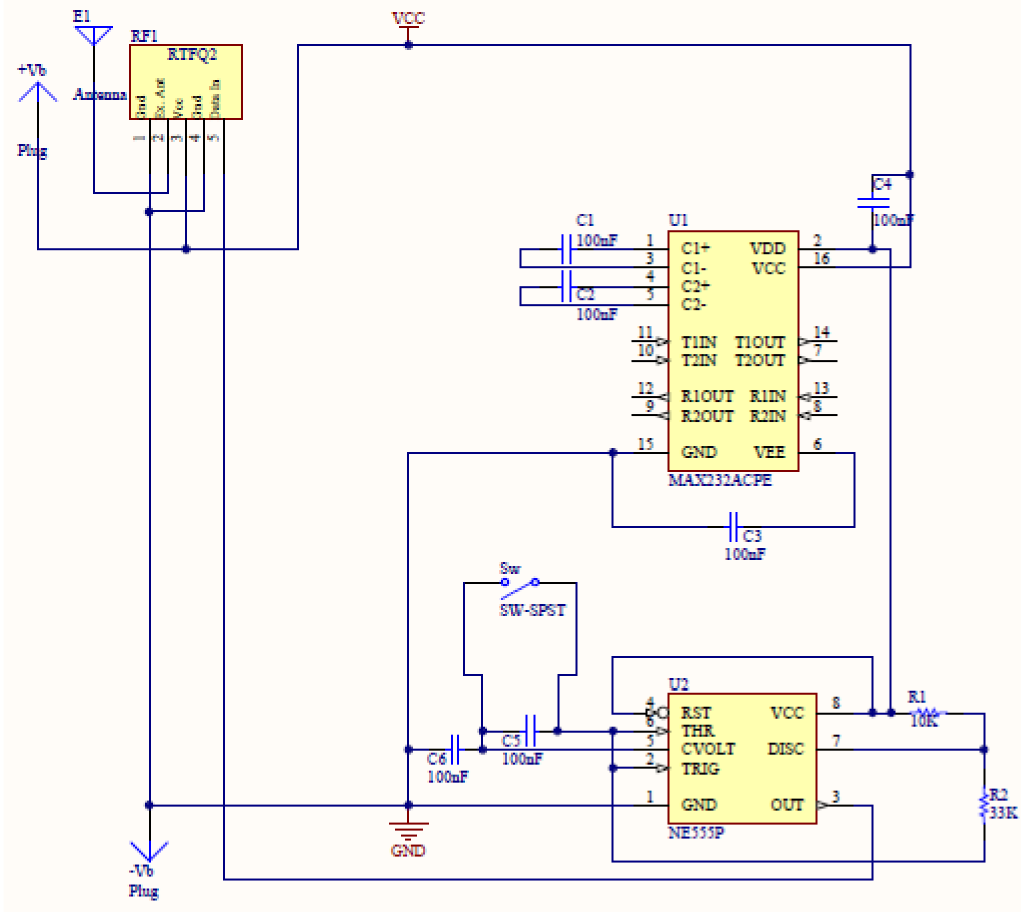
B – Proximity Sensing Rings w/ Wireless Transmitter Wrist Pack

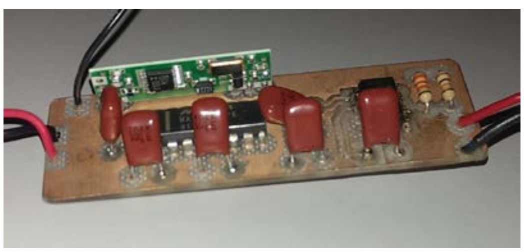
QTY	ITEM
2	Rings
4	Reed Switches
1	RF Transmitter Circuit Board w/ Power Switch
1	Battery Pack
1	Wrist Wallet

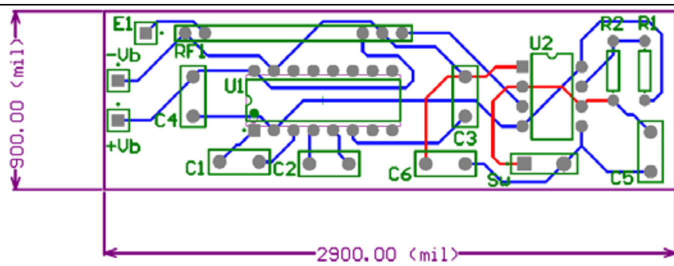


A. Velcro straps
B. "Superglue" adhesive
C. Pinch/Friction grip
D. Sewn-in Elastic Band
E. Screw &Helicoil Insert
F. Magnets/2-sided tape
G. Solder/Wired cable

* Reed switch sends a signal via the RF transmitter when in proximity of the Trigger Magnets





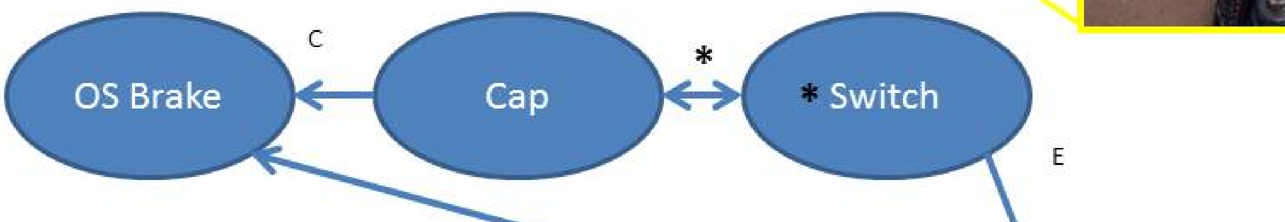


Comment	Description	Designator	Footprint	LibRef	Quantity
Plug	Battery + (Vdc=3V)	+Vb, -Vb	PIN1	Plug	2
Cap	Capacitor	C1, C2, C3, C4, C5, C6	CAPR5.08-7.8x3.2	Cap	6
Antenna	Generic Antenna	E1	PIN1	Antenna	1
Res1	Resistor	R1, R2	AXIAL-0.3	Res1	2
RTFQ2	RTFQ2 FM transmitter 433.92MHz	RF1	RTFQ2	RTFQ2	1
SW-SPST	Single-Pole, Single-Throw Switch	Sw	SPST-2	SW-SPST	1
MAX232ACPE	+5V Powered, Multi-Channel RS-232 Driver/ Receiver	U1	PE16A	MAX232ACPE	1
NE555P	Precision Timer	U2	P008	NE555P	1

Contribution	Component Name	Source/FileName	Unit Cost	Cost in Assembly
System	Ring	Original Design/sensor mount ringV3.SLDPRT	N/A – Rapid Prototyping	$10*
System	Reed Switch	Machine Shop Stock	N/A	$8*
System	Potting Adhesive	Machine Shop Stock	N/A	$0.10
System	RF Transmitter Circuit Board	Original Design/Altium Design File	N/A – Additional design schematic	$25*
System	Circuit Board Enclosure	Original Design/File Stored on Machine Shop Computer	N/A – Rapid Prototyping	$5*
System	Velcro Tie	P.O./20110825-DriveCap_ComputerCableStore-Beyene	$9.95	$0.90
System	Battery Magazine	Personal Purchase - RadioShack	$5	$5
System	Batteries	P.O./ N/A	N/A	$10*
System	Commercial Runner’s Wrist Wallet	P.O./20120510-DriveCap-REI-Beyene	$15	$15
Storage	Wiring	Machine Shop Stock	N/A	$2*
Storage	Storage Case	P.O./20120328-DriveCap-MCM Electronics-Beyene	$21.36	$21.36
Testing	Battery Charger	P.O./ N/A	N/A	$30

2. Braking Assistance Detection:

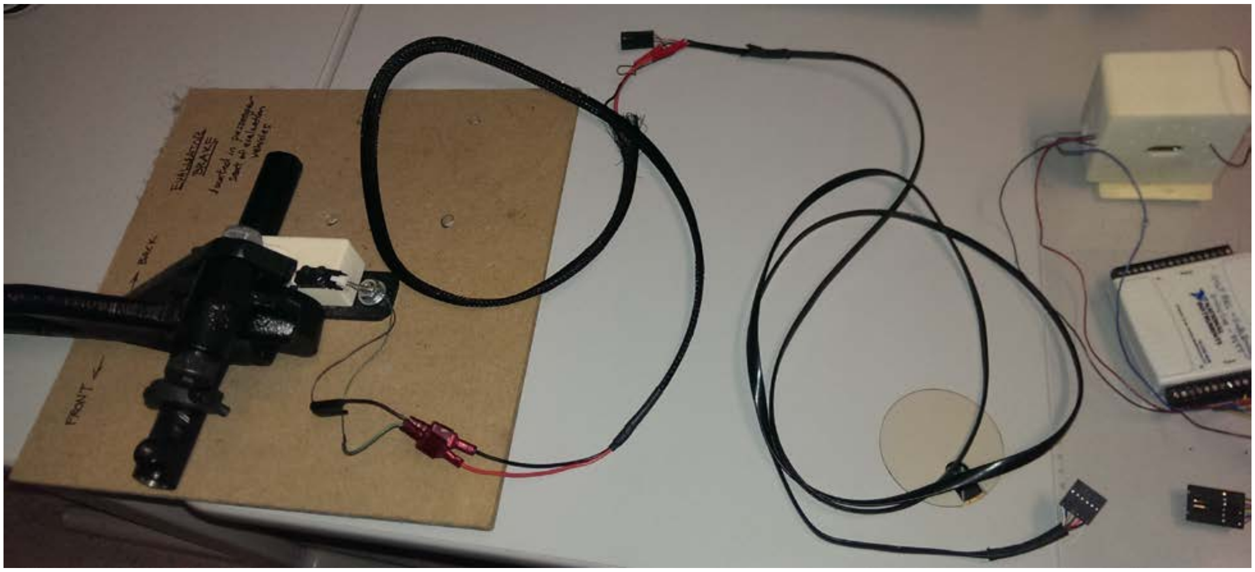
QTY	ITEM
1	OS Brakes passenger side brake assembly
1	Pulley Center Cap
1	Roller Ball Switch
1	Switch Mounting Bracket
2	Magnets



A. Velcro straps
B. "Superglue" adhesive
C. Pinch/Friction grip
D. Sewn-in Elastic Band
E. Screw &Helicoil Insert
F. Magnets/2-sided tape
G. Solder/Wired cable

* Sliding contact interface tuned to disengage when brake is applied by the driving evaluator (passenger brake)

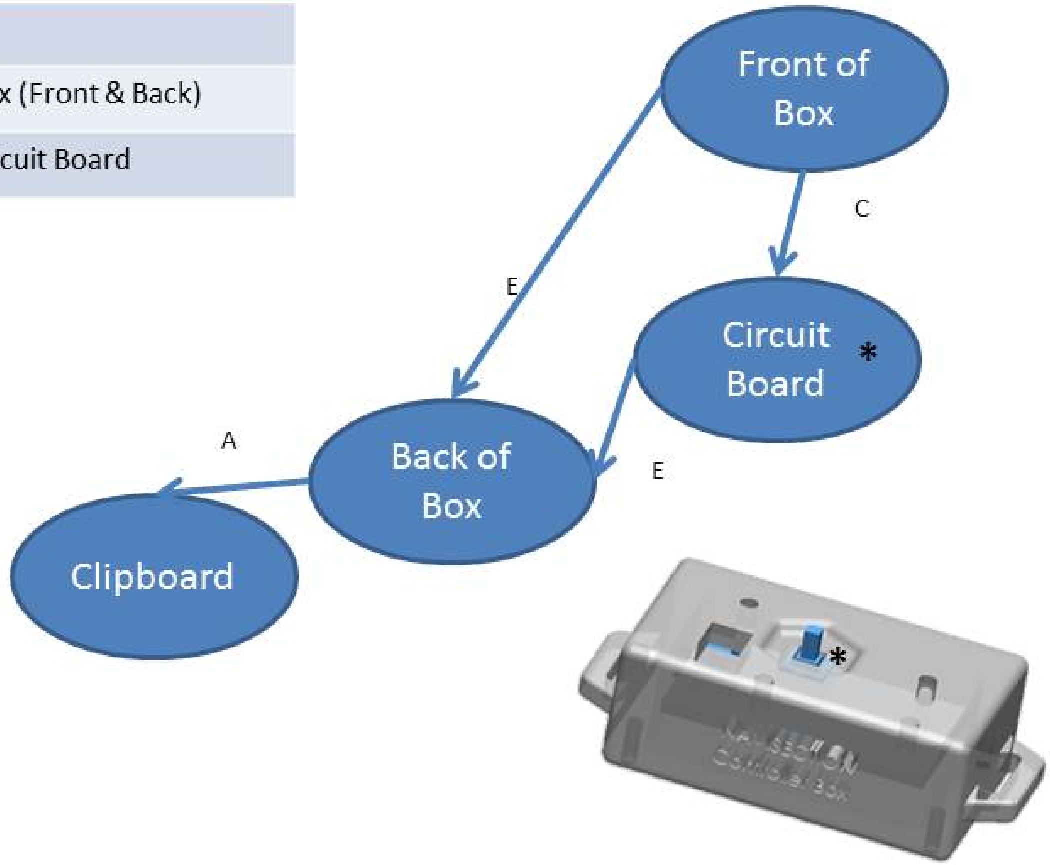
The roller-ball switch has a cable that extends under the floor mats and connects to the main cable, which leads to the NI DAQ Box. Connector issues during mock trials prompted a modification to bypass the connector with a solid connection to the main cable. This modification made the brake switch cable a continuation of the main cable.



Contribution	Component Name	Source/FileName	Unit Cost	Cost in Assembly
System	Cap on Pulley Mechanism	Original Design/brake striking plate.SLDPRT	N/A – Rapid Prototyping	$2*
System	Roller-Ball Switch	Machine Shop Stock	N/A	$8*
System	Fastener Screws	Machine Shop Stock	N/A	$1*
System	Bracket	Original Design/brake sensor bracketV4.SLDPRT	N/A – Rapid Prototyping	$10*
System	Helicoil Inserts	Machine Shop Stock	N/A	$0.50*
System	Bracket Adhesive – Dual Sided Tape	Machine Shop Stock	N/A	$0.10*
Testing	Kinobo LED Web Cam	P.O./20120322-DriveCap-AmazonKinobo B3-Beyene	$16.99	$16.99
Testing	CCTV – Test Monitor	P.O./20120618-CCTVCameraPros-Beyene	$329.99	$329.99
Testing	Universal Mount	P.O./ N/A	N/A	$25*

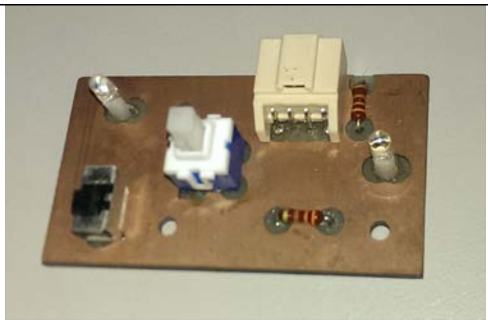
3. Verbal Cues Assistance Logger:

QTY	ITEM
1	Evaluator's Clipboard
1	NAViSection Controller Box (Front & Back)
1	NAViSection Controller Circuit Board

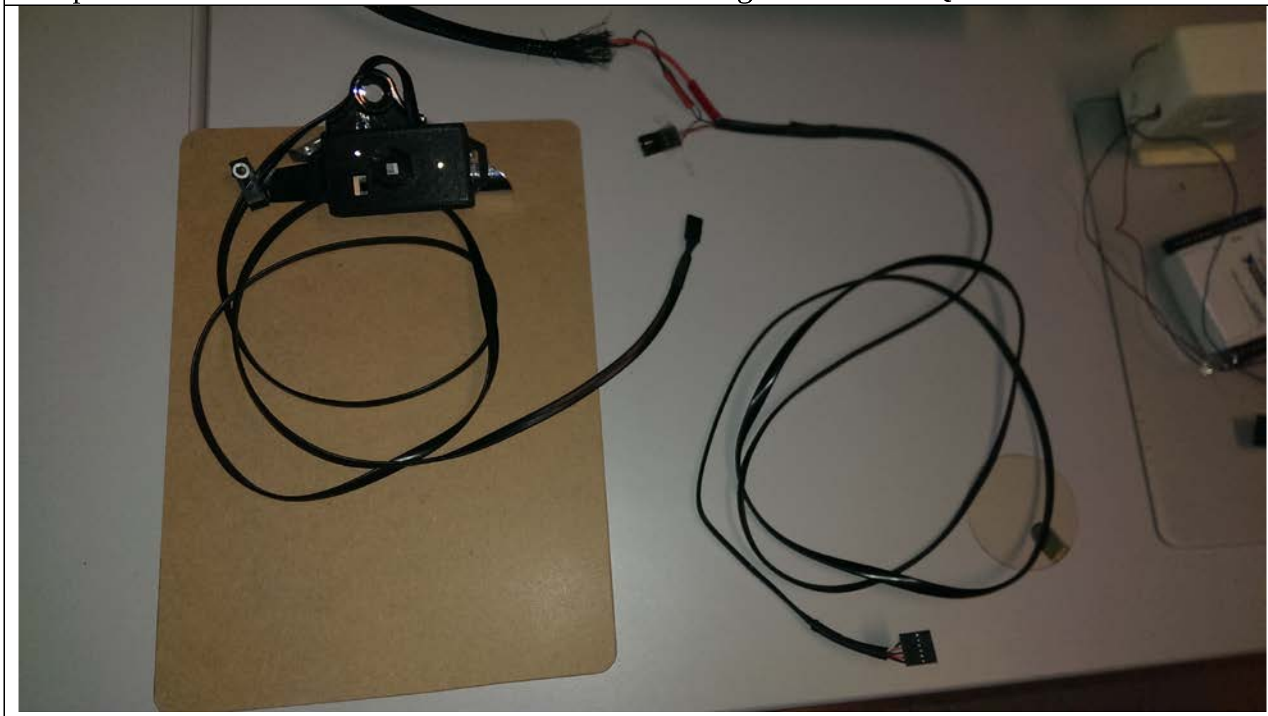


A. Velcro straps
B. "Superglue" adhesive
C. Pinch/Friction grip
D. Sewn-in Elastic Band
E. Screw &Helicoil Insert
F. Magnets/2-sided tape
G. Solder/Wired cable

* Instantaneous button depression by driving evaluator indicates that a verbal cue assist (prompt) was provided to the student or client



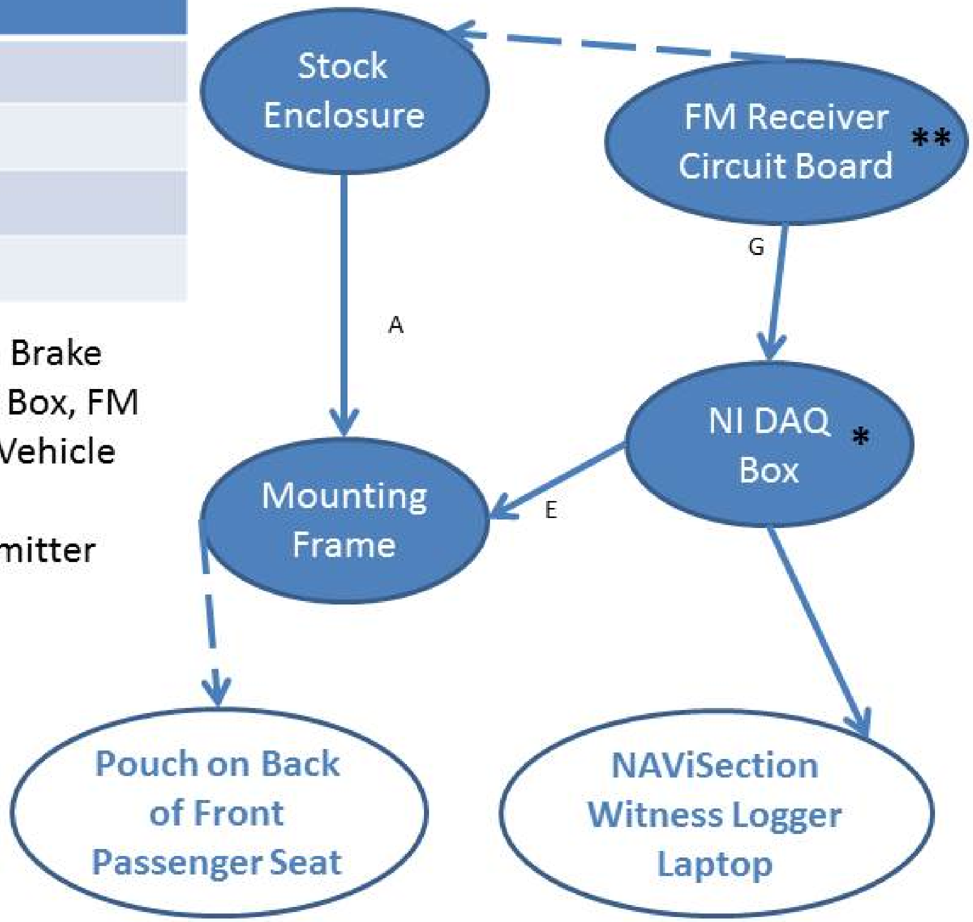
NAViSection circuit board shown within an enclosure with a cable and cable guide (tie down) on a clipboard. The cable connects to the main cable leading to the NI DAQ box.



Contribution	Component Name	Source/FileName	Unit Cost	Cost in Assembly
System	NAViSection Controller Box Top	Original Design/Navisection Case Top V5.SLDPRT	N/A – Rapid Prototyping	$5*
System	Helicoil Inserts	Machine Shop Stock	N/A	$1.75*
System	Circuit Board	Original Design/Altium Design File	N/A – Additional design schematic	$15*
System	NAViSection Controller Box Bottom	Original Design/Navisection Case Bottom.SLDPRT	N/A – Rapid Prototyping	$1*
System	Fastener Screws	Machine Shop Stock	N/A	$1*
System	Dual Lock	Machine Shop Stock	N/A	$0.50*
System	Cable Guide	P.O./ N/A	N/A	$0.05*
Testing	N/A	N/A	N/A	N/A

4. Data Acquisition System:

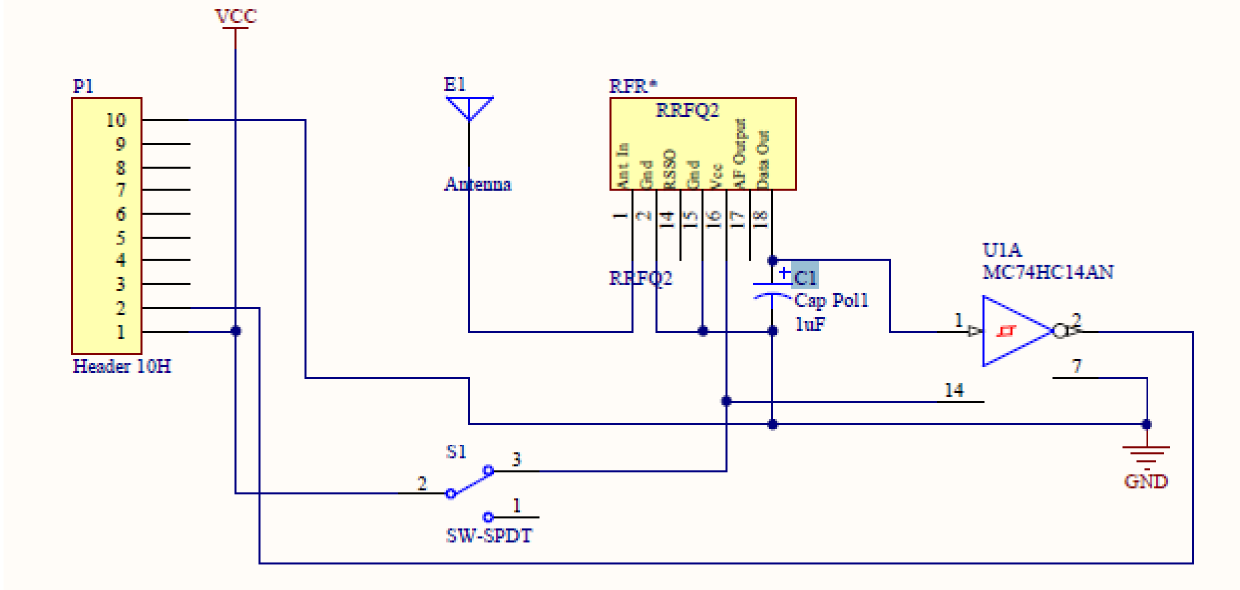
QTY	ITEM
1	Mounting Frame
1	FM Receiver Circuit Board
1	Stock Enclosure
1	NI DAQ Box (USB - 6008A)

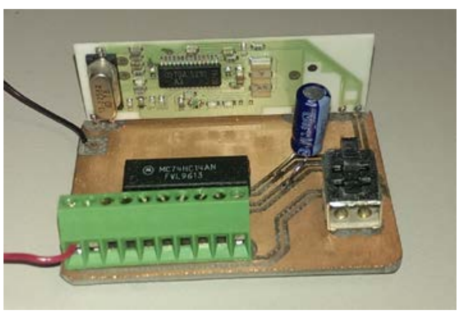


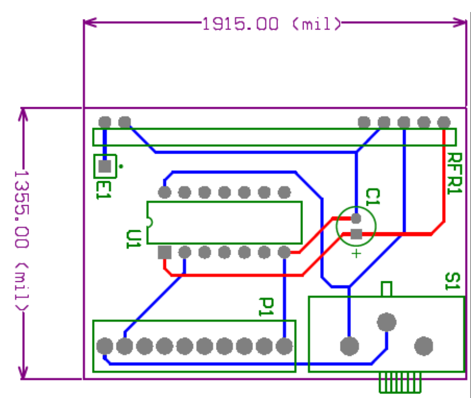
* Wired connections to Switch on Brake Assembly, NAViSection Controller Box, FM Receiver Circuit Board, and Main Vehicle Brake Switch

** Receives signal from FM Transmitter Circuit Board

A. Velcro straps
B. "Superglue" adhesive
C. Pinch/Friction grip
D. Sewn-in Elastic Band
E. Screw &Helicoil Insert
F. Magnets/2-sided tape
G. Solder/Wired cable

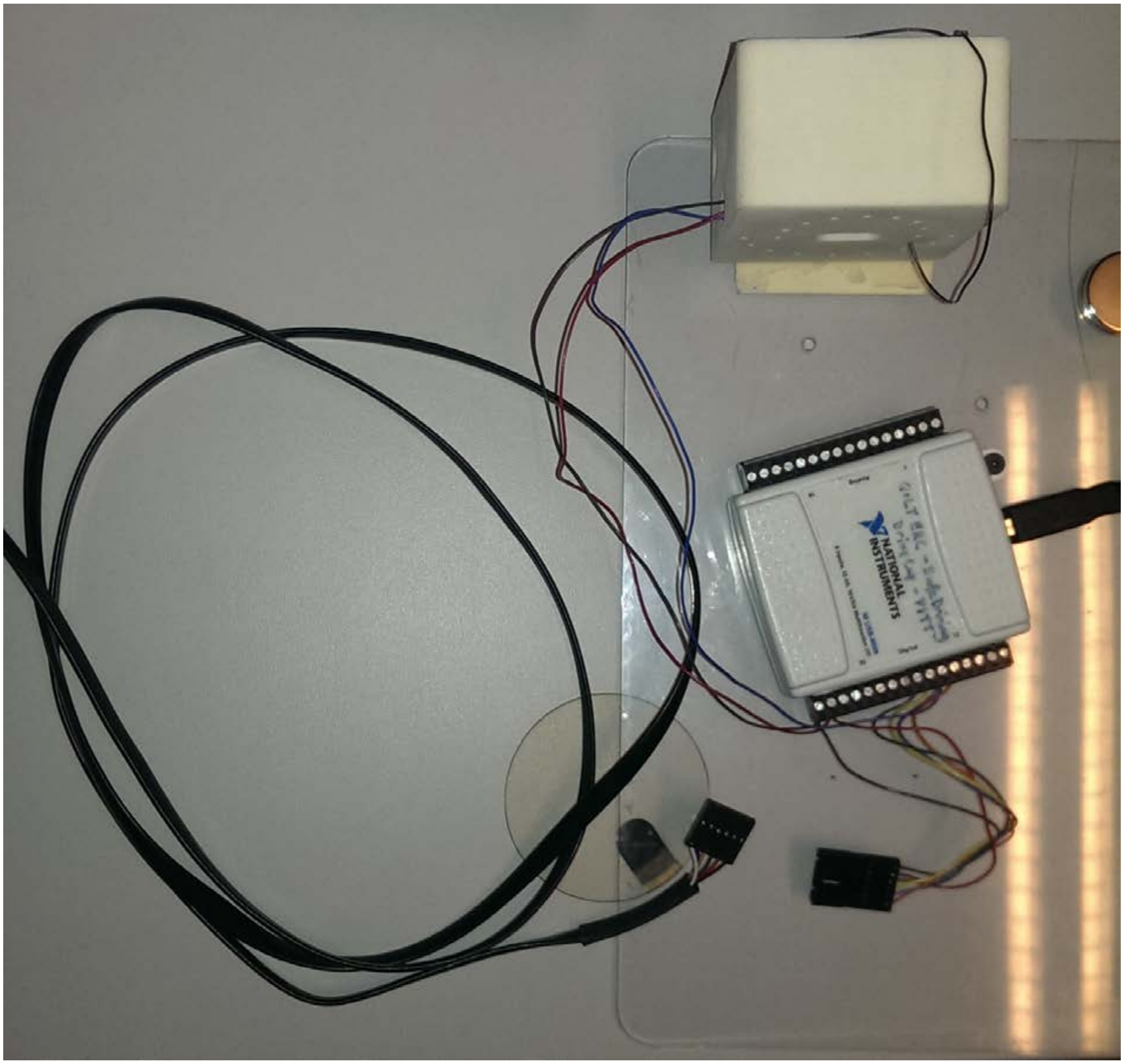




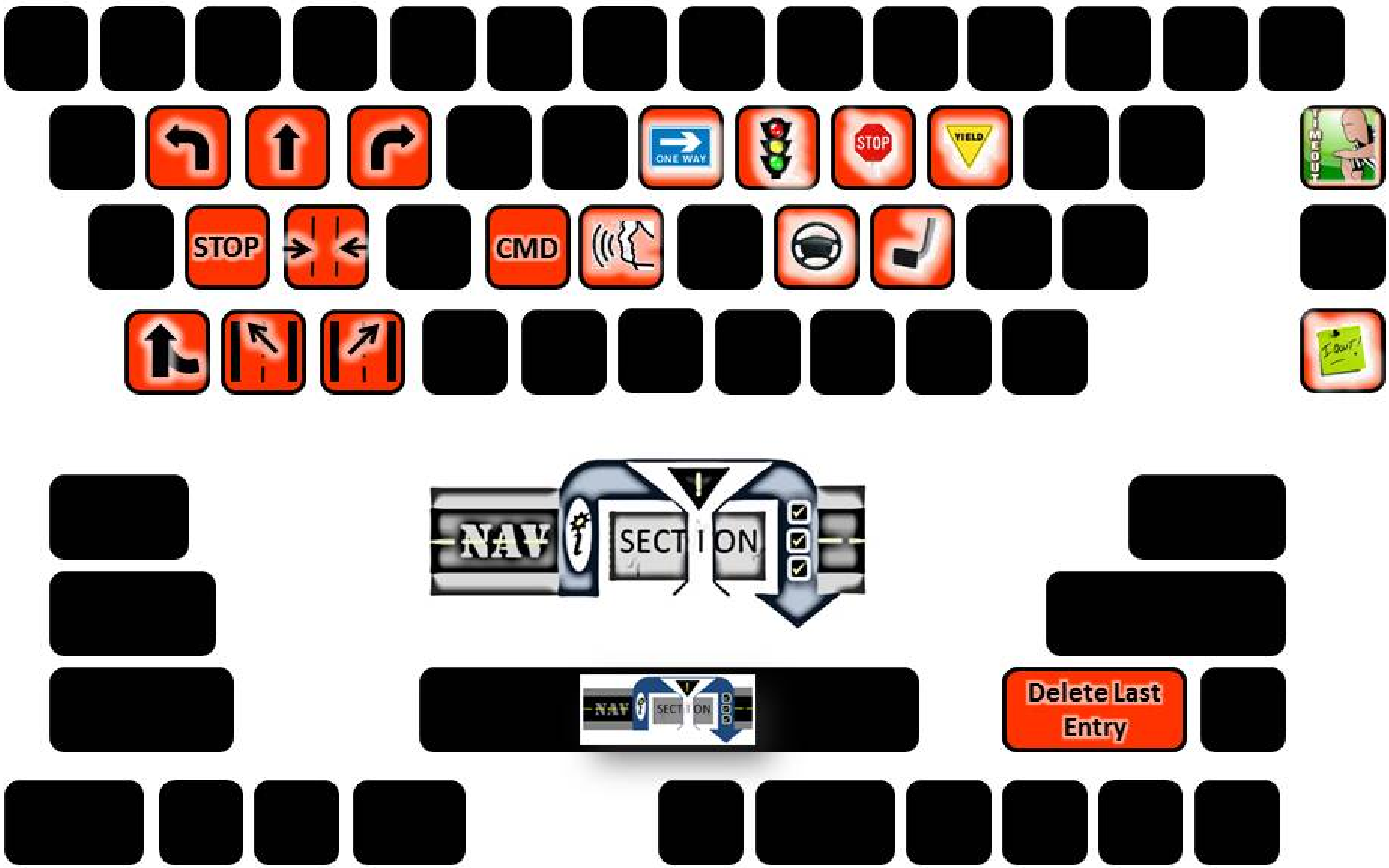


Footprint	Comment	LibRef	Designator	Description	Quantity
CAPPR2-5x6.8	Cap Pol1	Cap Pol1	C1	Polarized Capacitor (Radial)	1
PIN1	Antenna	Antenna	E1	Generic Antenna	1
10 POS screw terminal	Header 10H	Header 10H	P1	Header, 10-Pin, Right Angle	1
RRFQ2	RRFQ2	RRFQ2	RFR*	RRFQ2 FM receiver 433.92MHz	1
CK SPDT Slide Switch	SW-SPDT	SW-SPDT	S1	SPDT Subminiature Toggle Switch, Right Angle Mounting, Vertical Actuation	1
646-06	MC74HC14AN	MC74HC14AN	U1	Hex Schmitt Trigger Inverter	1
					6

The main cable leading to the NI DAQ Box connects to the input leads via a connector. From that connection, the cable descends from the rear of the front passenger seat and follows the floorboard to the front cabin.



Laptop Keyboard Insert for Witness Logging



Contribution	Component Name	Source/FileName	Unit Cost	Cost in Assembly
System	Base Frame	Basic Geometry (8x11 with round corners)	N/A – Laser Cut Acrylic	$5*
System	Spare Enclosure	Machine Shop Stock	N/A	$5*
System	Dual Lock	Machine Shop Stock	N/A	$0.50*
System	FM Receiver Circuit Board	Original Design/Altium Design File	N/A – Additional design schematic	$25*
System	NI DAQ Box	P.O./20120322-DriveCap-NI-Beyene	$152.10	$152.10
System	Bolt and Hex Nuts	Machine Shop Stock	N/A	$0.10*
System	Wiring/Cables	Original Design	N/A – Additional design schematic	$8*
System	NI LabView	Online Download	$60.00	$60.00
Testing	Sun glasses	P.O./20120510-DriveCap-REI-Beyene	$19.95	$19.95
Testing	Sun glasses case	P.O./20120510-DriveCap-REI-Beyene	$8.00	$8.00
Testing	Carabiner	P.O./20120510-DriveCap-REI-Beyene	$8.95	$8.95
Testing	Laptop	Personal laptop	$840	$840
Testing	Keyboard cover	P.O./20111219-DriveCap-A Best Store-Beyene	$16.95	$16.95
Testing	DriveCap recharging unit	P.O./20120530-DriveCap-Radio Shack-Beyene V2	$61.99	$61.99

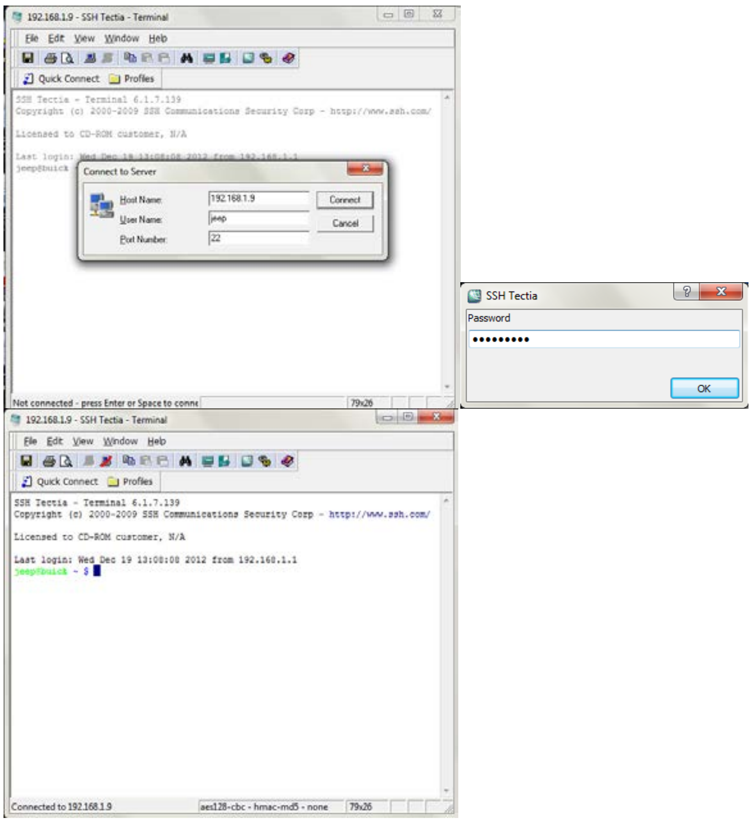
APPENDIX E

NAVISECTION DATA COLLECTION PROTOCOL

The NAViSection Data Collection Protocol provides full documentation of all steps and sequences developed for consistent and reliable trials based in the ADP evaluation vehicle. The following pages demonstrate how the NAViSection Witness Logger integrated communications and synchronization across CMU’s NavLab DriveCap IVDR, CMU’s Ubicomp Android Phone Data Logger (with two phones and a Zephyr Bioharness unit for accelerometer data, and the assisted-driving event detection equipment, developed at HERL.

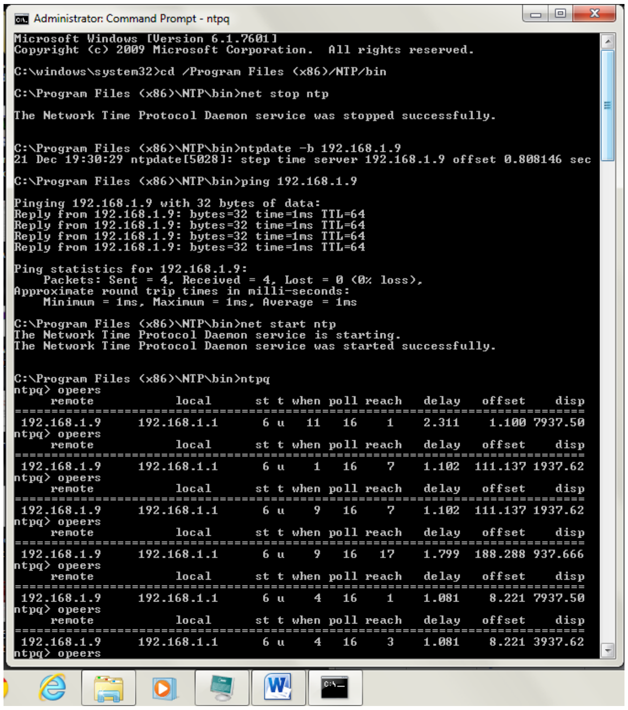
Data Collection Setup Protocol

1. Power on DriveCap
    a. Plug into cigarette lighter
    b. Turn on vehicle
    c. Switch DriveCap on
2. Perform Time sync
    a. Plug in DriveCap Ethernet cable to NAViSection laptop
    b. Open SSH Tectia Terminal
    (Desktop>Navisection design folder>Navisection Study folder>Navisection shortcut)
    c. Click ok to Error message
    "Failed to open a secure terminal session: can't connect to server"
    d. Click on Quick Connect
        i. Enter host name: 192.168.1.9, user name: jeep
        ii. Enter password: DriveCap0 (Note: click on pop-up window first)



    e. Open DOS Command Window
        i. Start/Command Prompt
        ii. Right click and select Run as Administrator
    f. Run NTPdate
        i. Type>> cd /Program Files (x86)/NTP/bin
        ii. Type>>net stop ntp

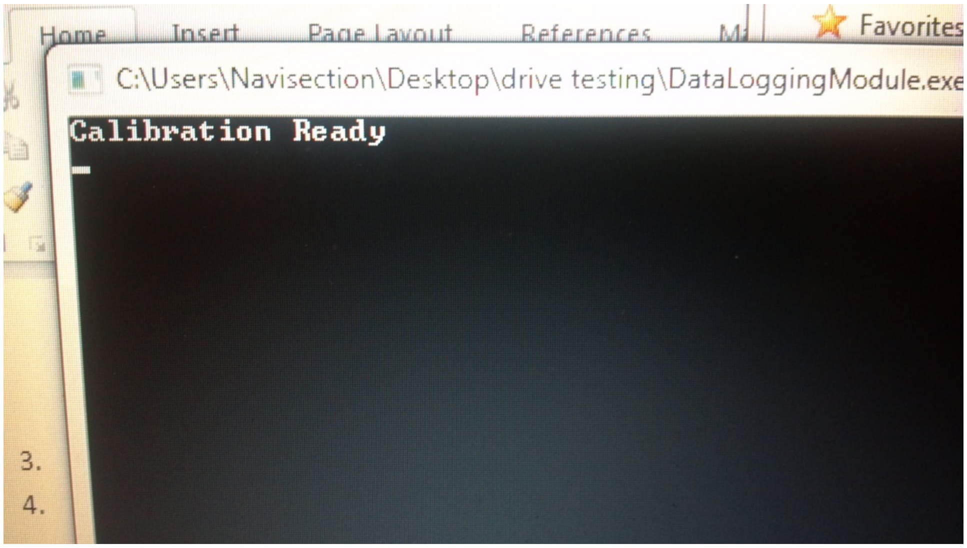
iii. Type>>ntpdate –b 192.168.1.9
iv. Type>>net start ntp
v. Type>>ntpq
vi. Type>>opeers (repeat opeers command with brief pause until "*" appears)
vii. Exit Command Prompt



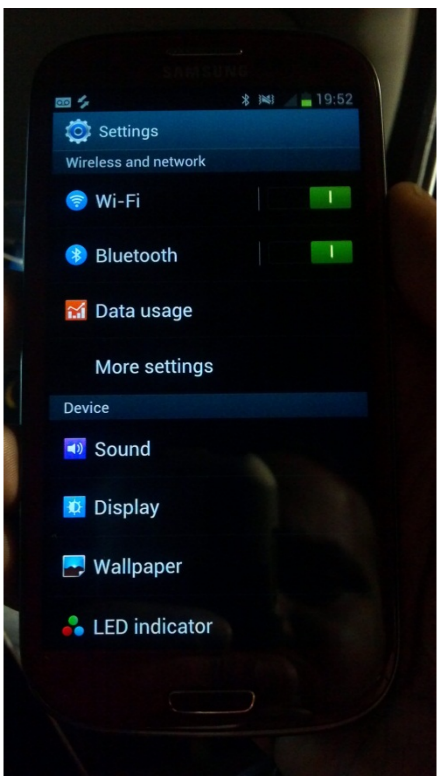
g. Go to SSH Tectia Terminal
h. Shutdown computer: Type>> sudo shutdown now,
see error message "Disconnected (local): Connection lost: connection lost" and click ok
i. Minimize SSH Tectia Terminal
j. Unplug Ethernet cable from NAViSection laptop
k. Turn power switch off on DriveCap box
l. Turn off car engine

3. (OPTION) Install Steering Wheel Kit
    a. Apply surface fabric and brackets containing two magnets
    b. Apply leather wrap with Velcro fasteners
    c. Apply commercial steering wheel cover with elastic gap expansion segment
4. Setup Android Phone Loggers
    a. Turn on Droid, Samsung and Bioharness
    b. Silence phones

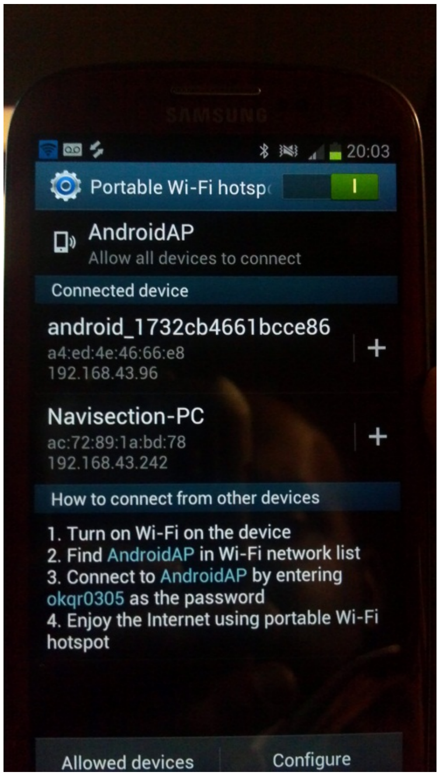
c. Open DataLoggingModule on NAViSection laptop
(Desktop>drive testing folder>DataLoggingModule.exe)



d. Setup wifi tethering hot spot on Samsung
(Settings→More Settings→tethering and portable hotspot)

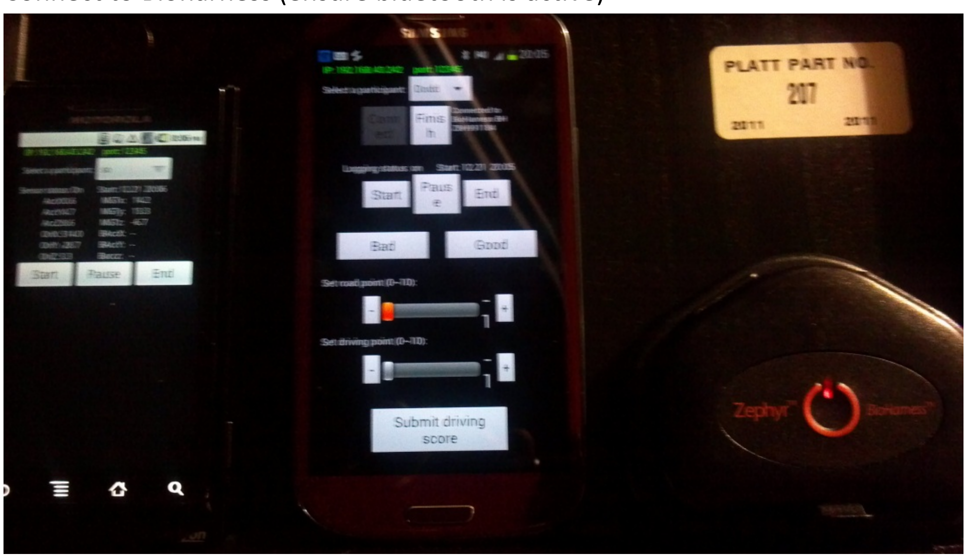


e. Verify connections to network an match IP to NAViSection laptop
(Note: Select Tethering and Portable Hotspot to see connection details and follow instructions at bottom of screen)

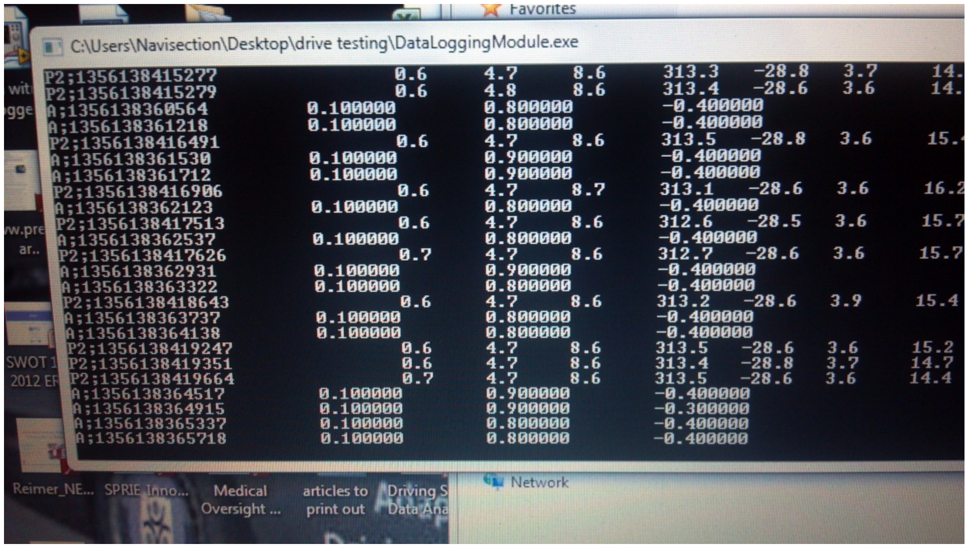


f. Open DrivingLog Apps on phone home screens

g. Connect to Bioharness (ensure bluetooth is active)



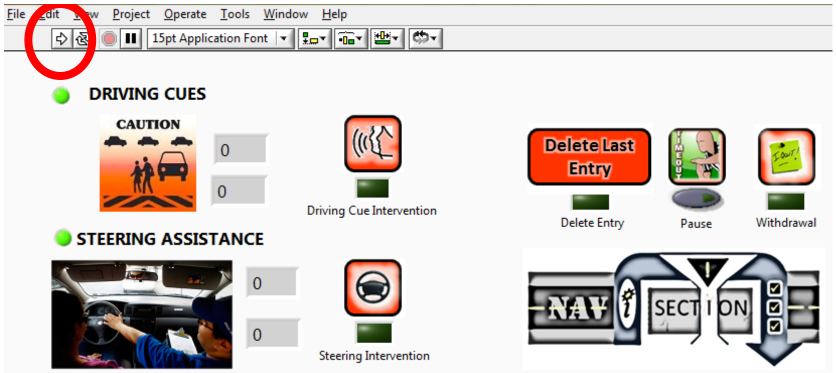
h. View DataLoggingModule to confirm proper function



i. Mount Droid phone to steering wheel

5. Setup NAViSection Data Collection
   a. Plug in NI DAQ box usb cable
   b. Plug in LED web cam usb cable
   c. Open NAViSection LabView routine
      (Desktop>Main Witness Logger)
   d. Open Dell Webcam Central
6. Prepare NAViSection Tools
   a. Verify new or recent batteries in Proximity sensing rings wireless transmission wrist pack
   b. Verify webcam view is suitable
   c. Verify presence of passenger brake switch
   d. Verify integrity of cable to NAViSection Controller box mounted on CDRS clipboard
7. Setup Brake Camera TV and Mount
   a. Install TV mount on headrest
   b. Mount TV in holder
   c. Plug in rechargeable, external battery unit
   d. Plug monitor cable into NAViSection Laptop, and turn TV on
   e. Open Windows Mobility Center
      (Start>Accessories>Windows Mobility Center)
   f. Click on Disconnect external projector, select Extended desktop
   g. Resize and drag Dell Webcam Central onto TV's desktop view
8. Check signals and Begin Observation

a. Start NAViSection LabView routine



b. Verify activation of automatic sensors/switches

c. Verify logging turned on by NAViSection controller box

d. Turn DriveCap box on

[NOTE: look for DriveCap box's green switch/amber light]

e. Press start on Samsung phone (submit driving scores at end of each Trip segment)

f. Proceed with active observation protocol

g. Wear seatbelt, silence phone, silence NAViSection laptop, wear sunglasses when desired

9. Stop NAViSection collection
    a. Confirm end of recording on NAViSection Controller box
    b. End NAViSection LabView routine
    c. Disconnect NI DAQ box
    d. Disconnect LED webcam
    e. Secure/stow USB connectors for next use
    f. Shutdown LabView
    g. Shutdown Dell Webcam Central (screen should revert to laptop cam view automatically)
    h. Disconnect TV from laptop and turn TV off
10. Stop Android Phone collection
    a. Submit final driving scores
    b. Click Finish
    c. Press End on Samsung phone
    d. Remove Droid from steering wheel
    e. Press End on Droid phone
    f. Go to DriveLoggingModule window and press "0" to safely end routine
    g. Power down phones and Bioharness
11. Stop DriveCap collection
    a. Plug Ethernet cable from DriveCap into NAViSection laptop
    b. Repeat 2b-d to communicate with DriveCap
    c. Type>>stop_collection (in SSH Tectia Terminal)
    d. Verify successful stop with "repomon" command, repeat "stop_collection" as needed
    e. Type ctrl + c to end search "Looking for IPT Server on buick …"

12. Convert and Download data
    a. Open New File Transfer Window, enter “/data” in destination
    b. In SSH Tectia Terminal, Type>> ./convertDriveCap (no spaces, case sensitive)
    c. In File Transfer Window, Select and drag Data Folders to local Data storage
    d. In SSH Tectia Terminal, Type>> cd /data
    e. Type>> mv <filenamedate*.*> <DATA_CONVERTED> (repeat if multiple dates are left)
    f. (OPTION) refresh file transfer window to verify success of operation
    g. In SSH Tectia Terminal, Type>> cd
    h. Shutdown computer: Type>> sudo shutdown now, await error message and click ok
    i. Close SSH Tectia Terminal and File Transfer Window
    j. Unplug Ethernet cable from NAViSection laptop and secure/stow for next use
    k. Turn power switch off on DriveCap box
    l. Turn off car engine
13. Stow Brake Camera TV and Mount
    a. Put TV back into pouch
    b. Uninstall mounting bracket from headrest
    c. Stow both in trunk
    d. Place rechargeable, external battery in small case
14. Stow NAViSection Tools
    a. Stow steering wheel cover in trunk
    b. Stow Proximity Sensor Rings and Wrist pack in small case
    c. Leave NAViSection Controller Box and all other components as installed, in place
    d. Pack up NAViSection laptop
    e. Return small case to ADP office for battery charging as needed
15. (OPTION) Stow Steering Wheel Kit
    a. Remove leather Velcro wraps
    b. Stow magnetic brackets in case compartments
    c. Gather inner protective lining
    d. Stow leather wraps and inner lining in zipper pouch on back of case
    e. Stow case in car trunk

APPENDIX F

NAVISECTION DEMONSTRATION STUDY DATA RESULTS

The following tables present data from the NAViSection Pilot Study. The data collected included demographics, medical history, driver history, clinical assessment results, on-road evaluation results, system status for all data collection equipment, and the measures for assisted-driving events. The results of data analysis were presented in Chapter 5.

Participant Number	Gender	Age	Medical Impairment	Pacemaker	Number of Medications
1	m	87	Employer Regulation	Yes	6
2	m	85	Employer Regulation		n/a
3	f	32	Cerebral Palsy		4
4	f	65	Post-Polio (PPMA)		6
5	f	76	Spinal Cord Injury		15
6	f	65	Multiple Sclerosis	Yes	1
7	m	62	Dementia		1
8	f	71	Stroke (CVA)		14
9	m	87	PennDOT Random Screening		n/a
10	f	54	Multiple Sclerosis		n/a
11	f	[redacted]	[redacted]	[redacted]	[redacted]
12	f	62	Multiple Sclerosis		n/a
13	f	[redacted]	[redacted]	[redacted]	[redacted]
14	f	86	Memory Declines		2
15	m	51	Stroke (CVA)		2
16	m	66	Stroke (CVA)		9
17	m	55	Stroke (CVA)		5
18	m	76	Traumatic Brain Injury		2
19	m	54	Stroke (CVA)		0
20	m	22	Aspergers/ ADHD		2
21	f	81	Recent Falls		4
22	m	82	Balance/ Neurological		10

Participant Number	Snellen Vision Test	Confrontation Vision Test	Trailmaking Part A (Cognitive)	Trailmaking Part B (Cognitive)	Muscle Power	Range of Motion
1	above	nt	above	Above	above	WNL
2	above	above	above	Above	above	WNL
3	above	nt	above	Above	above	BNL
4	above	above	above	Above	below	BNL
5	above	above	above	Above	above	WNL
6	above	above	above	Above	below	WNL
7	above	nt	above	Above	above	WNL
8	above	nt	above	Above	above	BNL
9	above	above	above	Above	below	BNL
10	above	above	above	Above	below	WNL
11	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
12	above	above	above	Above	below	BNL
13	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
14	nt	nt	nt	Below	nt	nt
15	above	above	above	Above	above	BNL
16	above	above	above	Above	above	WNL
17	below	nt	above	Above	above	WNL
18	above	above	above	Above	above	BNL
19	above	above	above	Above	above	WNL
20	above	above	above	Above	above	WNL
21	above	above	above	Above	below	BNL
22	below	nt	nt	Above	nt	above

nt = not tested, WNL = within normal limits, BNL = below normal limits

Participant Number	Years of Driving Experience	Citations, Tickets & Accidents (self report)	Vehicle Setup	Baseline Evaluation	Case Outcome
1	67	no	standard	pass	pass
2	60+	no	standard	pass	pass
3	0.25	no	modified	Np	seek funds
4	50	yes	modified	Np	st test pass
5	30+	no	standard	Np	pass
6	20+	no	standard	Np	driver cess
7	46	yes	standard	Np	fail eval
8	55	no	standard	Np	pass
9	65	no	standard	pass	pass
10	40	no	modified	Np	st test pass
11	[redacted]	[redacted]	[redacted]	[redacted]	omit
12	46	yes	modified	pass	st test pass
13	[redacted]	[redacted]	[redacted]	[redacted]	did not volunteer
14	65	no	standard	Np	fail eval
15	35	yes	standard	pass	pass
16	50	no	standard	pass	pass
17	39	no	standard	pass	pass
18	56	no	standard	Np	pass
19	36	yes	standard	pass	pass
20	1	yes	standard	Np	parent supervised training
21	6	yes	standard	Np	fail eval
22	66	yes	standard	Np	fail eval

modified = modified vehicle interface (ex. hand controls), np = no pass

Participant Number	DriveCap Data Status	NAViSection Verbal Cue Assist & Data Logging	NAViSection Steering Assist Detection	NAViSection Brake Assist Detection	Android Log Data Status	Bioharness Data Status	Android Orientation Data Status	Comments
1	N/A	Functional	Unused	Functional	N/A	N/A	N/A	cell phones disconnected, DriveCap hard drive failure Option B applied for steering assist due to pacemaker use
2	N/A	Functional	Functional	Functional	Functional	Functional	Functional	DriveCap hard drive failure
3	N/A	Functional	Functional	Functional	Functional	Functional	Functional	DriveCap hard drive failure
4	N/A	Functional	Functional	Functional	Functional	Functional	Functional	DriveCap hard drive failure
5	Functional	Functional	Functional	Functional	Functional	Functional	Functional	
6	Functional	Functional	Unused	Functional	Functional	Functional	N/A	steering wheel cell case removed! Option B applied for steering assist due to pacemaker use
7	Functional	Functional	Unused	Functional	Functional	Functional	N/A	steering wheel cell case removed! investigator decision to omit steering assist due to setup time constraint

Participant Number	DriveCap Data Status	NAViSection Verbal Cue Assist & Data Logging	NAViSection Steering Assist Detection	NAViSection Brake Assist Detection	Android Log Data Status	Bioharness Data Status	Android Orientation Data Status	Comments
8	Functional	Functional	Functional	Functional	Functional	Functional	N/A	steering wheel cell case removed!
9	Functional	Functional	Functional	Functional	N/A	N/A	N/A	wifi disabled
10	Functional	Functional	Functional	Functional	Functional	Functional	Functional	
								OMIT, NAViSection controller box and proximity sensing rings not functional, did not record session
12	N/A	Functional	Unused	Functional	Functional	Functional	Functional	did not turn on DriveCap power, poximity sensing rings not functional resulting in Option B setup
								declined enrollment
14	N/A	Functional	Unused	Functional	Functional	Functional	Functional	DriveCap dead battery, proximity sensing rings not functional resulting in Option B setup
15	Functional	Functional	Unused	Functional	Functional	Functional	Functional	proximity sensing rings not functional resulting in Option B setup

Participant Number	DriveCap Data Status	NAViSection Verbal Cue Assist & Data Logging	NAViSection Steering Assist Detection	NAViSection Brake Assist Detection	Android Log Data Status	Bioharness Data Status	Android Orientation Data Status	Comments
16	Functional	Functional	Unused	Functional	Functional	Functional	Functional	proximity sensing rings not functional resulting in Option B setup
17	Functional	Functional	Unused	Functional	Functional	Functional	Functional	proximity sensing rings not functional resulting in Option B setup
18	Incomplete	Incomplete	Unused	Incomplete	Incomplete	Functional	Incomplete	proximity sensing rings not functional resulting in Option B setup, witness logger laptop battery died before end of session
19	Functional	Functional	Functional	Functional	Incomplete	N/A	N/A	bioharness and sw orientation data not collected due to errors in BT pair and wifi teathering
20	Functional	Functional	Unused	Functional	Functional	Functional	Functional	participant opted not to interface with steering wheel kit for steering assistance detection during consenting, Option B applied
21	Functional	Functional	Functional	Functional	Functional	Functional	Functional	
22	Functional	Functional	Functional	Functional	Functional	Functional	Functional	

Participant Number	Total Count of Assisted-Driving Events	Total Duration of Physical Assistance Events (sec)	Number of Steering Assistance Events	Duration (sec)	Number of Braking Assistance Events	Duration (sec)	Number of Verbal Cue Assistance Events
1	0	0.0	0	0.0	0	0.0	0
2	0	0.0	0	0.0	0	0.0	0
3							
4							
5	6	12.0	1	1.2	2	10.8	3
6	1	12.7	0	0.0	1	12.7	0
7	14	12.1	1	N/A	6	12.1	7
8	11	5.9	0	0.0	3	5.9	8
9	3	0.0	0	0.0	0	0.0	3
10							
11							
12							
13							
14	4	4.0	0	0.0	2	4.0	2
15	0	0.0	0	0.0	0	0.0	0
16	1	0.0	0	0.0	0	0.0	1
17	0	0.0	0	0.0	0	0.0	0
18	4	0.9	0	0.0	1	0.9	3
19	1	0.0	0	0.0	0	0.0	1
20	7	0.0	0	0.0	0	0.0	7
21	15	70.2	3	5.6	6	64.6	5
22	5	9.3	1	1.0	1	8.3	3

APPENDIX G

CONCEPTUAL MAP OF VERBAL CUES FROM FREE SPEECH DURING ON-ROAD DRIVING EVALUATION

In order to explore the concept of awareness in conjunction with compliance in following rules, this conceptual document was prepared to justify how verbal cue assistance informs decisions by a driver rehabilitation specialist. The map illustrates the difference between idle discussion and the key types of speech that may enhance documentation regarding a client's performance with safe driving decisions and awareness of the roadway rules/environment that he or she is expected to attend to at all times while the vehicle is in motion.

Conceptualization on Verbal Cues

I. Verbal Cues
   A. Speech by client
   B. Speech by evaluator
      1. Conversation
      2. Discussion on Topic (“Driving Cues”)
         a. Instruction on Navigating a driving route
         b. Commentary on other drivers/environmental conditions
         c. Explanation of road design & right of way
         d. Critical Cues
            i. Honest feedback on successful demonstration of driving capability
            ii. Reflection/inquiry on self-awareness of driving incident
            iii. Honest feedback on driving capability lapses

Research Questions

Honest feedback on driving capability lapses →?

Relation to a specific class of error
(Implication for crash risk?) → ?

*Presence of CDRS assistance?

In addition to above,

Reflection/inquiry on self-awareness of driving incident → ?

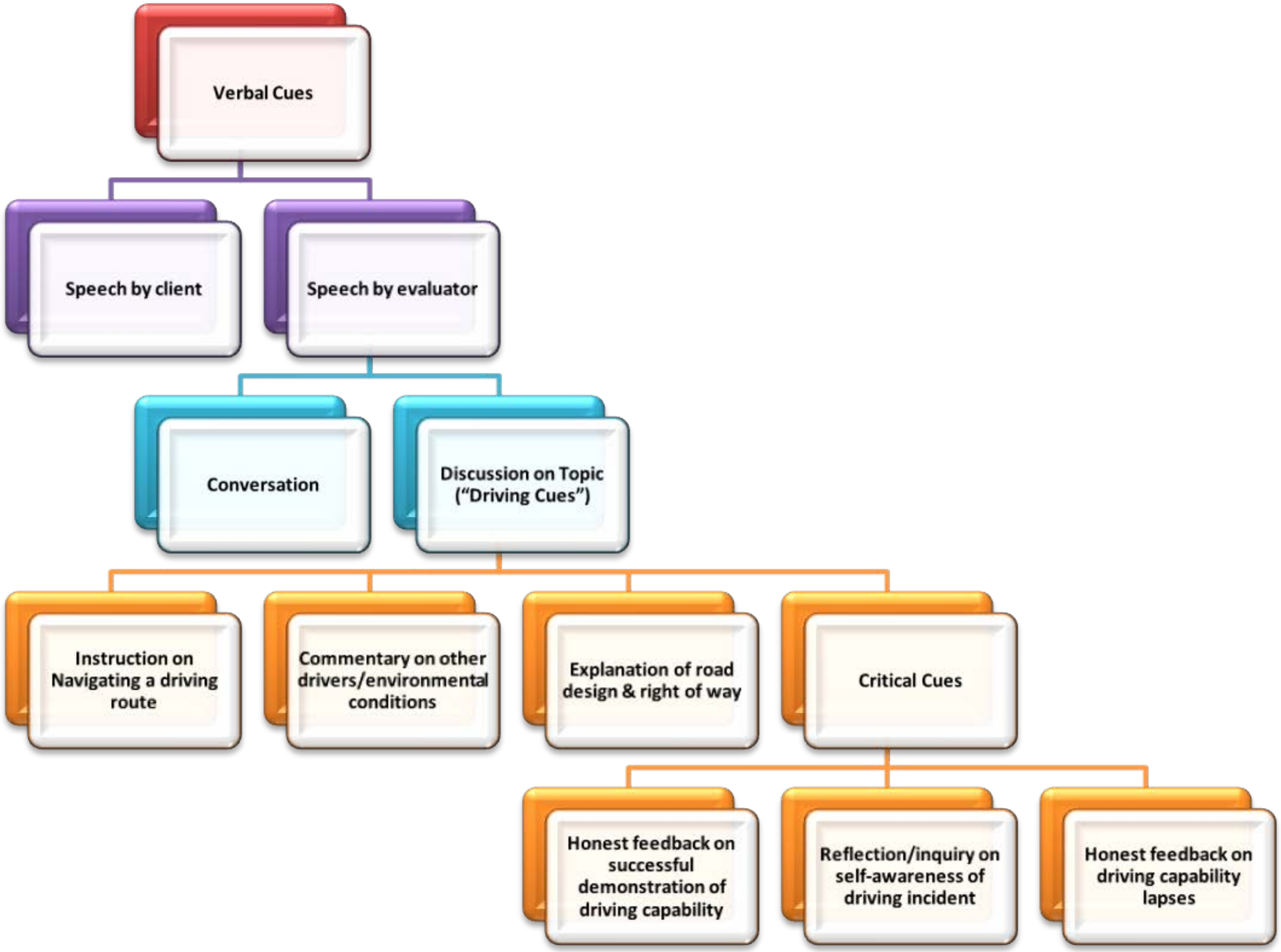
Critical comments on targeted driving maneuvers → ?

Relation to awareness of driving capability saturation for specific class of error
(Implication for crash risk?) → ?

*Presence of CDRS assistance?

Data Analysis Procedure

Critical Driving Cue → Correlate with a class/type of error → Presence of CDRS assistance? → Correlation of NDS Data Pattern?



Verbal Cues
Speech by client
Speech by evaluator
Conversation
Discussion on Topic ("Driving Cues")
Instruction on Navigating a driving route
Commentary on other drivers/environmental conditions
Explanation of road design & right of way
Critical Cues
Honest feedback on successful demonstration of driving capability
Reflection/inquiry on self-awareness of driving incident
Honest feedback on driving capability lapses

Noted Common Phrases (not exhaustive)

Instructional			
orientation	**maneuver**	**clarifier**	**@ target**
Up ahead	stop	left	light
now	Change lanes	right	sign
next	turn	straight	intersection
When safe to do so...	go		Structure (tree, fire hydrant)
	Pull over		
Reflective			
What did you think about that?			
What happened there?			
Tell me about that?			
Is this the same like driving your own car?			
Is everything comfortable in my car?			
Are you comfortable in my car?			
Evaluational (Praise & Criticism)			
You are crossing the (left/right) lane divider			
You are too close to the (left/right) lane divider			
You are rolling through stops without achieving a complete, solid stopped position			
You are not stopping at the proper position at an (intersection/stop sign/stop bar)			
Your speed going into left turns lacks control (*classic hand control error)			
Your entry position to the next lane during a turn is misdirected			
You are braking late			
You are following too closely behind the vehicle ahead of you			
You are going fast/going at the high end of the speed limit			
You are not using the (*specific*) mirror(s)			
You are not performing head checks			
You are striking/depressing the brake pedal while accelerating			

APPENDIX H

QUICK VIEW CHART FOR AMA PHYSICIANS GUIDE TO ADRES

On the following pages, a succinct table shows how physicians are expected to address their patient's driving related skills when concerning issues raise a "red flag" for assessment. The AMA ADReS provides a review of evidence-based literature on clinical assessment tools, which best correlate to the possible need for on-road driving evaluations.

Impairment source	Domain class	Age-related trend	Function performance	Skill driving relation	Task SIPDE	Test clinical exam	Score threshold	Guideline Treat/Refer
stroke, retinitis pigmentosa, glaucoma, cateracts, macular degeneration, ptosis	vision	yes	far visual acuity	crucial to many driving tasks	SI	Snellen/Sloan/ETDRS/ Rosenbaum	> 20/40 >20/70 or	corr. lens corr. lens &
	vision	yes	near visual acuity	reading maps, gauges, controls	SI	Snellen/Sloan/ETDRS/ Rosenbaum	>20/100	refer to DRS
	vision	yes	upper visual fields	see traffic light and street signs	SI	confrontation testing		refer to DRS
	vision	yes	peripheral visual fields	see lateral road signs and pedestrians	SI	confrontation testing		refer to DRS
	vision	yes	contrast sensitivity	night time driving, incliment weather	SI			
	vision	yes	accommodation & adaptation	lighting changes & glare	SI			
	vision		angular movements	detect objects in motion	SI			
	vision		dynamic visual acuity	read objects in motion	SI			
	vision		depth perception	track size & depth of objects close by	SI			
	vision		color	color differentiation, color of signs	SI			
osteoarthritis, musculoskeletal disease, pain, *CVA/stroke/MS/MD/CP*	motor & somatosensory	yes	muscle strength	entry, egress, operation	E	motor strength, rapid pace walk	>9 sec, < 4/5 in up & low extremit	refer to DRS
	motor & somatosensory	yes	endurance		SIPDE			refer to DRS
	motor & somatosensory	yes	range of motion	flexibility, joint stability , turning to view	E	range of motion	not w/in norm limites	refer to therapy
	motor & somatosensory	no	proprioception	balance	E	rapid pace walk	>9 sec	refer to DRS
obstructive sleep apnea, dimentia, *TBI*	cognitive	no	crystallized (short/long term) memory	static, historical reference - vehilce ops, destination, rules of the road	DE	Trailmaking Pt. A&B	> 180 sec	refer to DRS
	cognitive	??Natural/ disease	working memory	refresh to primary task when processing simultaneous info	SIPDE	Clock Drawing Test w/Freund Scoring Criteria	incorrect or missing element	refer to DRS
	cognitive	no	visual perception	recognition	I	UFOV		
	cognitive	yes	visual processing	detection	I	DHI		
	cognitive	?	visual search	scanning	S			
	cognitive	yes	visuospatial skills	locating in space	P			
	cognitive	yes	selective attention	prioritize stimulus & focus	SIPDE	UFOV		
	cognitive	yes	divided attention	focus bandwidth (capacity & partitioning)	SIPDE	UFOV		refer to DRS
	cognitive	yes	exec. Func. Sequencing	prediction, decision, & execution	PDE			
	cognitive	yes	exec. Func. Planning		PDE			
	cognitive	yes	exec. Func. Judgment		PDE			
	cognitive	yes	exec. Func. Decision making		PDE			
	cognitive	?	language	reading	IP			
	cognitive	?	vigilence (awareness - attention)		SIPDE			

SIPDE = Scan, Identify, Predict, Decide, & Execute

Does not predict crash risk!!!

The individual tests in ADReS have been validated as measures of their particular function and in some cases have been studied in relation to driving. Althoug we are still awaiting more evidence-based medical studies to link these test with crash risk, these screens can detect new-onset visual, cognitive, or motor problems that may be amenable to an intervention — subject to state laws

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