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ASSESSMENT OF A SAFE DRIVING PROGRAM FOR NOVICE DRIVERS AND SMART JERSEY BARRIER DESIGN TO MINIMIZE ANIMAL-TO-VEHICLE COLLISIONS

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ASSESSMENT OF A SAFE DRIVING PROGRAM FOR NOVICE DRIVERS AND SMART JERSEY BARRIER DESIGN TO MINIMIZE ANIMAL-TO-VEHICLE COLLISIONS

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by
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ABSTRACT

Each year, the total number of vehicles, motorists, highway infrastructures, and distance traveled by drivers increases on a global basis. This rise in personal and commercial ground vehicle usage brings with it the advantages of the modern age, but it is not without societal cost. Vehicular incidents result in tens of thousands of deaths each year in the United States alone. For this reason, research has been performed to advance driver safety while simultaneously providing wildlife with means to avoid animal-to-vehicle collisions (AVC). In this thesis, two solutions are proposed: a driver education program with classroom experiences, in-vehicle resources, and innovative assessment tools; and a redesigned Jersey highway barrier which offers driver notification and animal egress when wildlife cross roadways.

Vehicular crashes accounted annually for 41,338 and 37,648 fatalities between 1994 to 2009 in the United States and European Union, respectively (ECRS, 2012), (FARS, 2012). In general, the skills and experiences of novice drivers do not favorably compare to motorists with significantly greater driving time and life experiences. A safe driving program tailored to young drivers and their at risk behaviors has been collaboratively developed by Clemson University and the Richard Petty Driving Experience. This program educates novice motorists using both in-vehicle and classroom modules based on critical vehicular scenarios identified from accident databases. Appropriate attitudinal behaviors when operating a motor vehicle, general information for car maintenance, and vehicular control strategies are introduced during the classroom and in-vehicle roadway events. During the safe driving program, students participate in

four modules: braking to realize proper stopping technique, obstacle avoidance curriculum to facilitate proper lane selection and collision avoidance, tailgating to learn about following distance, and loss of control to react when a vehicle is about to become laterally unstable. Students are evaluated using both in-vehicle instructor metrics and the objective based questionnaires which assess critical driving skills and attitudinal knowledge, respectively. The assessment results from twenty-six driving classes consisting of 662 drivers, whose ages primarily ranged from 15-20 years old, were analyzed. Overall, the participants demonstrated a nearly proficient safe driving skill level at the completion of their respective programs as evidenced by 71.3%, 79.1%, 81.4%, and 80.6% scores during the braking, obstacle avoidance, tailgating, and loss of control modules, respectively. Further, the students displayed while an average 16.4% increase between the pre-and post-test scores on general automotive safety knowledge.

Barriers are commonly used on roadways to separate vehicles traveling in opposing directions and to protect against possible head-on collisions. However, these barriers may interfere with wildlife passage such that animals become trapped on the road. Typically, small animals cannot find safe passage across all traffic lanes due to the presence of solid barriers and eventually die if struck by a vehicle. The occurrence of animal-to-vehicle collisions also presents a dangerous scenario for motorists as a driver may intuitively swerve to avoid hitting the animal. In this study, a redesigned Jersey style barrier, named the Clemson smart portal, will be presented and discussed. This roadway barrier features a portal for small animal travel, along with a mechatronic-based warning system to notify drivers of animal passage. The smart barrier concept empowers the animals to cross the roadway through the portal, while a sensor detects their presence and activates a strobe light to alert motorists. Laboratory tests have successfully demonstrated this new barrier's capability to detect animal presence for various scenarios.

DEDICATION

This document, and the work within it, is dedicated to my mother, Landis Clark, my father, Joseph Clark, and my bride to be, Ashley Grice. Thank you for everything and I love you all. Without your support, hard work, love, and God's grace, none of this would have happened. Thank God for you three and Jesus Christ.

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NOMENCLATURE LIST

a	Car acceleration (g's)
a_{pi}	Car deceleration at index i (g's)
a_{pj}	Car deceleration at index j (g's)
a_p	Car deceleration (g's)
dz	Driver displacement along earth's z axis (ft)
E	Overall module score
FWS	Front wheel skid
NP	Nearly proficient skill set
O	Objective module score
p	Driver x,y position in Cartesian 2-D frame (ft)
P	Proficient skill set
r	Earth's radius (ft)
RWS	Rear wheel skid
SWS	Steer while skidding
t_r	Reaction time(s)
v	Car velocity (mph)
x	Driver x position in Cartesian frame (ft)
x_{stop}	Length of braking zone (ft)
y	Driver y position in Cartesian frame (ft)
Ψ	Vehicular yaw angle (deg)
θ	Driver latitudinal position (deg)
φ	Driver longitudinal position (deg)
Ω	Throttle control (%)
+	OR logical operator

CHAPTER 1

INTRODUCTION

Road safety affects virtually all individuals in the United States, Europe, and other developing countries. Drivers who do not adhere to the rules of the road not only endanger themselves, but also their passengers, other motorists, pedestrians, and society in general. Poor driving behavior is most often prevalent by young drivers who lack both experience and full attitudinal development. Younger individuals are more prone to believe they can pilot any scenario regardless of circumstances. This faulty outlook often proves to be dangerous and many times fatal due to their personal thresholds and lack of knowledge regarding machine limits. Fortunately, recent research has produced a new driver training curriculum to improve drivers' ability to safely manage roadway situations. In addition to driver behavior, another factor influences road safety.

The physical highway infrastructure is designed to maintain safety (e.g., Jersey barriers, roadway safety rails) but often at an unforeseen cost. These highway devices often have severe consequences for local wildlife. Despite recent innovations, such as animal-only-paths that bypass vehicular traffic, there are few efforts at altering already applied infrastructures. An innovative change to Jersey barriers has been explored both analytically and experimentally to assuage these negative influences.

1.1 Young Drivers and Safe Roadway Operations

Each year thousands of drivers are injured or killed in car crashes. From 1994 to 2007, highway accidents accounted for over 660,000 deaths in the United States of

America (FARS, 2012). Vehicular crashes represent the largest endangerment to individuals in the 15-20 years old age bracket (NHTSA, 2011). Previous driver educational programs were intended to outfit young drivers early in their lives with the necessary information for proper and safe operation of vehicles (Warner, 1972). However, the effectiveness of the methods used might be questioned due to the high annual toll of roadway accidents and human suffering. Typically, driver instruction is restricted to a classroom environment and attempts to inform individuals on topics ranging from general information to proper vehicle operation. However, the information presented may be overly generic, often not specific enough to be directly applicable. Furthermore, traditional classrooms are unable to deliver in-vehicle operating experience (Simmons-Morton *et al*, 2006). Consequently, a new generation of instruction programs has been developed to address several shortcomings of traditional training and is validated by multiple studies.

It is important for young drivers to receive adequate “behind the wheel” time in a vehicle to learn driving skills. This experience is the foundation of the individual’s ultimate skill set for managing a vehicle in the complete array of roadway events that might occur. Traditionally, in-vehicle experience was gained through supervised driving of the family car. However, the needed operational experience of young drivers is much more than driving through neighborhoods and secondary roads. Specific skills such as steer while skidding, throttle control, proper headway, and brake control are difficult to learn in only these driving conditions. Licensure processes often don’t account for driving experience; even graduated licensing programs are prone to this issue. A safe driving program should focus on developing an appropriate attitudinal foundation for operating a motor vehicle. Young individuals often lack a reasonable sense of their own personal skill sets and therefore, because of the training they have had, have developed a state of overconfidence. Combining a lesser awareness for personal limits with overconfidence can lead to a hazardous situation when navigating highway occurrences. Drivers should be helped to understand the factors that hinder responses when operating a vehicle as opposed to receiving instruction focused solely on improving performance.

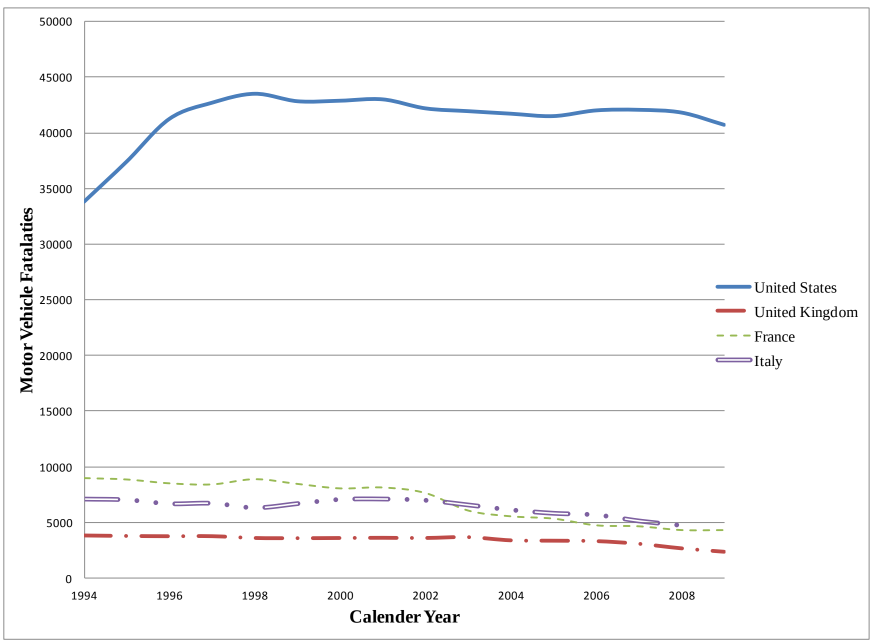

Figure 1.1: Automotive related fatalities in the United States, United Kingdom, France, and Italy from 1994 to 2009 (ECRS, 2012)

Operating a vehicle under highway conditions requires careful and concentrated attention on a motorist's part to safely navigate any scenario. Given young drivers' limited foundation for safely managing a vehicle under road conditions, it is important to address a myriad of topics. Individuals need to understand the influence of vehicle limitations, vehicular parameters, and proper attitudinal response can have when driving a motor vehicle. These general factors comprise a substantial portion of the dynamics involved in roadway occurrences. Performance levels can vary vastly from one vehicle to the next. For example, a large SUV will require significantly more time to stop as compared to a lighter sports car that is designed around a different set of performance parameters. Further, regardless of the vehicle, certain thresholds such as relative speed and appropriate steering input must be maintained. Improper modulation of these parameters can result from driver oversight, or might indicate a driver's lack in understanding for the effect his actions might have on his vehicle and surroundings.

Figure 1.2: Instructors discuss factors that may save young drivers' lives during a tent module at a Richard Petty Safe Driving Event (Charlotte, NC)

Integrating this area of concern with the ones previously mentioned, a new training program designed to inform young drivers of the complications associated with safely managing a vehicle has been introduced. This program consists of both lecture and in-vehicle learning experiences for young drivers. It includes instructional environments that introduce students to many of the complications previously mentioned, as well as additional hazards they may face. In-vehicle experiences provide both behind the wheel time and an opportunity to experience various dangerous driving circumstances in a simulated, safe, and controlled manner. A sampling of 480 students from this program was evaluated, and their safe driving capabilities were assessed as a result of their participation in the program. This demographic consisted of 19 total classes that occurred across the entirety of the 2010 calendar year. Information gathered to judge the participants' capabilities was based around empirical and electronic data captured during their in-vehicle experiences.

1.2 Assessing Young Drivers

Although it is imperative for young drivers to be prepared to safely managing roadway events, adequately preparing them to do so requires the establishment of an assessment method. These evaluation methods must serve two purposes: first, a metric of measuring a driver's threshold driving capabilities, and second, a control to allow the effectiveness of the training program to be determined. A means to detail a motorist's skill set enables quantifiable measures to be established to describe performance. Drivers are not assessed only subjectively, e.g. from bad to good, but also objectively according to a pre- and post-test questionnaire. Also, quantified performance measures permits the effectiveness of the safe driving program to be evaluated. Advancement of student safe driving capabilities is determined using an instructor subjective rubric and participant responses to the set of questionnaires.

Two categories must be addressed when evaluating motorists: the vehicular dynamics involved in a driving event, and the knowledge possessed by drivers. Subjective instructor rubrics assess the finer details of students operation of a motor vehicle by evaluating driving events according to various driving and vehicular parameters. However, additional aspects of participants' safe driving comprehension can be detailed by administrating a general driving knowledge test. This questionnaire is administered prior to student's experiencing the safe driving program and at the conclusion of the program. The questionnaire consists of 14 questions regarding general driving knowledge (refer to Appendix A). Integrating information detailing the driver event with the participant's driving comprehension provides a more comprehensive assessment of a motorist's safe driving capabilities.

1.3 Highway Animal Barriers

Highway infrastructures protect drivers from a myriad of roadway dangers but are often not designed to safeguard both motorists and local animal populations. Many infrastructure features protect drivers and pedestrians, but in many cases endanger wildlife. Of these traffic safety devices, concrete barriers pose one of the greatest threats to wildlife safety. These barriers, being a continuous medium, typically extend for miles as they function to separate opposing flows of highway speed and dense traffic. Given their presence along highway stretches, they often create an insurmountable obstacle for animals that stray onto a road. By segregating traffic flow with these concrete dividers, animals may become trapped on the inside shoulder where the barriers separate traffic. After an animal encounters one of these obstacles and fails to overcome it, they are likely to be killed before escaping back to the roadway shoulder and surrounding vegetation. Infrastructures, known as animal barriers, have been designed to address this complication in remote areas.

In recent years, attention has been given to developing a means to keep animals safe from traffic flow. These facilities provide existing systems with safe passage options for large sized animals such as deer and moose. The most common means of deterring animal-to-vehicle collisions is a pathway either over or under roadways. Diverting vertebrate travel around current highways has proven an effective option for deterring wildlife-to-vehicle collisions. An alternative provision is employing a culvert as a secondary travel route for wildlife. However, by reimagining currently implemented Jersey barriers, a new infrastructure has been developed to empower animals to escape a vehicular related expiration.

A new subclass of intelligent Jersey barrier design was developed and named the Clemson Smart Portal (CSP). This new barrier consists of a passage running through its base and an electronics system to monitor animal activities. Concrete barriers tend to entrap wildlife on roads, but the innovative infrastructure is designed to present them a means of egress. Animals are enabled to escape traffic through a passageway in the smart portal's structure. Although this option is beneficial to wildlife, it presents an additional variable for motorists to consider. The potential of egress is wasted if wildlife blindly enter additional traffic. Therefore, an electronics package was developed to monitor the animals' actions and notify drivers of their presence. These actions are detected by a passive infrared (PIR) sensor that senses the motion of any warm body that emits an appropriate phase of black body radiation. In response to these movements, a strobe light flashes to warn drivers to the animal's presence. This technology allows individuals to prepare for most wildlife entering the roadway.

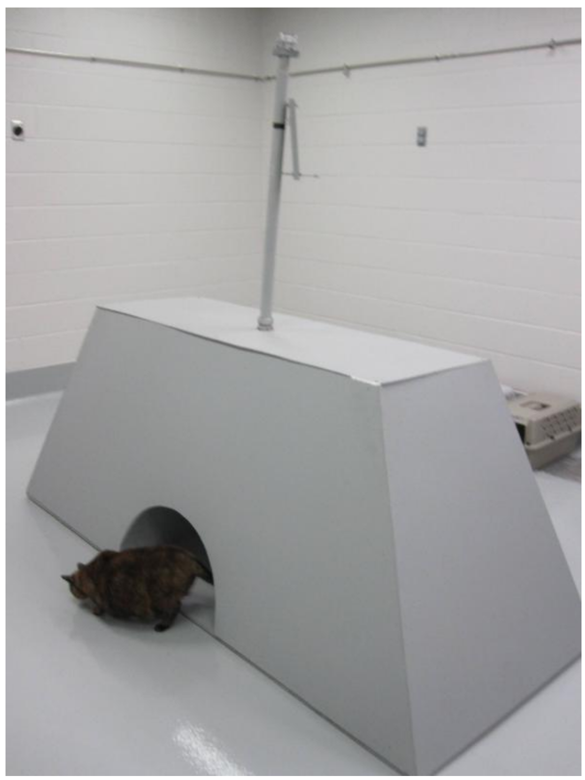

Figure 1.3: Laboratory testing of the Clemson Smart Portal with domesticated felines in a controlled environment at the Godfrey-Snell Research Facility

Laboratory tests investigated the feasibility and functionality of the smart barrier. Three domesticated small felines were released into a controlled environment and allowed to freely interact with a prototype. The animals showed no hesitations in engaging the apparatus and frequently employed the available passage to travel through the unit. The equipped electronics package was repeatedly successful in detecting animal movements and correlating these actions via a light warning system.

1.4 Thesis Organization

An array of driving safety measures will be presented in this thesis. Chapter 2 introduces the new safe driving program, with an evaluation of the program's effectiveness on safe driving comprehension of young drivers. Chapter 3 discloses a more focused evaluation of the program's effect on participants over a two-year time period. The intelligent Jersey barrier design is discussed in Chapter 4 with laboratory demonstrations. Conclusions and recommendation are presented in Chapter 5. Finally, the questions of the pre- and post-tests are shown in Appendix A, the evaluation rubrics applied throughout the safe driving program are outlined in Appendix B, a sample Matlab code used to assess driver data is presented in Appendix C, and graphs of both good and bad driver vehicular parameters are contained in Appendix D.

CHAPTER 2

ASSESSMENT OF A SAFE DRIVING PROGRAM FOR NOVICE OPERATORS

Every year, the United States and European Union are plagued by the deaths of young drivers due to vehicular crashes; the number one rated killer of people ages 15-20 years old (NHTSA, 2011). From 2000 to 2006, 19,076 American motorists in the age range of 15-19 years old were killed in fatal car crashes (CDC, 2012). Although statistics have shown a decrease in the number of reported fatal accidents involving young operators (NHTSA, 2011), more can be done to equip these novice motorists to properly manage common driving scenarios. Instructing them on driving skills alone though is ineffective, with studies showing it is better to teach individuals to adapt their driving style to a given situation rather than applying a performance based training system (MacNeil, 2006). It is important to recognize that skill based training are not ideal since young drivers are prone to overconfidence in their driving abilities (Gregersen, 1995). Paralleling these two studies, the most effective training programs should be empirically based and designed to focus on factors of a specific demographic.

One critical factor for young drivers is their lack of experience and proper attitudinal behavior (Mayhew *et. al*, 2002). A safe driving program has been developed by Clemson University Automotive Safety Institute and Richard Petty Driving Institute to directly address the safe driving problems of young motorists. By immersing them into a controlled environment, these individuals are provided an opportunity to develop their driving capability and comprehension.

Traditionally speaking, the optimal setting for young driving training is perceived as a driver education class (Warner, 1972). However, the majority of student time comes from in-class instruction with only a fraction of the entire time typically spent behind the wheel of an actual car. This learning approach was based on the assumption that students practicing at home with their family's vehicle the classroom lessons. Some states required anyone younger than 21 to undergo driver training similar to this format for licensing (Williams *et al.*, 1996). However, this method has been proven ineffective due to the inadequate amount of supervised driving time for most young motorists (Simons-Morton *et al.*, 2006). The creation of educational program must be carefully conceptualized and implemented, as many programs resulted in a negative safety impact (Stock *et al.*, 1983). A study completed in Denmark exemplified the implementation of a new driver education program (Carstensen, 1993). Unlike studies based around traditional programs, Carstensen found this system to improve crash rates. While Cartensen's investigation was based on an ideal case, it nonetheless presented an example of an effective driving program designed for younger vehicle operators.

Research on the next generation of driver training programs has shown a need to focus on drivers' behavior, skill limitations, and safety perspectives. These are critical driver characteristics to operate a vehicle, as studies have shown programs that focus only on performance skill levels are optimally ineffective and possibly increase crash risks (Senserrick, 2007). Instructional procedures applied must be realistic and practical (Hatakka *et al.*, 2002), and they should must contain information relative to young drivers' attention errors, vehicle speeds, and visual searching (McKnight, 2006). An instructional environment that addresses these topics, while providing instruction and an understanding of preventive driving, should be designed into novice operators programs (Gregersen *et al.*, 2003), (Berg *et. al*, 2004).

The remainder of the paper is organized as follows: Section 2 describes the four training modules implemented in the instructional program. Section 3 introduces the rubrics developed by Norfleet (2009) and Clark (*et al.,* 2012). Section 4 offers a case study for the assessment of the safe driving program. Finally, Section 5 contains the summary. Appendix A presents the questions administered to students during the program, while Appendix B covers the two assessment methods employed in this study, and Appendix C contains a complete Nomenclature List.'

2.1 Driving and Tent Modules

The safe driving program begins by administering a pre-test to students, followed by the participants completing multiple driving and tent modules. At the conclusion of instruction the participants undertake a post-test. A schematic diagram of the learning and assessment activities is given in Figure 2.1. The test questions are located in Appendix A. The modules in the training program include braking, obstacle avoidance, tailgating, and loss of control. The braking module teaches students the required skills to safely stop a vehicle and allows them to practice in which they go from a prescribed trap velocity to a complete stop. The obstacle avoidance module enables students to learn how to safely drive around roadway hazards while maintaining control. The tailgating module allows the student to experience the proper following distance for different traffic scenarios, ranging from normal traffic circumstances to bumper-to-bumper rush hour type conditions. Further, they gain first had experience with the relative distances between vehicles and appropriate stopping distance. Finally, the loss of control module allows students to integrate all concepts together and experience instances where the car's wheels begin to slip and recover vehicle control. All four in-vehicle modules have been designed to offer real-world experiences based on the common factor leading to fatal driving scenarios. As the students undertake each module, they rotate out of driving the cars and into an accompanying instructional tent. Each tent event is specifically designed to supplement the given in-vehicle scenarios. Upon completion of the tent curriculum, the students return to the vehicles to practice.

2.1.1 Braking Module

Motorists less than 20 years old often lack the awareness to demonstrate proper stopping distances in emergency events. Further, drivers may not understand the physical limits of their vehicles in terms of deceleration and handling. In this module, students are instructed on factors contributing to braking, stopping distance, and safety. Students accelerate to a prescribed trap speed, momentarily maintain it, and once signaled to brake with traffic lights, apply brakes to stop the car before the stop strip (refer to 1.2). Although the in-vehicle experience prepares students for abrupt stops, novice operators require additional instruction to successfully navigate these situations. The tent module reviews headway distance, ABS versus non-ABS braking functionalities, pile up effect, impact of loose (e.g., gravel) and slick (e.g, wet) surfaces on stopping distances, regulating brake pressure, and stopping a vehicle without inducing a wheel skid.

2.1.2 Obstacle Avoidance Module

When a collision with a roadway obstacle is possible, driver attentiveness and reaction largely dictates the situational outcome. Young drivers over-confident in their abilities may not recognize that multiple concurrent actions are required to safely avoid the hazards. The in-vehicle portion of the obstacle avoidance module has students driving a straight lane, and at a specified time per the instructor, must driver their car in one of three adjacent and parallel lanes. Figure 2.3 shows a student starting to steer their vehicle into the specified right most lane from the center one. A set of three overhead signal lights illuminate the proper lane for student entry at an appropriate speed. The student must observe the light change, steer the vehicle into the proper lane, and come to a controlled stop in the available space. This process is done in four pairs of two passes on an oval like course. Emulating a real life scenario, one of the passes includes a distraction (e.g., cellphone, track side event, etc.) while driving.

The tent module provides an interactive lecture based on these in-vehicle obstacle avoidance reactions. Students are instructed on the core principles of avoiding roadway obstacles; scan, anticipate, decide, and move-countermove. Integrating these concepts with those from the other three modules will prepare participants to safely navigate roadway obstacles. Students must mind their surroundings, scanning for possible hazards. Being sensitivity to potentially harmful instances can prepare young drivers to safely respond to these conditions. Students are reminded of the need for seat belts and proper attitude. Fatality and injury statistics are introduced to help students comprehend safety issues. For example, 1,652 deaths and 22,372 serious injuries could be avoided at 90% public use of seat belts (NHTSA, 2010). Proper mind set is of equal importance for safe driving. Young individuals are highly influenced by the actions of their peers. Novice drivers may be afraid to be “self conscious” if they are pressured to act outside of their peer’s accepted procedures. Further, their inexperience may leave them lacking a sense of danger (Boyle and Vanderwolf, 2003), (Fell *et al*., 2005).

2.1.3 Tailgating Module

Tailgating can be characterized as following too closely behind the lead vehicle and often results from the following car driver traveling too fast for conditions, inattention, and/or improper following headways. These three attribution factors account for 31%, 10.2%, and 1.5% of all crashes in the United States, respectively (Jensen *et al*, 2010). A training module has been created to educate young drivers on the dangers of tailgating and how to safely avoid it through in vehicle practice and tent discussions. As shown in Figure 2.4, a three lane oval course, with a lead truck in the middle lane containing a special apparatus allows students to follow behind in the left and right lanes. The truck is equipped with a tailgating apparatus on its hitch that spans into the left and right lanes. This tool emulates the rear of two vehicles for following drivers. As the truck begins to accelerate, the students should follow suit while maintaining an instructor prescribed distance. Next, upon reaching the trap speed, the truck abruptly brakes and the students follow suit or risk bumping into the flexible apparatus. This acceleration and braking sequence is sequentially performed a preselected number of times. The goal is for the students to avoid the apparatus; thus providing them an opportunity to practice appropriate headways. Simply put, experiencing proper headways should help young drivers better understand proper following distances and attitudinal practices.

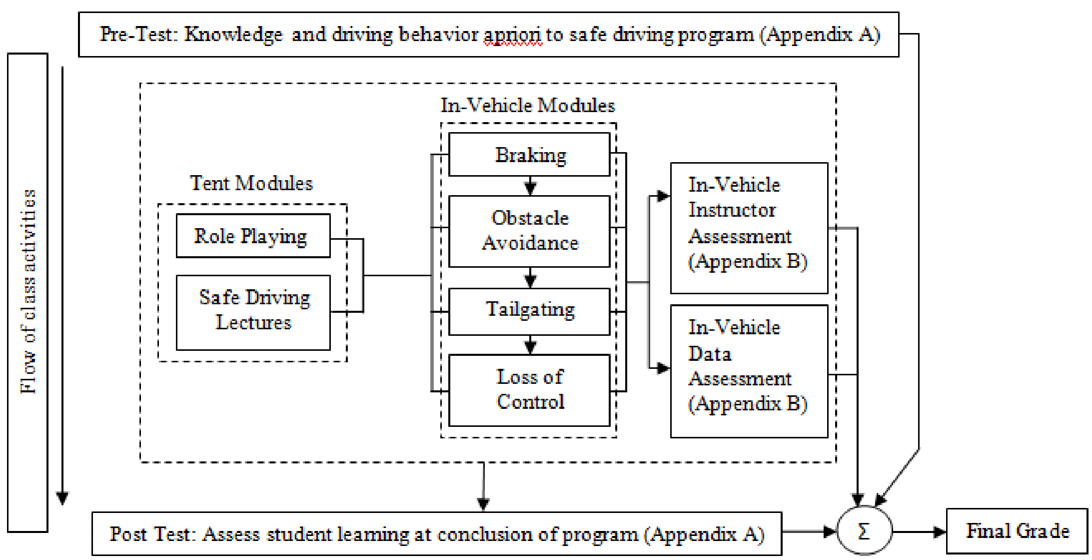

Figure 2.1: Evaluation strategy for safe driving program participants

The accompanying tent module offers additional information and statistics to augment the in-vehicle practice time. The instructor lead discussion focuses on safe following distances and how ambient conditions can alter operating conditions from "ideally" safe guidelines. Rear ending a vehicle is a common occurrence, so young operators need to understand the cause and effect ramifications. Students are instructed to maintain a proper mindset when following a vehicle (i.e., no aggressive driving), consider proper following distance, regulate brakes, knowing their vehicle's performance levels, and be aware of possible pile up effects.

Figure 2.2: A student practice run on the braking module course which requires them to stop their vehicle prior to the stop strip

Tailgating commercial vehicles can quickly escalate this dangerous driving behavior. The tent module discusses tailgating larger trucks with students sitting in a parked semi and viewing the mirrors to learn firsthand about visible and blind spots relative to the driver's seat. Students are asked to observe their surroundings once in the driver's seat and state who they observe. Instructors then inform the student that their peers are populating blind spots, and ask them to step out and see where those students are located. This exercise vividly illustrates the no-zones and reinforces the dangers of tailgating large vehicles.

Figure 2.3: Student responding to signal lights while completing the obstacle avoidance module

2.1.4 Loss of Control

Driving a vehicle on the edge of lateral stability when cornering is a dangerous, and sometimes fatal occurrence. In this module, drivers experience front and rear wheel skidding, hydroplaning, and cornering on a closed road course. A student experiencing a front wheel skid is shown in Figure 2.5. The participants are cautioned about typical reactions in these scenarios, and instructed how to overcome them. For instance, upon completion of this module, students should possess a sensitivity to the feel of a wheel skid and how to safely react to it. Participants are reminded recovery from loss of control is a driver's last opportunity to avoid an incident and/or emergency situation.

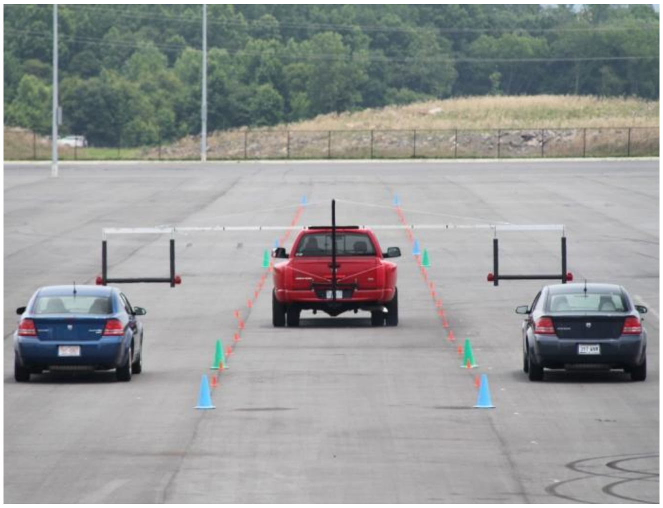

Figure 2.4: Lead pickup truck equipped with a tailgating apparatus as two student vehicles follow behind

The tent module covers concepts such as maintaining the vehicle good battery, connecting jumper cables to jumpstart a vehicle and changing a tire. Restarting a vehicle with a dead battery is an important skill when help is not readily available (tire change, etc.). Having emergency rations, maintenance items, and safety equipment can save lives in these events.

Figure 2.5: Loss of control module offers an experience of rear and front wheel skidding

2.2 Assessment Methods

As students experience the six hour training program, their answers to questions, reactions as observed by the instructors, and vehicle operation recorded per in-vehicle devices are collected. Subjective and objective assessments were applied to fully quantify each student's performance. The developed objective method produces an unbiased assessment of students with measurable vehicle parameters. Concurrently, instructor evaluations consist of information observed while the student drives the various modules. These two metrics are presented in Appendix B.

2.2.1 Objective Evaluation of Driver-Vehicle Performance

The instruction vehicles are equipped with general purpose data acquisition units to collect data to evaluate the driver performance for each module. The availability of vehicular data can help assess student performance as shown in Tables B.1 through B.4. The recorded vehicle parameters included the chassis vehicular GPS coordinates (r, θ,φ), car velocity, v, and car acceleration, a_p. The vehicular GPS coordinates can be transformed into a localized (x,y) two dimensional Cartesian reference frame (refer to Figure 2.6) by assuming relatively small displacements of the instruction vehicles along the earth's z axis. In this analysis, $x = r\sin\theta\cos\varphi$, $y = r\sin\theta\sin\varphi$, *and* $p = (x, y)$. The vehicle's velocity is calculated based on position changes with respect to the GPS satellite's position. The acceleration is recorded by an integrated accelerometer, and the remaining variables (e.g., t_r, Ψ) are extracted from these known signals as shown in

Figure 2.7. Each parameter is scored on a 0 to 5 increment by instructors and weighted to emphasize critical parameters

The recorded in-vehicle data is preferably directly viewed by the instructor, communicated to the students and then transferred immediately to the evaluation sheets, or if time does not persist, then performed off line. Only the participant's last module run will be applied in the assessment methodology. In the past, extensive vehicle data was collected which hindered student assessments, so a new method has been developed that offers immediate student data. This approach allows swift coaching opportunities relative to each module. Specifically, a "black box" data acquisition system is placed in-vehicle which is composed of a data acquisition unit coupled to an integrated visual notification system to supplement instructor visual evaluation of students. The scores of Section 4 will reflect only the subjective rubric and students' pre and post test scores. However, the objective evaluation may be readily integrated when available.

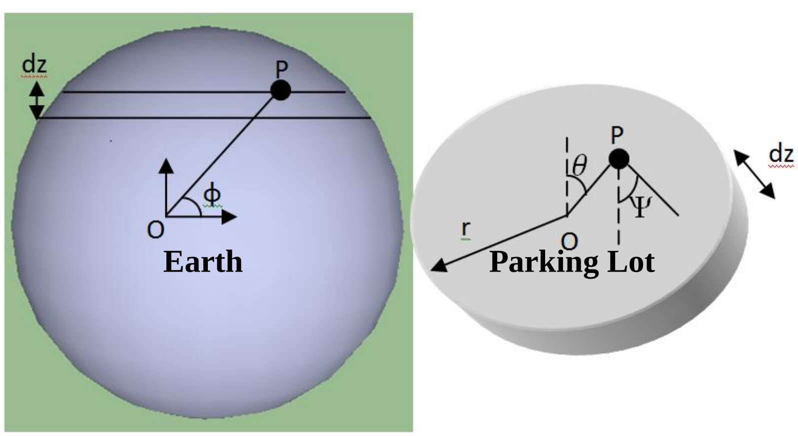

Figure 2.6: Cross section of earth with cut out of height dz; vehicular position derived in a two dimensional plane

2.2.2 Subjective Grading Rubric

In-vehicle instructors accompany all students when driving each module and evaluate their performance using a subjective rubric (refer to Tables B.5 through B.8). Partial credit for less proficient capabilities produces a flexible evaluation metric which equips the instructor to accurately quantify student skills. All factors are scored from 0 to 5 within a weighting system that emphasizes critical attributes. Due to the dependency of this rubric on the in-vehicle instructors' observations, it's vital to train them to properly handle both the students and the vehicular observations simultaneously.

The instructors receive focused training through "train-the-trainer" workshops which participants review the module and in-vehicle content. Specifically, the driving instructors are coached on how to best to deliver the program and evaluate the drivers in a uniform manner. The instructors learn how to observe the factors of each module, and what an appropriate response by a participant looks and feels like. In this regard, the written curriculum helps ensure a standard driving program for all students. Periodic training of the instructors provides confidence in the subjective rubrics. The final grade may be computed according to Table B.9 with integration of the objective and subjective materials.

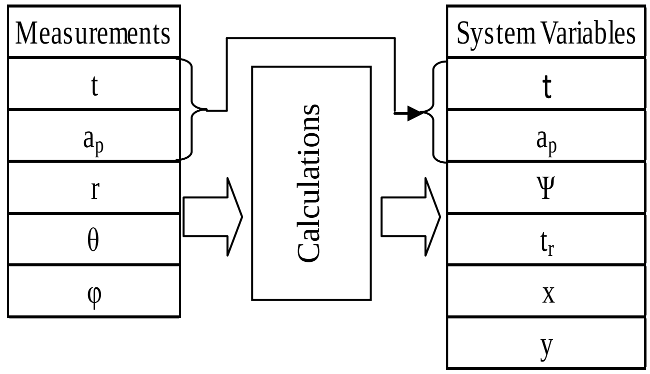

Figure 2.7: Measurable and calculated variables which define the objective assessment's core factors

2.3 Case Study-Novice Driving Program

In this paper, a case study will be presented which consists of three complete safe driving classes at the Atlanta Motor Speedway (Atlanta, GA). Classes 1, 2, and 3 consisted of 27, 27, and 16 participants, respectively. The weather for Classes 1 (Sat, AM) and 2 (Sat, PM) was a warm summer day with moderate precipitation and steady winds. The temperature and winds were comparable for Class 3 but with negligible rain fall. The average performance for the three classes in each module and program have been summarized in Table 2.1. Classification of the participant's safe driving skill sets are as follows: a grade lower than 75% is labeled a developing skill, 75% to 85% represents nearly proficient skills, and greater than 85% corresponds to a proficient skill level.

The participants have been evaluated on the pre-test, four modules, and post-test as previously discussed. Each class displayed low pre-test scores when compared to the post-test values which coincides with the expectation of young drivers' lower levels for safe driving comprehension. The students were evaluated upon completion of each in-vehicle module. During the braking module, Classes 1, 2, and 3 were evaluated at 84.3%, 88.1%, and 85.5%, respectively. Classes 1 and 2 showed nearly proficient operation in the obstacle avoidance module, with Class 3 assessed at a proficient threshold. Evaluative scores for the tailgating module of Classes' 1, 2, and 3 were nearly proficient, proficient, and proficient. Lastly, all three Classes were evaluated as nearly proficient during the loss of control module. The students' post-test scores showed a significant climb, >19% relative to their pre-tests. These increases in scores gage the progression of participants' comprehension for safe driving knowledge and responses. Finally, the overall evaluations were as follows: Classes 1 and 2 were assessed as nearly proficient, and Class 3 observed to be proficient.

2.4 Summary

The safe driving program instructs novice drivers how to properly evaluate and respond to hazardous driving scenarios. The braking, obstacle avoidance, tailgating, and loss of control modules emulate conditions that statistically prove to be harmful or fatal to young drivers. These modules focus on proper behavioral and attitudinal responses. To analyze the drivers' skill sets, a sampling of three classes has been reviewed in a case study. Two classes displayed a nearly proficient level of skill while the third group showed a proficient driving level. The participants improved their knowledge as evident by their pre and post test scores. The next step in the project is the collection, analysis, and creation of a database as the classes are offered to more young drivers.

Table 2.1: Three safe driving programs offered in Atlanta, GA with D≤75%, 75%<NP≤85%, and 85%<P where D=Developing skill set, NP=Nearly proficient skill set, and P=Proficient skill set with all scores out of 100%

Date	Aug 2010		
Location	Atlanta, GA		
Class	1	2	3
Pre-Test	57.7%	60.3%	60.2%
Braking	84.3%	88.1%	85.5%
Obstacle Avoidance	84.7%	80.2%	85.0%
Tailgating	84.0%	85.2%	89.7%
Loss of Control	80.6%	76.2%	83.6%
Post-Test	80.3%	80.0%	84.2%
Total Score	83.4%	82.4%	86.0%
Standard Deviation, σ	1.9%	5.3%	2.6%
Rating	**NP**		**P**

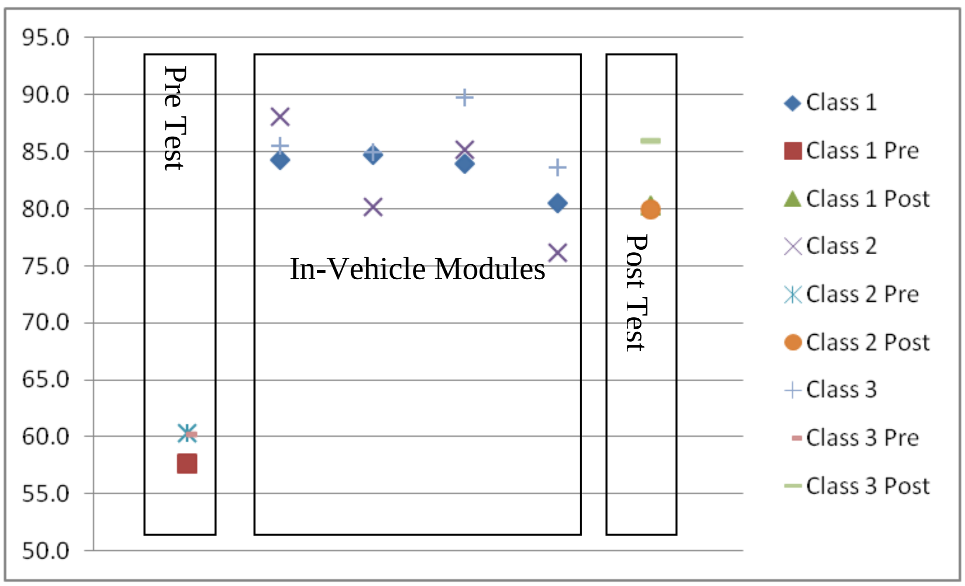

Figure 2.8: Average module scores in four modules (braking, obstacle avoidance, tailgating, and loss of control), grouped according to class

CHAPTER 3

FOCUSED NOVICE DRIVER PROGRAM -

ASSESSMENT RESULTS AND DISCUSSION

Each year, young drivers achieve state supervised licensure to operate a motor vehicle (FHWA, 2012). The licensure process typically consists of a written, vehicle, and eye test with or without a learner's permit and driver's education. Young drivers' handling capability and proper response to hazardous situations may not be at an acceptable level. From 1994 to 2009, an average of 41,338 drivers per year from the 15-20 years old age bracket were killed due to vehicular crashes in the United States (FARS, 2012). This statistic is one contributing factor to an epidemic plaguing many developed countries: vehicular fatalities have become the number one killer of drivers from 15-20 years old (NHTSA, 2009). Current efforts to mitigate these vulnerabilities have not been fully effective, as young drivers continue to be involved in accidents with high frequency (Williams *et al.*, 1996, CDC, 2012). Further, communities have failed to acknowledge and/or implement the findings of these new studies in driver education programs (Lonero *et al.*, 2010). Consequently, studies seeking a foundation for new approaches to providing young drivers with proper tools for safely managing highway dynamics have become necessary.

Existing educational programs for young drivers have been ineffective, largely due to extensive driving experience being delegated to personal exercises rather than instructor observed activities (MacNeil, 2006, Simons-Morton *et al.*, 2006). Widespread corporate and individual opinion supports this argument, with popular belief that current driving education infrastructures are not performing at an acceptable level (Bishop *et al.*, 2005). Recent attempts have been made to establish a standard measure of what driver education programs should become (NHTSA, 2009). At Clemson University, research into an improved safe driving program which addresses the shortcomings of current driver education curriculums afford young motorists with attitudinal/behavioral training to augment their ability to safely respond in dangerous instances (Jensen *et al.*, 2011). Additionally, the developed Clemson University/Richard Petty Driving Experience safe driving program addresses parameters at the core of most accidents involving young drivers while simultaneously providing in-vehicle experience. This is vital, as young drivers generally lack sufficient operating experience and/or sensitivity to the dangers of the road (McKnight, 2006). In this next generation program, the student's in-vehicle experience is comprised of four vehicular modules, described in Section 2. Student comprehension of safe driving is evaluated using pre- and post- tests administered before and after experiencing each module. Although this training system has demonstrated a positive influence on young drivers, the establishment of a quantifiable assessment was required. Researchers in Japan have shown that the driver's risk factor may be determinable from their acceleration patterns (Naito *et al.*, 2009). A follow up study ascertained the applicability of braking and steering patterns to describe a driver's risk factor (Miyajima *et al.*, 2011). As a driver's performance can be quantified through the classification of vehicle operation variables, a supplemental assessment methodology was designed for the safe driving program (Clark et al., 2012).

Operating a motor vehicle involves a series of actions through the human-machine interface as shown in Figure 3.1. Some of the primary skills associated with assessing the core factors of the in-vehicle modules have been explicitly listed (braking, obstacle avoidance, tailgating, and loss of control). To assess driver performance, both in-vehicle instructor ratings for each module and the pre- and post-test questionnaires are evaluated to calculate an overall driver rating. Although not implemented in this study, real time vehicle operating data can be recorded, analyzed, and integrated into the assessment methodology. The remainder of this paper is organized in the following manner. Section 2 contains the CU-RPDE safe driving program with the driver evaluation methods. Section 3 presents a large database of student results to illustrate the driving program's effectiveness. Finally, Section 4 presents the conclusions.

3.1 Safe Driving Program: Student Driving Activities and Learning Tent Modules

A six-hour safe driving program has been developed that delivers focused driving experiences and concise information based lectures to the young participants. The course time is divided into a welcome session with initial assessment, four lecture and driving modules, and wrap up with final assessment. The trained instructors accompany students throughout the program, acting as coaches to offer immediate feedback on performance, as well as assess the last run for each in-vehicle module. The program essentially consists of a knowledge based pre-test, tent modules, driving modules with subjective assessment, and a knowledge based post-test in a fast paced quarter-day.

3.1.1 In-Vehicle Modules

The in-vehicle portion of the safe driving program consists of four in-vehicle modules: braking, obstacle avoidance, tailgating, and loss of control modules. The first module is braking in which students experience a quick braking scenario, requiring them to stop their car within a prescribed distance. Second, participants have to steer their vehicle into the appropriately signaled lane during the obstacle avoidance module. Next, the tailgating module has the student practicing proper following distances relative to a lead truck as shown in Figure 3.2. Finally, the loss of control module allows the individual to experience the feel of their car undergoing a wheel skid and the accompanying reduction in controllability and steerability. Each of these modules will now be briefly discussed.

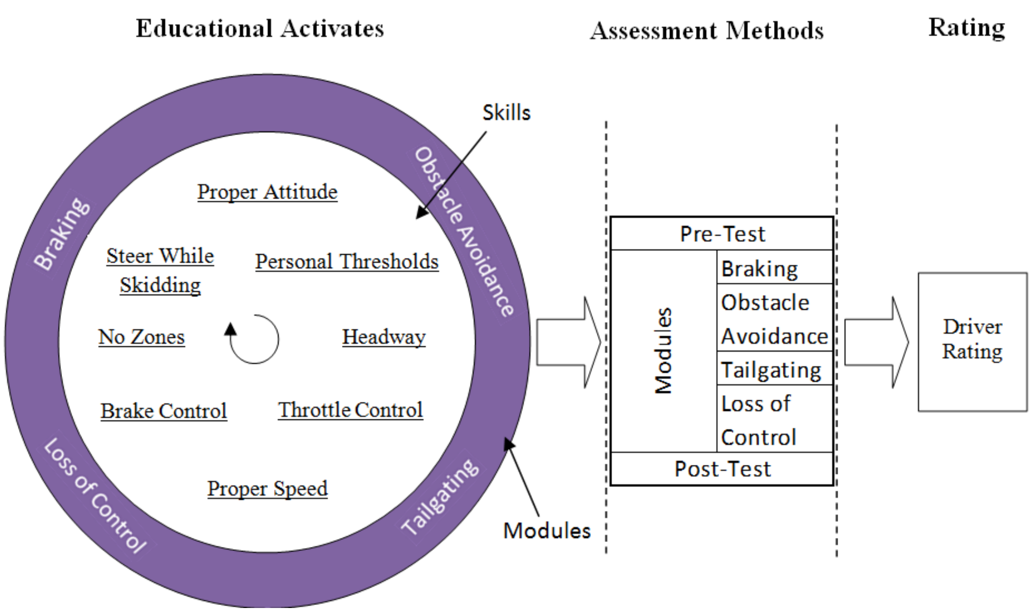

Figure 3.1: Overview of the safe driving program with assessment

Braking Module: The incorrect application of base brakes when operating a ground vehicle can place a driver into a hazardous roadway situation. This driving module consists of a long straight away with three overhead traffic signals to specify where participants should stop their vehicles. Drivers are requested to bring their vehicle to the prescribed trap speed, and upon the traffic signal lighting red, stop before a specified location. The subjective braking assessment has the in-vehicle instructors observing the drivers for their operational trap speed, stopping before the stop strip, the distance from the vehicle's front end to the stop strip, proper braking technique, and whether the individual anticipated the maneuver.

Obstacle Avoidance Module: Avoiding obstacles that exist in a driver's lane of travel requires quick and proper application of both brakes and steering, recognition of a safe alternative to the current travel lane, and appropriate placement of the vehicle within the new lane of travel. The obstacle avoidance course design consists of a straight away that splits into three parallel lanes, with the three overhead signal lights specifying the correct lane for students to obtain. The participants must operate on the straight away at the stated trap speed, and upon light change (red lights signify "closed" lanes) must quickly navigate their vehicle to the specified lane. The subjective evaluation for this module assesses each driver on operating at trap speed, correct braking technique used, steering wheel technique, correct lane choice, correct car positioning, and whether they anticipated the maneuver.

Tailgating Module: Properly following a vehicle while driving in traffic necessitates a proper following headway, but the driver must be constantly prepared to quickly react to a hazard by stopping and/or avoiding it. This module's roadway is a large oval course, with lanes for two separate student vehicles and a lead truck equipped with a tailgating apparatus. The tailgating apparatus consists of two arms that extend from the rear of the truck into the two student lanes, with soft material as each arm to ensure participant safety. The two student vehicles follow the lead truck while maintaining a prescribed distance, and as the truck arbitrarily and abruptly brakes, the participants must stop their vehicles before contacting the flexible tailgating apparatus which feature brake lamps similar to a lead vehicle in each lane. The in-vehicle instructors assess the students according to the subjective rubric: proper headway distance, distance to lead truck once stopped, proper braking technique, proper acceleration and speed, and premature application of brakes.

Figure 3.2: Two students following the lead truck outfitted with the tailgating apparatus in the tailgating training module

Loss of Control Module: The occurrence of a rear wheel or front wheel skid can be hazardous for all drivers on degraded roadway surfaces, and requires the coordination of the throttle, brake, and steering wheel to safely recover. This driving module consists of a skid pad (80 foot diameter), and roadways featuring s-turns and water on various surface locations. The students begin the exercise by engaging the skid pad and then undergoing the s-turns, and experiencing alternating dry and wet surfaces. On the final run, the subjective metric evaluates students on trap speed, proper positioning of vehicle, adequate operating speed, correct technique, recognition of a front wheel skid and rear wheel skid, appropriate line of sight, and anticipation of the necessary maneuvers.

3.1.2 Tent Modules and Program Pre- and Post-Tests

Students are instructed on general vehicle maintenance and behavioral responses when not driving the vehicles. A tent module accompanies each in-vehicle module, with participants rotating between the driving and class room. These classroom lectures supplement the in-vehicle experiences by emphasizing the importance of crucial driving skills and proper behavior/attitude while driving. The tent modules also introduce students to the topics of proper vehicle maintenance, no zones around large commercial trucks, and the importance of seat belts, as shown in Figure 3.3. Student knowledge is assessed before and after the safe driving program by pre-test and post-test examinations. These multiple choice quizzes are similar, acting to capture the behavior and knowledge pool of participants prior to the safe driving program while measuring the attitudinal response and knowledge gained at the conclusion of the program. Refer to Clark *et al.*

(2012) for the test questionnaires in Appendix A. The students' performances during the safe driving program are assessed in two manners: an instructor completed subjective rubric and objective pre- and post-tests. Trained instructors accompany participants for each module and evaluate them according to the subjective methodology.

Figure 3.3: Students are instructed to properly maintain their motor vehicles in the tent module which accompanies the obstacle avoidance module

3.2 Assessing Safe Driving Programs Offered in Florida, Georgia, and North Carolina

A case study consisting of 26 safe driving classes to 661 students during the 2010 and 2011 calendar years will be presented. The performance averages for each class (pre-test, modules, and post-test) are presented in Table 3.1. The average participant age was 16 years old, with ages primarily between 15 to 18, and a gender distribution of 54.6% male and 45.4% female. The skill ratings have been separated into three tiers: an assessment of 75% or lower was developing (D), 75% to 85% was nearly proficient (NP), and greater than 85% was classified as proficient (P).

The participants were assessed on pre-test questionnaires, four in-vehicle modules, and post- test questionnaires. The in-vehicle subjective evaluation by the instructors will be discussed first followed by the two objective test measures. The braking module results show that fourteen classes were rated as developing, eight were nearly proficient, and the remaining four were proficient. An average score, $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, of 71.3% was realized for this module, a developing skills grade, with a standard deviation, $\sigma = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x}_i)^2}{n}}$, of 10.2%. For the obstacle avoidance module, eight classes operated at a developing skill level, twelve displayed a nearly proficient capability, and six demonstrated a proficient threshold. The students achieved an average score of 79.1% with a 7.67% standard deviation. As shown in Figure 3.4, the brake module scores were generally lower than the obstacle avoidance exercise, which can be partially attributed to its placements as the first driving skill. Further, the students must learn how to effectively brake their vehicle which is not an everyday occurrence given that light braking is typical on most roadways.

Table 3.1: Sampling of average scores from safe driving programs offered between February 2010 and November 2011 where D (Developing) $\leq$ 75%, 75% < NP (Nearly Proficient) $\leq$ 85%, and 85% < P (Proficient) and all scores are rated out of 100%

Date	Location	Class	AM/PM	Pre Test	Braking	Obstacle Avoidance	Tailgating	Loss of Control	Post Test	Score	Standard Deviation	Overall Rating
Feb 2010	Charlotte, NC	1	AM	62.1%	61.3%	81.2%	75.2%	77.9%	72.0%	73.9%	8.7%	D
		2	PM	55.9%	65.5%	78.3%	82.6%	79.6%	62.3%	76.5%	7.6%	NP
		3	AM	65.1%	57.4%	84.3%	82.8%	73.3%	78.7%	74.4%	12.4%	D
Mar 2010	Atlanta, GA	4	AM	61.1%	52.7%	64.2%	81.4%	70.9%	66.4%	67.3%	12.1%	D
		5	PM	63.1%	65.6%	62.0%	79.9%	75.3%	74.3%	70.7%	8.3%	
May 2010	Orlando, FL	6	AM	62.1%	71.6%	84.7%	87.5%	92.3%	78.6%	84.0%	8.8%	NP
		7	PM	50.4%	75.5%	86.6%	83.9%	90.9%	63.4%	84.2%	6.5%	
		8	AM	60.1%	76.5%	83.1%	87.7%	90.5%	77.5%	84.5%	6.1%	
Jul 2010	Charlotte, NC	9	AM	62.2%	77.0%	86.3%	82.7%	83.7%	86.1%	86.2%	3.9%	P
		10	PM	64.1%	86.1%	83.0%	86.6%	76.8%	87.4%	83.1%	4.5%	NP
Aug 2010	Atlanta, GA	11	AM	57.7%	84.3%	84.7%	84.0%	80.6%	80.3%	83.4%	1.9%	NP
		12	PM	60.3%	88.1%	80.2%	85.2%	76.2%	80.0%	82.4%	5.3%	NP
		13	AM	60.2%	85.5%	85.0%	89.7%	83.6%	84.2%	86.0%	2.6%	P
Nov 2010	Charlotte, NC	14	AM	59.6%	86.5%	79.5%	81.6%	85.4%	82.7%	83.3%	3.3%	NP
		15	PM	61.5%	76.0%	74.5%	77.7%	83.1%	80.7%	77.9%	3.8%	
Dec 2010	Atlanta, GA	16	AM	60.2%	73.9%	69.0%	79.7%	76.0%	83.0%	74.6%	4.5%	D
		17	PM	55.6%	81.1%	73.9%	79.3%	67.9%	77.9%	75.5%	6.0%	NP
Dec 2010	Orlando, FL	18	AM	63.2%	64.8%	85.5%	72.0%	81.6%	80.3%	74.1%	10.5%	D
		19	PM	60.0%	76.5%	75.0%	77.1%	76.6%	83.1%	76.2%	1.1%	NP
Mar 2011	Charlotte, NC	20	AM	48.7%	69.6%	79.1%	69.1%	81.3%	77.9%	74.9%	6.4%	D
		21	PM	60.3%	69.3%	84.1%	76.7%	88.6%	79.5%	76.7%	6.0%	NP
Oct 2011	Charlotte, NC	22	AM	50.5%	66.5%	89.3%	81.7%	79.9%	61.4%	79.7%	9.5%	
		23	PM	55.9%	59.6%	90.8%	80.0%	81.6%	61.6%	79.8%	14.2%	
Nov 2011	Atlanta, GA	24	AM	53.7%	60.2%	67.7%	86.4%	81.2%	60.9%	73.5%	11.8%	D
		25	PM	55.9%	58.8%	73.7%	85.2%	77.9%	57.3%	74.8%	11.7%	
		26	AM	54.1%	62.5%	72.0%	81.8%	81.2%	72.4%	74.4%	9.1%	
Mean Scores		-	-	58.6%	71.3%	79.1%	81.4%	80.6%	75.0%	78.2%	7.2%	-
Standard Deviation		-	-	4.4%	10.2%	7.7%	4.9%	5.8%	8.9%	5.1%	-	-

Figure 3.4: Graphical display of scores for braking and obstacle avoidance modules

For the tailgating module, nine classes were rated as developing, ten were assessed as nearly proficient, and seven operated proficiently. The overall average for tailgating was 81.4% with a 4.86% standard deviation. Similarly, the loss of control module results rated four classes as developing, fifteen being nearly proficient, and five as proficient. The students were able to obtain an average score of 80.6% with a 6.16% standard deviation. The module scores for tailgating and loss of control have been graphically displayed in Figure 3.5. The overall student performance is much higher for the later events (in comparison to Figure 3.4) with the tailgating exercise highly favored by the students per their written comments. Note the fluctuation in module scores which reflect variations in student driver skills during the assessment runs.

The student's understanding of vehicle operation and safety has been evaluated by comparing the differences in the pre- and post-test scores. Each class's pre-test versus post-test questionnaires scores showed an increase in safe driving comprehension, with an average gain of 16.4% and a standard deviation of 7.29% as shown in 3. 1. Lower pre-test scores for young drivers would be expected due to their limited experience and knowledge of safe driving practices. As displayed in Figure 3.6, the comparison of questionnaire scores ranged from 1%-29% which reflects a need to ensure consistent delivery of the tent module materials.

Figure 3.5: Graphical display of scores for tailgating and loss of control modules

The overall results of the safe driving program are shown in Table 3.1 (columns 10, 11, and 13) and Figure 3.7. These scores are based on the average assessment of each class' in-vehicle module runs (as shown in columns 6-9 in Table 3.1). Generally, these scores represent the participant's comprehension of in-vehicle behavior and reactions necessary for safe operation. Of the 26 classes, 10 were classifiable as developing skills (D), 14 displaying nearly proficient skills (NP), and 2 exemplifying proficiency (P). As stated previously, the overall ratings varied from class to class. The safe driving program was also effective at positively influencing the behavior of the young drivers. The post test scores quantify the students' level of understanding for driving behavior once they have completed the safe driving program. These questionnaire scores are based on the percentage of correct responses relative to the total number of questions. Approximately 42.3% of the 26 classes were assessed at post test scores of 80% or higher, and 65.4% of the classes were at scores of 75% or higher.

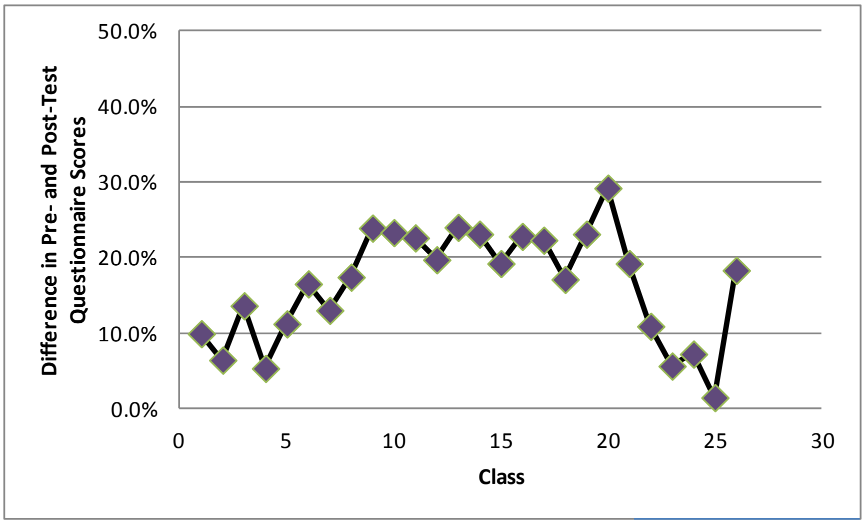

Figure 3.6: Comparison of pre- and post-test scores for the individual classes

The trends that exist amongst the students' overall and pre- versus post-test score differences yield insightful information regarding the safe driving program. The increase in overall scores from Table 3.1 for the in-vehicle modules show that students typically get better as the program progresses, as indicated by the rise between the overall braking (module 1) and loss of control (module 4) scores. The safe driving program succeeds at the goal of preparing young drivers for safe operation; Figure 3.7 shows the majority of classes fell within the nearly proficient ranking with some outliers as expected.

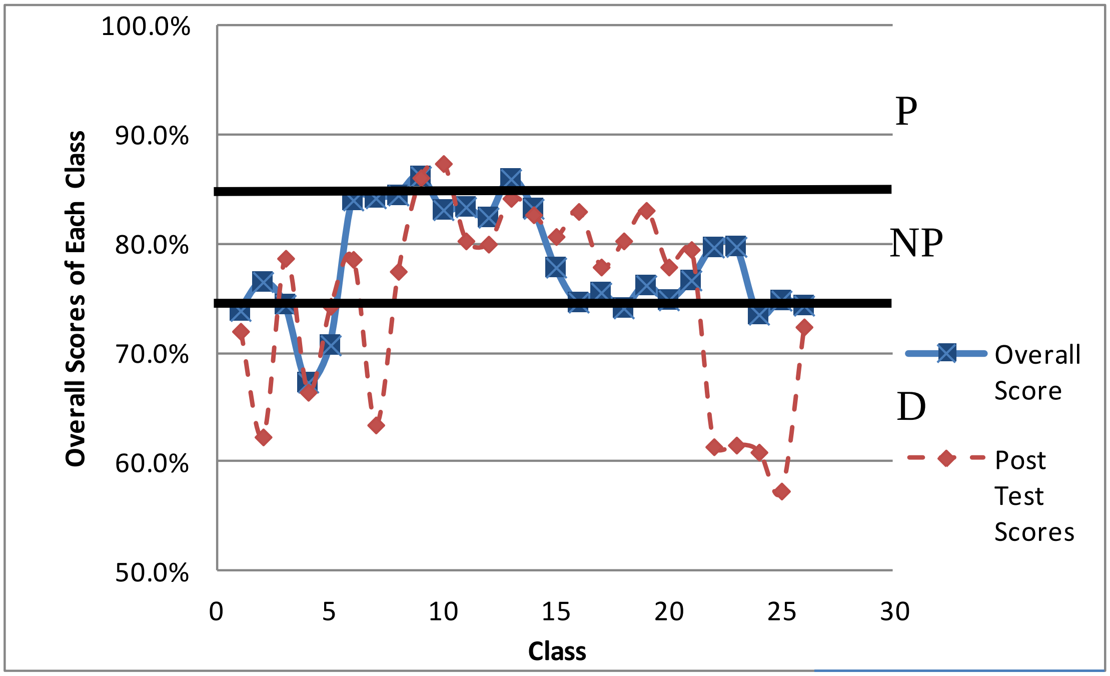

Figure 3.7: Overall scores of each safe driving program class based on the average in-vehicle module and post-test scores per Table 3.1 (column 11) with D (Developing) $\leq$ 75%, 75% < NP (Nearly Proficient) $\leq$ 85%, and 85% < P (Proficient)

3.3 Conclusion

The safe operation of motor vehicles by novice drivers requires a concentrated effort of parents, teachers, and licensing agencies as well as drivers with good judgment and skills. In this paper, a driver education curriculum has been implemented and assessed to help address the recurring need for better driver training programs. Combining objective pre- and post-test questionnaires with instructor observations produced a powerful approach to quantify and detail driver performance. The application of equal contributions from the subjective and objective methods achieves a robust assessment of driver proficiency. This program was applied to 26 classes across three states with 661 participants. The averaged results showed that many students in all classes improved to a nearly proficient operating level from the training program. Concurrently, the effectiveness of the safe driving program is confirmed by the significant increase of post-test scores relative to pre-test performances.

CHAPTER 4

A SMART JERSEY HIGHWAY BARRIER WITH PORTAL FOR SMALL ANIMAL PASSAGE AND DRIVER ALERT

Modern transportation systems have facilitated societal transformations around the world during the past century. However, mobility advancements have tradeoffs which must be evaluated in terms of vehicle occupant and pedestrian safety, wildlife impact, environmental damage, and economic cost. Vehicles offer personal mobility solutions but they also precipitate vehicular accidents involving drivers, passengers, pedestrians, and/or animals on a frequent basis. The introduction of multiple lane roadways which feature concrete center barriers to protect vehicles from traffic cross-over collisions may unfortunately result in a rise in animal fatalities. While these roads allow for significantly higher travel speeds and reduced risk of head on accidents, the impact on the local wildlife community may be considerable. For instance, animals may find their way onto these roads when attempting to cross through the continuous concrete wall and become trapped since they cannot readily find egress. Eventually the animals die when hit by a vehicle or safely return to the roadway's shoulder and surrounding vegetation. To alleviate the frequency of these animal-to-vehicle collisions on roadways with solid barriers, an alteration to the current barrier design may prove fruitful. It should be noted that traffic engineers would likely prefer to eliminate the presence of animals from the roadway altogether through the construction of fences parallel to the road. Although a valid solution, the cost (initial construction and on-going maintenance) may prove to be burdensome for the responsible agencies.

Current roadway barriers attempt to protect motorists from deadly head on vehicular collisions. While guarding drivers and passengers from these accidents, it also creates an obstacle that animals cannot likely overcome due to their lower cognitive abilities. An altered barrier design could maintain vehicle safety and offer safe passage for many animals on the roadway. One such traffic device reimaging exercise yields an intelligent Jersey style barrier (an ordinary Jersey barrier has been shown in Figure 4.2b), named the Clemson smart portal (CSP) with the general concept displayed in Figure 4.1. This barrier may be implemented as a divider between traffic flow and simultaneously allow animal egress across the roadway through the small oval opening at the base. These barriers may be placed at approximately half mile intervals along the highway. In addition, the barrier will alert drivers to an animal's passage by visual notification using flashing lamps; the light color can be selected using tinted hard plastic lens based on the traffic engineer's preference. The system functionality also facilitates the observation of the animal types utilizing the portal, the number of animal crossings, and the roadway conditions. Finally, signs would need to be erected at the start of the given road section to alert drivers to the barriers and potential animal crossings.

The remainder of this paper is organized as follows. Section 2 discusses the types of roadway barriers currently in use throughout North America. Section 3 presents the overall design concept for the smart barrier including structural and electrical issues. Schematics are introduced for the geometric dimensions and self-contained electronics package. Section 4 contains a case study in which laboratory tests have been conducted using small animals to demonstrate the concept. Finally, Section 5 contains the conclusion.

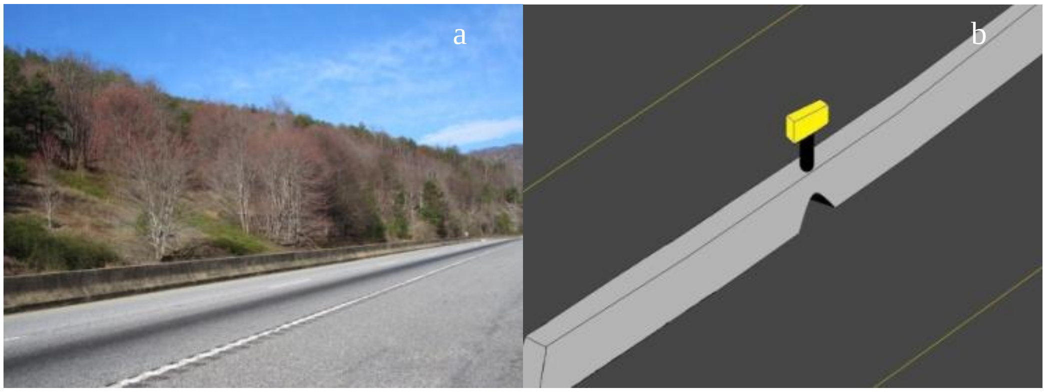

Figure 4.1: (a) Rural roadway with Jersey barrier, and (b) Clemson University smart portal concept

4.1 Types of Highway Barriers for Traffic and Animals

Traffic barriers should be targeted to the intended application with the engineering objectives ranging from protecting passenger and commercial vehicles from opposing traffic to ideally allowing animals safe passage. There are multiple barrier types including guard rails, Jersey barriers, Fitch barriers, and cable guards as shown in 4.2. These traffic devices can be found throughout major and secondary roadways with varying frequencies in the United States. This section will review highway and animal barriers.

4.1.1 Traffic Barriers

Guard rails, shown in 4.2a, are metal rails, connected by wooden or metal posts to the ground, located along the edge of the road (e.g., Safe Zone, 2012). This barrier type redirects a vehicle back onto the roadway if a car or truck comes into contact with it. The rails are usually designed to absorb some impact energy through deformation which often “mangles” the original metal shape. However, standard guard rails may be too low in height to effectively accommodate collisions with larger vehicles. A European reimagining of the guard rail has been proposed to address collisions of both regular and large sized vehicles (MAXI-RAIL, 2012). This guard rail design has been designated as a “Super Rail” due to its larger than normal size. Jersey barriers, shown in Figure 4.2b, are much like a wall, typically made of steel reinforced concrete, and act as a traffic divider (ACI, 2012). A Jersey barrier’s structure limits a vehicle’s lateral movement to minimize damage to the vehicle itself and prevent traffic cross-overs. The innovative smart barrier is a modified version of a Jersey barrier.

Fitch barriers are plastic barrels filled with either water or sand as shown in Figure 4.2c (Enterprise Flasher, 2012). They are organized with increasing sand/water volumes so that the smallest volume barrel is positioned in the anticipated direction of the collision. Accordingly, drivers would initially experience a lower resistance force upon collision as the first barrier fails due to impact. The vehicle’s energy is partially dissipated by the given barrel rupturing and releasing its contents. The subsequent barrels that the driver then contacts will contain higher volumes of sand/water than the previous ones allowing for more energy to be dissipated. This roadway safety approach produces a lower initial resistance, which helps to reduce/prevent injuries to the occupants, which then gradually offers greater resistance until the vehicle has come to a complete stop. Cable guards, shown in Figure 4.2d, utilize steel cables held in place by metal posts to prevent or alleviate traffic cross-overs (MDOT, 2012). The cables' residual tension absorbs a car's energy thereby either significantly reducing the speed and/or stopping the vehicle.

Figure 4.2: Roadway barriers in the United States: (a) guard rail (TLJE, 2012), (b) Jersey barrier (ACI, 2012), (c) Fitch barrier (Enterprise Flasher, 2012), and (d) cable guard (MDOT, 2012)

4.1.2 Animal Barriers

In recent years, social awareness has increased regarding animal fatalities due to animal-to-vehicle collisions. Although the erection of animal barriers (e.g., fences) may prevent animals from entering roadways, these barriers have not fully solved the problem as animals still attempt highway crossings to traverse their territory. Recent attention has been directed towards producing better solutions for barriers that enable wildlife safe passage across roadways either by directing animal traffic underneath or over the roads.

Noro *et al* (2012) discussed a variety of issues regarding animal-to-vehicle accidents. Some of the available solutions for animal friendly barriers include wildlife underpasses, wildlife overpasses, and culverts. Daniels (2012) created an adjustable alley for large animals such as cattle. Dahlin *et al.* (2002) developed a series of magnetic articles to influence the path of moving objects, including animals. Van Liere (2012) proposed an intelligent actuated gate for animal traffic. Perlo *et al.* (2006) developed a driver warning system that alerts motorists to the presence of nearby animals. Gzybowski (1999) proposed to alter Jersey barriers by creating a small passageway through the barrier. This passageway could be used for small animals to find egress from traffic flow, but contains no warning system to alert drivers to their presence. The barrier redesign in this paper calls for a similar gateway, but contains an intelligent animal detection system to alert drivers. Finally, Cavallaro *et al.* (2005) developed a set of guidelines and principles for implementing animal barriers in Ventura County, California, which are most commonly animal underpasses.

Complying with constraints regarding vehicle safety, mitigating animal danger may lead to wildlife being redirected under traffic flow by installation of wildlife underpasses. The Canadian Wildlife Park underpass, presented in Figure 4.3a, provides an example of an effective application of these barriers in controlling animal travel around highways (CPWS, 2012). The animal migratory paths are detoured underneath the existing highway by the erection of fencing along the trails' borders. Another successful implementation of a wildlife underpass is The Lake Jackson Ecopassage in Florida (TLJE,2012). This location has erected a wall that prevents small animals from traveling onto the road and forces them to use an open path leading under the flow of traffic. Figure 4.3b displays the Payne's Prairie Ecopassage wildlife underpass (USGS, 2012). All three wildlife underpass examples have proven the design to be plausible.

When it is not possible to divert animal travel underneath existing transportation infrastructure, it may be acceptable to provide an animal-only conduit by employing a wildlife overpass or a covert. A wildlife overpass serves the same functionality as a wildlife underpass, but directs animals above vehicular traffic by application of an overhead pathway. Figure 4.3c illustrates an implementation of the wildlife overpass using a tunnel like structure for vehicular travel and backfill for animal travel to bypass the road. The US Highway 93 wildlife overpass (Wells, Nevada) completed in Summer 2010 has shown that while this approach can prove costly it can be effective in offering animals with an alternate path (Elko Daily, 2012). If cost is a primary constraint, then wildlife culverts may be considered. For example, a drainage duct typifies a culvert's multi-functional potential as it channels water runoff and simultaneously provides a route for animal travel. The Parks of Canada have begun in recent years to apply wildlife culverts, among other infrastructures, in hopes of reducing wildlife-to-vehicle collisions and improving vehicle safety (Parks Canada, 2012).

All of these infrastructures are typically located in remote locations, or along roadways, that cut through heavy animal migratory paths and/or animal colonies.

Figure 4.3: Samples of dedicated animal passages for roadways: (a) wildlife underpass (CPWS, 2012), (b) Payne prairie ecopassage (TLJE, 2012), (c) wildlife overpass (FHWA, 2012), and (d) wildlife culvert (Parks Canada, 2012)

4.2 Clemson Smart Portal

Current Jersey class barriers address the two objectives of minimizing damage to lateral vehicles upon contact and preventing traffic cross-overs. However, these roadway structures fail to address the problem of animal-to-vehicle collisions due to wildlife entering the roadway and becoming trapped. In other words, a common complication of the Jersey class barrier is the potential for animals to become stranded on roadways, but with a structural modification a small portal offers animal egress from traffic. The Clemson smart portal also features electronics to notify motorist of animal passage. Coupling a passive infrared sensor (PIR) to a flashing light system notifies drivers of an animal traveling through the portal. Figure 4.4 shows the conceptualized CSP and the prototype used during laboratory testing. The remainder of this section will expand on the structural and electronic designs.

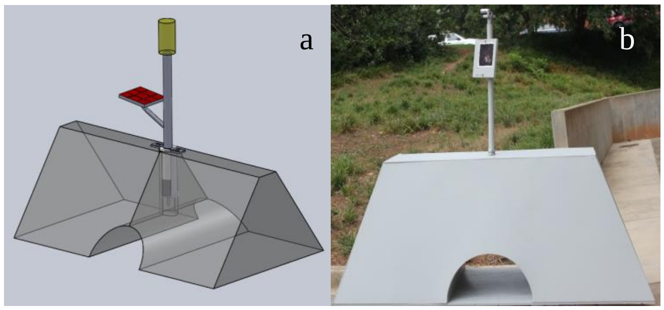

Figure 4.4: Clemson smart portal highway barrier - (a) concept, and (b) laboratory prototype

4.2.1 Structural Design

Jersey barriers are typically manufactured using concrete with steel reinforced bars. Existing Jersey barriers can be retrofitted by cutting openings for the electronics package (vertical) and the passageway (horizontal). For new Jersey barriers, they may be created to accommodate both the structural requirements and the animal portal with the vertical access hole for the electronic package as shown in Figure 4.5. For proper implementation of the proposed barrier, portals should be placed approximately every half mile at designated stretches of the roadway to allow the animals multiple crossings locations. Signage should be erected to notify drivers of the smart barriers.

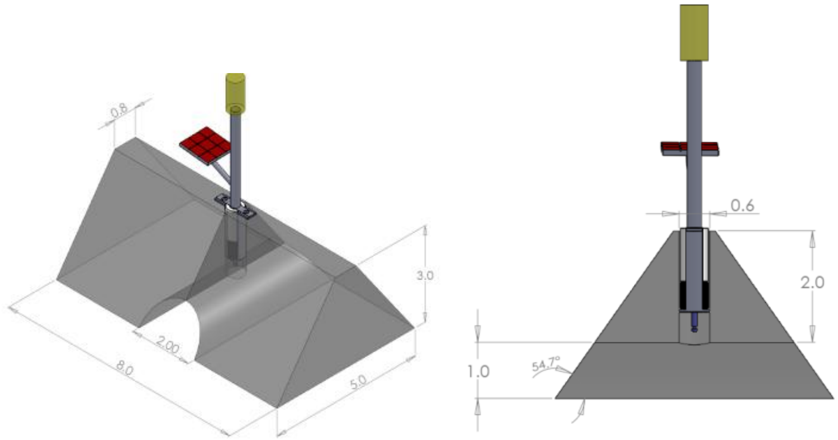

Figure 4.5: Smart portal with physical dimensions (feet)

4.2.2 Electronics Package Design

The integrated electrical system consists of a passive infrared motion sensor to detect animal activity through the passageway, a strobe light acting as a visual notification to drivers, cameras to identify the number and types of animals using the passage, and thermal sensors to identify road conditions such as air temperature, presence of water, and ice. The advantage of applying a PIR motion sensor is its response to naturally emitted black body radiation from a live entity which naturally filters out non-living body motion. This functionality will help to prevent false warnings in the portal. These components are powered by a 12VDC rechargeable battery and integrated with a solar panel for an operational regenerative energy source. There are two parts to the electronic stack: lower and upper components. The lower section was placed inside the smart barrier giving it some protection from the environment. The upper partition rises out of the aperture but only exposes the strobe light and solar cell for maximized position for visibility. A dedicated appendage orients the solar cells to enable a proper angle for radiation absorption.

The electrical system detects animal crossings through the passage with the integrated PIR sensor. An animal traversing the pathway produces a PIR signal supplied to a relay resulting in power to operate the strobe light. The strobe lights will flash for a predetermined length of time to alert drivers to the animal's presence. Figure 4.6 presents the electrical circuit which operates the driver notification system. While this method provides driver's a means to avoid animal-to-vehicle collisions, the functionality of the CSP can be expanded to include an observational tool. Installing an optical camera in the electrical packaging allows images and video of animals traversing the portal to be recorded. The optical camera can be programmed to determine the animal types and time periods. After the imagery has been recorded, the electronics will "call home" to deliver the data. This creates an opportunity to observe wildlife movements, migratory trails, the number of animals using the barrier, etc. However, observation is not limited to animals but also can be used to analyze roadway conditions. For example, roadway conditions including, but not limited to, air temperature, standing and flowing water, and ice may be observable. A thermal sensor enables the camera to distinguish between water and ice, as well as discern air temperature. The integration of these functionalities is presented in Figure 4.7, which outlines the entire system configuration of the smart barrier. While these components comprise the upgraded barrier's functionality, security components must also be present to guard against tampering.

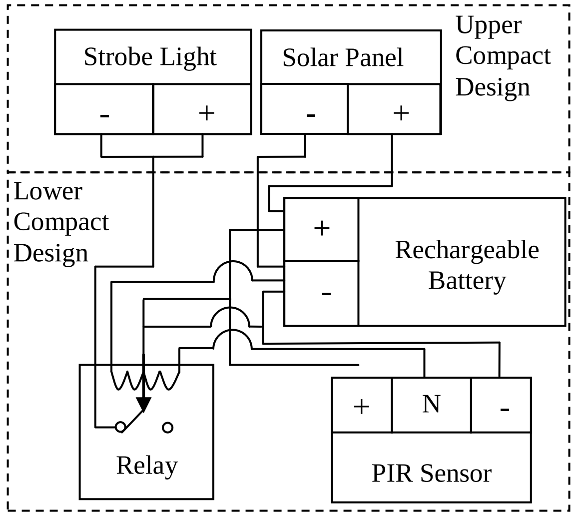

Figure 4.6: Electrical circuit for smart barrier featuring solar panel, rechargeable battery, electrical relay, strobe light, and passive infrared (PIR) sensor

4.3 Case Study: Laboratory Demonstration with Small Animals

To validate the concept of the smart portal, controlled laboratory experiments were performed at Clemson University in the Godfrey-Snell Research Facility. Prior to testing, IRB/IACUC approval was obtained to utilize the on-site small animals. The testing process was performed in an enclosed laboratory environment using the prototype shown in Figure 4.4b which was placed into the controlled setting. Three felines were released to interact with the apparatus; the testing rubric in Table 4.1 summarizes the crucial animal interactions to assess the effectiveness of the smart barrier.

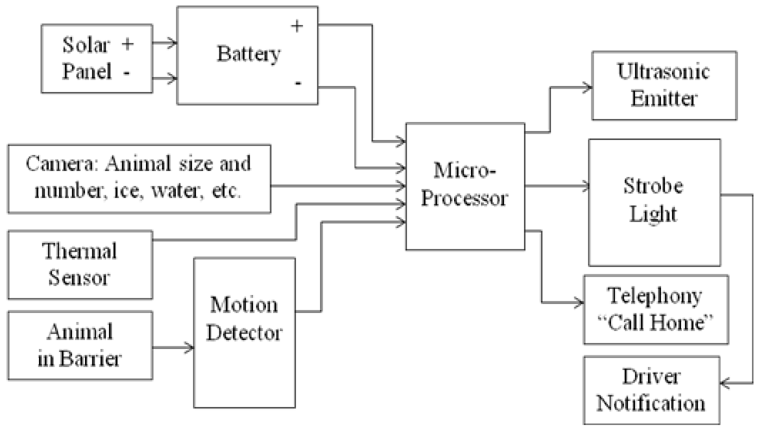

Figure 4.7: System configuration diagram for smart barrier outlining full functionality

During laboratory tests, the smart portal was successful in the detection of animals crossing through the opening in single and parallel manners (Test #1 and #2). Figure 4.8 presents one instance of two animals simultaneously travelling through the portal, with the system recognizing both animals' actions per Test #2. In contrast, Test #3 required an animal to walk along the side of the barrier without entering the portal. Although the animals repeated this action throughout the laboratory event, the prototype smart barrier operated properly by not recognizing their movements as reported by the failure of Test #3. It should be noted that the PIR sensor operates with a conical field of view and given its installation in the aperture, it functions with a limited field of view. The sensor could only sense animals after their entry into the passageway which is ideal since traffic passing by a roadway should not trigger the lights. Overall, by empowering animals with a means of egress from roadway conditions and providing a driver notification system, this redesign may prove to reduce animal-to-vehicle collisions.

Table 4.1: Summary of Clemson portal laboratory demonstration with animal subjects

Test No.	Description of Test	Detection	
		Pass	Fail
1	One Animal Crossing Through Portal	X	
2	Two Animals Crossing (series, parallel) Through Portal	X	
3	Animal Walking Along Side Barrier		X

4.4 Conclusion

An intelligent Jersey barrier called the Clemson Smart Portal has been presented and discussed in this paper. The smart barrier consists of a passage for small animals to utilize for egress across roadways with continuous center traffic dividers. Animals traveling through the opening are detected by a PIR motion sensor which triggers an electrical circuit to flash a strobe light that notifies drivers to the animals' presence. Through utilization of an optical camera as well as a thermal sensor, the electronics could observe the types and numbers of animals using the passage, along with identifying real time roadway conditions. A prototype was successfully demonstrated in a controlled laboratory environment using small animals. The results clearly show the ability to recognize animal movements and notifying observers to those actions. The next step will be a field study to evaluate the impact with wildlife.


Figure 4.8: Animals passing through the smart barrier portal during laboratory testing

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The safety of roadways can be improved throughout the world with attention to vehicle design, highway infrastructure standards, and driver training. Every year approximately 26,000 motorists are affected by animal to vehicle collisions, with an additional 200 human fatalities as a result of these events (Berk, 2011). Concurrently, the annual injury rate in the United States is approximately 100,000 drivers, not including the approximate 40,000 deaths attributed to vehicular crashes (FARS, 2012). Research on driver training and roadway barriers offers viable solutions to assuage these societal epidemics. The next generation driver education program has shown a dramatic increase in training young drivers to safely operate a motor vehicle. Similarly, the Clemson Smart Portal can lead to a reduction in the number of wildlife to vehicle collisions.

5.1 Driver Training and Evaluation

A safe driving program which integrates lecture based tent modules with behind the wheel experiences of in-vehicle modules has been developed by CUASRI and RPDE and introduced over the 2010 and 2011 calendar years to prepare young motorists for safe driving. General knowledge detailing the maintenance and operation of a motor driven vehicle is presented to students during the tent modules. Participants are also informed to the importance which proper attitude has when operating an automotive vehicle. In-vehicle modules place students in four different driving scenarios, allowing students an opportunity to experience the dynamics of these driving events while within a safe and controlled environment. In-vehicle instructors accompany the participants for the full program while simultaneously acting as coaches that provide feedback on performance.

The safe driving capabilities of 661 students from 26 safe driving classes were considered in a case study focusing on the safe driving program's effectiveness. These students were found to have an average overall score of 78.2% through the four driving modules which correlates to a nearly proficient safe driving level. Students were able to display a positive trend from instructor evaluations as they progressed to each in-vehicle module. Also, participants typically saw a noticeable increase between their pre- and post-test scores, showing a developing comprehension for safe driving knowledge upon program completion. The safe driving program's effectiveness is strongly confirmed by the nearly proficient evaluation of the sampled classes and the substantial increase in knowledge relative to the beginning and conclusion of the program.

5.2 Smart Jersey Barrier

A new design iteration of Jersey class highway barriers, which consists of an integrated electronics package and animal pathway for egress, has been proposed. The design incorporates a protected path through the base of the barrier, intended to empower animals to escape traffic flow. This protected path would hopeful reduce the likelihood of a wildlife-to-vehicle collision (WVC). Additionally, an electronics package has been integrated as a means to alert drivers to animal actions and provide a renewable energy source. As vertebrates make use of the given pathway, a passive infrared sensor enables power flow to a strobe light. The strobe light alerts oncoming traffic in both directions to the presence of an animal within the passage. An incorporated solar panel coupled to a rechargeable battery provides a renewable power system.

Laboratory testing has proven the functionality of the Clemson Smart Portal's design. However, testing was limited to a controlled environment where no vehicular interactions or environmental factors could be integrated. Future work would necessitate a smart portal prototype applied to a field study. This field test would exemplify the portal's capability of recognizing wildlife actions while simultaneously notifying motorists throughout various real world conditions. Concurrently, animal willingness to engage with the smart portal passage could be observed during the application. Finally, the prototype employed during the study would need to be made from concrete with steel rebar. This material would guarantee structural integrity if hit by a vehicle or other large object.

5.3 Recommendations for Future Research

Although the effectiveness of the safe driving program and the smart Jersey barrier has been demonstrated, future endeavors could be undertaken to further this research. Suggestions for future work regarding these topics are presented below in tabular form.

- In-Vehicle Data Collection: Further driver assessment could be gained by integrating objective in-vehicle data to the evaluation methodology. Applying electronically recorded vehicular parameters would enable the evaluation process to encompass parameters previously unobtainable. Incorporation of these additional factors would require the application of on-board data acquisition (DAQ) units for each student vehicle.

- Unique Instantaneous Feedback and Reports for Students: Instantaneous feedback should be available to students during their in-vehicle experience of the program. The availability of this information would allow participants to receive immediate feedback detailing their driving performance. Also, the information could be integrated into a template that would allow reports tailored to each student's operating capabilities and driving knowledge.

- Accreditation of Insurance Providers and Government Agencies: Government and automotive insurance accreditation should be sought to reinforce the presence of the safe driving program through professional and peer validation. Automotive insurer support would help convince parents and young drivers that the safe driving program is an investment by insurance rate reductions. Government accreditation would reinforce the authenticity of the safe driving program, and could be used to supplement current licensing processes.

- Expansion of Design Functionality: Supplemental sensors could be applied to expand the barrier's functionality to encompass additional operations. This could include video cameras, thermal sensors, and ultrasonic sensors. Coupling these sensors with internet functionality would enable each applied barrier to serve as a localized observation station for ambient roadway conditions respective to each apparatus's surroundings

- Field Study: A Clemson Smart Portal unit should then be implemented for a field study as a means of validating the design during real world events and settings. A field study would enable the intelligent Jersey barrier to be tested in environment consisting of varying vehicular traffic flow, precipitation, and potential collision. Observing operation in a dynamic ambience would present the smart barrier's strengths and where reinforcement in the design could be necessary.

- Structural Review for Crash Worthiness: The structural design of the smart portal should be reiterated according to the structural standardization of Jersey barriers. This would enable each smart Jersey barrier to protect motorists in the same manner as current Jersey barriers while simultaneously providing animals egress, alerting drivers, and serving any extended functionalities.

APPENDICES

Appendix A

Pre and Post Test Questions in Safe Driving Program

Question 1: When preparing to stop on dry pavement, I should allow how many seconds (at least) between my car and an object in front of me (like another car) to permit a safe stop?

a) 5 seconds

b) 75 seconds

c) 1 second

d) 3 Seconds

Question 2: When driving in the rain, it is best to…

a) Drive safely & maintain posted speed limits

b) Increase following distances by at least a second

c) Increase speed & be prepared for hard braking

d) Slow down & put your hazard lights on

Question 3: Which car will need the greater amount of distance to stop?

a) A lighter car, such as a Toyota Camry

b) A heavier car, such as a Hummer

c) A longer car, such as a Ford Taurus

d) All vehicles will stop in the same distance, regardless of weight or length

Question 4: Always inflate the tire to the air pressure specifications listed on the …

a) Door jamb label

b) Spare tire

c) Tire sidewall

d) Tire jack instructions

Question 5: If only 2 tires are replaced on your vehicle at a time, it is best to…

a) Mount them in the front

b) Mount them on the front & rear of either the driver's or passenger's side

c) Mount them in the rear

d) Mount them diagonally on the front & rear

Question 6: In what driving condition is my personal reaction time most vital for my safety?

a) Wet or slick roads

b) Icy or snowy pavement

c) Heavy traffic conditions

d) All of the above

Question 7: What is the single most effective safety system in your vehicle?

a) Anti-Lock Braking System

b) Safety Belt System

c) Electronic Control System

d) Traction Control System

Question 8: What is the average time for an alert driver to recognize and react to a dangerous situation?

a) Less than 1 second

b) 1 to 1.49 seconds

c) 1.5 to 2 seconds

d) 2.5 to 3 seconds

Question 9: To avoid a tailgating situation while driving, a safe headway is defined as …

a) A 1 second gap between the vehicle in front & your front bumper

b) A 2 second gap between the vehicle in front & your front bumper

c) A 3 second gap between the vehicle in front & your front bumper

d) A 4 second gap between the vehicle in front & your front bumper

Question 10: The "pile up" effect is most likely caused by:

a) Driving in wet conditions while using a safe following distance

b) Driving with underinflated tires

c) Driving through a work zone after hours

d) A driver watching only the vehicle directly ahead

Question 11: Speed and distance are related to stopping distance in what way?

a) As speed doubles, braking distance does not double (not 1:1 relationship)

b) As speed doubles, braking distance increases in the same proportion (an exact 1:1 relationship)

c) As speed doubles, braking distance more than doubles (not 1:1 relationship)

d) Speed and distance are not directly related

Question 12: One of the most important ways to prevent a loss of control situation is to

a) Steer away from hazards

b) Anticipate hazards before they occur

c) Brake to avoid hazards

d) Maintain posted speed limits

Question 13: To begin correcting a vehicle in a front wheel skid, one thing you should do is

a) Lightly apply the brakes

b) Lightly apply the gas pedal to increase speed,

c) Turn in the direction you want the vehicle to go

d) Apply hard braking

Question 14: To begin correcting a vehicle in a rear wheel skid, one thing you should do is

a) Apply hard braking

b) Turn into the skid

c) Let off the brake / gas pedals

d) Lightly apply the brakes

Appendix B

Objective Evaluation Metrics and Subjective Rubrics

Table B.1: Objective evaluation for the Braking Module; symbol "+" denotes OR logic operation

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Reaction Time (sec)	2	$t_r \le 1.5$	$1.5 < t_r \le 2$	$2 < t_r \le 2.5$	$2.5 < t_r \le 3$	$3 < t_r \le 3.5$	$3.5 \le t_r$	
2	Stopping Distance (m)	4	$x \le .7x_{stop}$	$.7x_{stop} < x \le .75x_{stop}$	$.75x_{stop} < x \le .80x_{stop}$	$.80x_{stop} < x \le .90x_{stop}$	$.90x_{stop} < x \le x_{stop}$	$x > x_{stop}$	
3	Peak Deceleration (g)	8	$a_p \le .70$	$.70 < a_p \le .60$	$.60 < a_p \le .50$	$.50 < a_p \le .40$	$.40 < a_p \le .30$	$a_p < .30$	
4	Yaw Angle (^{o})	2	$\|\Psi\|<1$	$1<\|\Psi\|<1.5$	$1.5<\|\Psi\|<2$	$2<\|\Psi\|<2.5$	$2.5<\|\Psi\|<3$	$3<\|\Psi\|$	
5	Speed (mph)	4	$34<v$ + $v<37$	$32 \le v<34$ + $37 \le v<38$	$30 \le v<32$ + $38 \le v<39$	$28 \le v<30$ + $39 \le v<40$	$26 \le v<28$ + $40 \le v<41$	$v<26$ + $41 \le v$	
								Score	

Table B.2: Objective evaluation for the Obstacle Avoidance Module; symbol "+" denotes OR logic operation

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Reaction Time (s)	6	$t_r \le 1.5$	$1.5 < t_r \le 2$	$2 < t_r \le 2.5$	$2.5 < t_r \le 3$	$3 < t_r \le 3.5$	$t_r \ge 3.5$	
2	Speed during return pass (mph)	3	$34<v$ + $v<37$	$32 \le v<34$ + $37 \le v<38$	$30 \le v<32$ + $38 \le v<39$	$28 \le v<30$ + $39 \le v<40$	$26 \le v<28$ + $40 \le v<41$	$v<26$ + $41 \le v$	
3	Speed during through pass (mph)	3	$34<v$ + $v<37$	$32 \le v<34$ + $37 \le v<38$	$30 \le v<32$ + $38 \le v<39$	$28 \le v<30$ + $39 \le v<40$	$26 \le v<28$ + $40 \le v<41$	$v<26$ + $41 \le v$	
4	Yaw Angle (^{o})	5	$\|\Psi\|<5$	$5<\|\Psi\|<10$	$10<\|\Psi\|<15$	$15<\|\Psi\|<20^o$	$20<\|\Psi\|<25$	$25<\|\Psi\|$	
5	Speed at lane split (mph)	3	$15.5 \le v$+ $v<16$	$15.0 \le v<15.5$ + $16 \le v<17$	$13 \le v<15$ + $17 \le v<19$	$11 \le v<13$ + $19 \le v<21$	$9 \le v<11$ + $21 \le v<23$	$v<9$ + $23 \le v$	
								Score	

Table B.3: Objective evaluation for the Tailgating Module; symbol "+" denotes OR logic operation

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Reaction Time (sec)	4	$t_r \le 1.5$	$1.5 < t_r \le 2$	$2 < t_r \le 2.5$	$2.5 < t_r \le 3$	$3 < t_r \le 3.5$	$3.5 < t_r$	
2	Headway before braking (ft)	8	$34 \le x$ + $12 < x$	$29 \le x < 34$ + $39 \le x < 44$	$24 \le x < 29$ + $44 \le x < 49$	$20 \le x < 24$ + $44 \le x < 54$	$10 \le x < 19$ + $54 \le x < 65$	$10 < x$ + $x \le 65$	
3	Speed before braking (mph)	2	$34 < v$ + $v < 37$	$32 \le v < 34$ + $37 \le v < 38$	$30 \le v < 32$ + $38 \le v < 39$	$28 \le v < 30$ + $39 \le v < 40$	$26 \le v < 28$ + $40 \le v < 41$	$v < 26$ + $41 \le v$	
4	Stopping Distance (ft)	2	$34 \le x$ + $12 < x$	$29 \le x < 34$ + $39 \le x < 44$	$24 \le x < 29$ + $44 \le x < 49$	$20 \le x < 24$ + $44 \le x < 54$	$10 \le x < 19$ + $54 \le x < 65$	$10 < x$ + $x \le 65$	
5	Braking Time (sec)	2	$x < 3$ + $3.2 \le x$	$3.2 \le x$ + $3.4 < x$	$3.4 \le x$ + $3.6 < x$	$3.6 \le x$ + $3.8 < x$	$3.8 \le x$ + $4.0 < x$	$4.0 \le x$ + $4.2 \le x$	
6	Vehicle Deceleration (g)	2	$a_p \le .70$	$.70 < a_p \le .60$	$.60 < a_p \le .50$	$.50 < a_p \le .40$	$.40 < a_p \le .30$	$a_p < .30$	
								Score	

Table B.4: Objective evaluation for the Loss of Control Module; symbol "+" denotes OR logic operation

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Deceleration in Corners (g)	5	$(a_{pi}-a_{pj}) \le .7$	$.7 \le (a_{pi}-a_{pj}) \le .75$	$.75 \le (a_{pi}-a_{pj}) \le .80$	$.80 \le (a_{pi}-a_{pj}) \le .85$	$.85 \le (a_{pi}-a_{pj}) \le .90$	$.90 \le (a_{pi}-a_{pj})$	
2	Acceleration out of Corners (g)	5	$(a_{pi}-a_{pj}) \le .7$	$.7 \le (a_{pi}-a_{pj}) \le .75$	$.75 \le (a_{pi}-a_{pj}) \le .80$	$.80 \le (a_{pi}-a_{pj}) \le .85$	$.85 \le (a_{pi}-a_{pj}) \le .90$	$.90 \le (a_{pi}-a_{pj})$	
3	Speed (mph)	5	$34 < v$ + $v < 37$	$32 \le v < 34$ + $37 \le v < 38$	$30 \le v < 32$ + $38 \le v < 39$	$28 \le v < 30$ + $39 \le v < 40$	$26 \le v < 28$+ $40 \le v < 41$	$v < 26$ + $41 \le v$	
4	Yaw Angle (^{o})	5	$\|\Psi\| < 45$	$45 < \|\Psi\| < 55$	$55 < \|\Psi\| < 65$	$65 < \|\Psi\| < 75$	$75 < \|\Psi\| < 90$	$90 < \|\Psi\|$	
								Score	

Table B.5: Subjective in-vehicle instructor evaluation for the Braking Module

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Trap Speed (mph)	2	Maintained a trap velocity of 34 to 35 mph	-	Maintained a trap velocity of no less than 33 and up to 34 mph or no less than 35 and up to 37 mph	-	Maintained a trap velocity of no less than 32 and up to 33 mph or no less than 35 and up to 37 mph	Maintained a trap velocity less than 32 or greater than 39 mph	
2	Distance from Stop Strip (ft)	8	Stopped within 0 to 5 feet of strip	Stopped within 5 to 10 feet of strip	Stopped within 10 to 25 feet of strip	-	-	Stopped farther than 25 feet from strip	
3	Stopped Before/After Strip	4	Before	-	-	-	-	After	
4	Anticipated Maneuver	2	No	-	-	-	-	Yes	
5	SWS Technique	4	Yes	-	-	-	-	No	
								Score	

Table B.6: Subjective in-vehicle instructor evaluation for Obstacle Avoidance Module

+

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Trap Speed (mph)	2	Maintained a trap velocity of 34 to 35 mph	-	Maintained a trap velocity of no less than 33 and up to 34 mph or no less than 35 and up to 37 mph	-	Maintained a trap velocity of no less than 32 and up to 33 mph or no less than 35 and up to 37 mph	Maintained a trap velocity less than 32 or greater than 39 mph	
2	Correct Lane	8	Yes	-	-	-	-	No	
3	Correct Car Position	4	Yes	-	-	-	-	No	
4	Anticipated Maneuver	2	No	-	-	-	-	Yes	
5	Correct Braking Technique Used	4	Yes	-	-	-	-	No	
								Score	

Table B.7: Subjective in-vehicle instructor evaluation for the Tailgating Module

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Proper Acceleration	2	Correct	-	-	-	-	Too Slow + Too Fast	
2	Distance from Rig (ft)	8	Stopped within 5 to 10 feet of rig	Stopped within 0 to 5 feet or 11 to 25 feet of rig	Stopped farther than 25 feet from rig	-	-	Hit Rig	
3	Proper Headway	2	Yes	-	-	-	-	No	
4	Anticipated Maneuver	2	No	-	-	-	-	Yes	
5	Constant Speed Reached	2	Yes	-	-	-	-	No	
6	Correct Braking Technique Used	4	Yes	-	-	-	-	No	
								Score	

Table B.8: Subjective in-vehicle instructor evaluation for the Loss of Control Module

No.	Criteria	Weight	Scores & Attributes						Subtotal
	Title		5	4	3	2	1	0	
1	Trap Speed (mph)	1	Maintained a trap velocity of 34 to 35 mph	-	Maintained a trap velocity of no less than 33 and up to 34 mph or no less than 35 and up to 37 mph	-	Maintained a trap velocity of no less than 32 and up to 33 mph or no less than 35 and up to 37 mph	Maintained a trap velocity less than 32 or greater than 39 mph	
2	Proper Position on Course	4	Yes	-	-	-	-	No	
3	Adequate Speed	1	Yes	-	-	-	-	No	
4	Correct Technique Used	4	Yes	-	-	-	-	No	
5	Anticipated Maneuver	2	No	-	-	-	-	Yes	
6	Recognition of FWS	2	Yes	-	-	-	-	No	
7	Recognition of RWS	2	Yes	-	-	-	-	No	
8	Correct Line of Sight	4	Yes	-	-	-	-	No	
								Score	

Table B.9: Final score for safe driving program

Source	Objective Score	Subjective Score	Subtotal
Pre-Test	-	-	
Braking Module			
Obstacle Avoidance Module			
Tailgating Module			
Loss of Control Module			
Post Test	-	-	
		Score	

Appendix C

Sample of Matlab Analytical Code for In-Vehicle Tailgating Module Assessment

```
%Section 1-    Extracting Measurable Parameters from data file



%Car Time Stamp
timec=xlsread('ReationTimeLJC171134v42.xlsx','A2:A312');

%Truck Time Stamp
timet=xlsread('ReactionTime170835for171134v42.xlsx','A2:A312');

%Car Velocity
carspeed=xlsread('ReationTimeLJC171134v42.xlsx','H2:H312')*2.24;

%Truck Velocity
truckspeed=xlsread('ReactionTime170835for171134v42.xlsx','H2:H312')*2.24;

%Headway Distance Between Car and Truck
headway=xlsread('ReationTimeLJC171134v42.xlsx','M2:M312');

%Headway Time Between Car and Truck from start, a, to first stop, b
headwaytab=xlsread('ReationTimeLJC171134v42.xlsx','N2:N146');

%Headway Time Between Car and Truck from first stop, b, to second stop, c
headwaytbc=xlsread('ReationTimeLJC171134v42.xlsx','N188:N301');

%Car Acceleration
caraccel=xlsread('ReationTimeLJC171134v42.xlsx','I2:I312')/(.3048*32.2);

%Truck Acceleration
truckaccel=xlsread('ReactionTime170835for171134v42.xlsx','I2:I312')/(.3048*32.2);

%Car Braking Rate
carbraking=xlsread('ReationTimeLJC171134v42.xlsx','J2:J312');

%Truck Braking Rate
truckbraking=xlsread('ReactionTime170835for171134v42.xlsx','J2:J312');
```

```
%Section 2-    Calculating Unmeasured Vehicular Parameters



%Next Two Lines Find Indexes of Braking Instances in Data Array
ind1=find(carbraking);
ind2=find(truckbraking);

%Calculating Relative Time Stamps to DAQ's Universal Time Stamp
time2c=timec-1267377245;
time2t=timet-1267377245;

%Subtracting Additional Distance so Headway is Only Between Front of Car
%and Rear of Truck
headway2=headway-4.42;

%Speed Difference Between the Car and Truck
speed=truckspeed-carspeed;



%Section 3-    Generating Graphs of Vehicular Data



%plot data

figure
subplot(3,4,1)
plot(time2c,headway2,28,0:.1:40,time2c(ind1(1)),0:.1:40);
text(28.5,25,'C'),text(time2c(ind1(1))+.5,25,'B');
xlabel('Time (s)');
ylabel('Headway (m)');
[ax,h]=plotyy(time2c,carspeed,time2c,headway2)
title('Speed and Headway of Tailgating');
xlabel('Time (s)');
ylabel(ax(1),'Speed Difference (m/s)');
ylabel(ax(2),'Headway (m)');

subplot(3,4,2)
plot(time2c,carspeed,15.5,0:.1:40,31,0:.1:40)
text(16.5,15,'B'),text(32,15,'C');
grid on
title('Speed of Car');
```

```
xlabel('Time (s)');
ylabel('Speed (m/s)');


subplot(3,4,3)
plot(time2c,caraccel,15.5,0:.01:1,31,0:.01:1)
text(16.5,.3,'B'),text(32,.3,'C');
grid on
title('Car Acceleration');
xlabel('Time (s)');
ylabel('Acceleration (m/s^2');

subplot(3,4,4)
plot(time2t,truckspeed,15.5,0:.1:40,31,0:.1:40)
text(16.5,15,'B'),text(32,15,'C');
grid on
title('Speed of Truck');
xlabel('Time (s)');
ylabel('Speed (m/s)');

subplot(3,4,5)
plot(time2c(1:1:145),headwaytab,15.5,0:.1:10,31,0:.1:10)
text(16.5,5,'B'),text(32,5,'C');
grid on
title('Headway Time Between A and B');
xlabel('Time (s)');
ylabel('Headway (s)');

subplot(3,4,6)
plot(time2c(188:1:301),headwaytbc,15.5,0:.1:10,31,0:.1:10)
text(16.5,5,'B'),text(32,5,'C');
grid on
title('Headway Time Between B and C');
xlabel('Time (s)');
ylabel('Headway (s)');

subplot(3,4,7)
plot(time2c,speed,15.5,0:.1:20,31,0:.1:20)
text(16.5,7.5,'B'),text(32,7.5,'C');
grid on
title('Speed Difference');
xlabel('Time (s)');
ylabel('Speed (m/s)');
```

```
%Section 4-    Evaluating Driver Performance



%Evaluating Headway Distance
%Array Length
for i=1:1:length(time2c)-1;

%Integrating Headway Distance
HeadwayInt(i)=(time2c(i+1)-time2c(i))*((headway2(i)+headway2(i+1)+14.5*2)/2);
p(i)=sum(HeadwayInt);
p(i+1)=p(i);
end

%Calculated Headway Parameter to Be Scored
I=sum(p)


%Evaluating Student Speed Relative to Truck
%Array Length
for s=1:1:length(carspeed)-1;

%Integrating Carspeed
ComparitiveC(s)=(time2c(s+1)-time2c(s))*((carspeed(s)+carspeed(s+1)+14.5*2)/2);

%Integrating Truck Speed
ComparitiveT(s)=(time2c(s+1)-time2c(s))*((truckspeed(s)+truckspeed(s+1)+14.5*2)/2);

%Summing Across Entire Array Index
c(s)=sum(ComparitiveC);
t(s)=sum(ComparitiveT);
c(s+1)=c(s);
t(s+1)=t(s);
end

%Comparative Car Speed
C=sum(c);

%Comparative Truck Speed
T=sum(t);

%Calculated Comparative Speed is Compared to Truck Speed According to Following
%Logic
if C>=T*1.15
```

```
    scoresint=10*.85;
elseif C>=T*1.3
    scoresint=10*.70;
elseif C<=T*.9
    scoresint=10*.80;
elseif C<=T*.85
    scoresint=10*.65;
else scoresint=10;
end

% Evaluating Car Braking Rate
%Array Length for Braking Event 1
for k1=1:1:114;

%Creating Braking Event Factors for Event 1 to Evaluate
K1(k1)=(25+14.5).*time2c(k1);
r1(k1)=sum(K1);
r1(k1+1)=r1(k1);
end

%R terms are the final braking parameters that are summed together, and according to
%final summation fall within rated categories
R1=sum(r1);

%Array Length for Braking Event 2
for k2=115:1:159;

%Creating Braking Event Factors for Event 2 to Evaluate
K2(k2)=1/2.*(25+14.5).*time2c(k2);
r2(k2)=sum(K2);
r2(k2+1)=r2(k2);
end
R2=sum(r2);
for k3=160:1:259;
K3(k3)=1/2.*(25+14.5).*time2c(k3);
r3(k3)=sum(K3);
r3(k3+1)=sum(K3);
end
R3=sum(r3);
for k4=260:1:length(time2c);
K4(k4)=1/2.*(25+14.5).*time2c(k4);
r4(k4)=sum(K4);
r4(k4+1)=r4(k4);
end
```

```
R4=sum(r4);


%Scoring Process of Braking Parameters R
R=I/(R1+R2+R3+R4)*10;
if R<=1.10 || R>=.90
   scoreh=50*1
end
if R<=1.20 || R>=.80 && R>1.1 && R<.90
   scoreh=50*.9
 elseif R<=1.30 || R>=.70 && R>1.20 && R<.80
   scoreh=50*.70
elseif R<=1.40 || R>=.60 && R>1.30 && R<.70
   scoreh=50*.45;
elseif headway2<=0
   scoreh=0;
elseif R<.1
   disp('broke')
end
scores(1)=0;
for h=66:1:length(carspeed)
   if carspeed(h)>=35 && carspeed(h)<=36
      scores(h-65)=10*1;
   end
   if carspeed(h)>36 && carspeed(h)<=37
      scores(h-65)=10*.9;
   end
   if carspeed(h)>37 && carspeed(h)<=38
      scores(h-65)=10*.8;
   end
   if carspeed(h)>38
      scores(h-65)=10*.7;
   end
   scores(h+1-65)=scores(h-65);
end


%Evaluating Headway Time
%Evaluating Headway Time for Each Braking Event According to Following Logic
if mean(headwaytab)>3 || mean(headwaytbc)>=3
   scoret=10*.85;
elseif mean(headwaytab)>=4 || mean(headwaytbc)>=4
   scoret=10*.70;
elseif mean(headwaytab)>=5 || mean(headwaytbc)>=5
```

```
   scoret=10*.55;
elseif mean(headwaytab)>6 || mean(headwaytbc)>=6
   scoret=10*.40;
else scoret=10*1;
end
```

Appendix D

Student Graphical Results

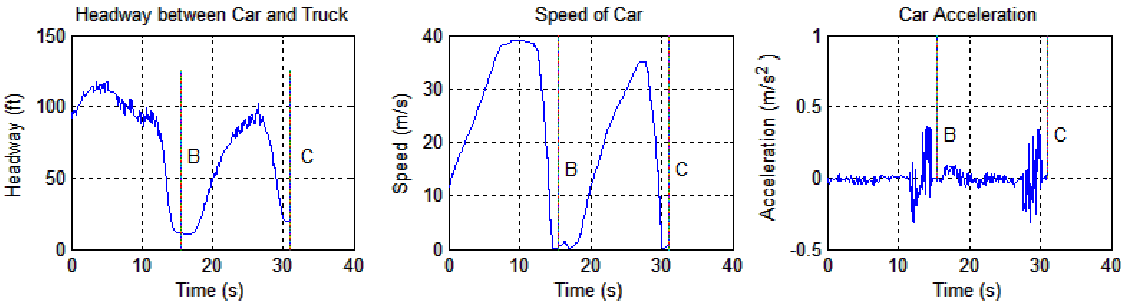

Figure D.1: Example of a good driver's headway distance, speed, and acceleration during the in-vehicle tailgating module

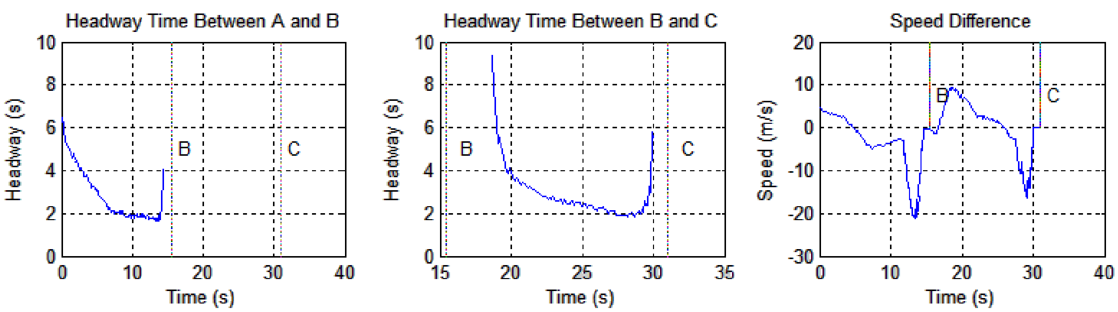

Figure D.2: Example of a good driver's headway time and speed relative to truck during the in-vehicle tailgating module

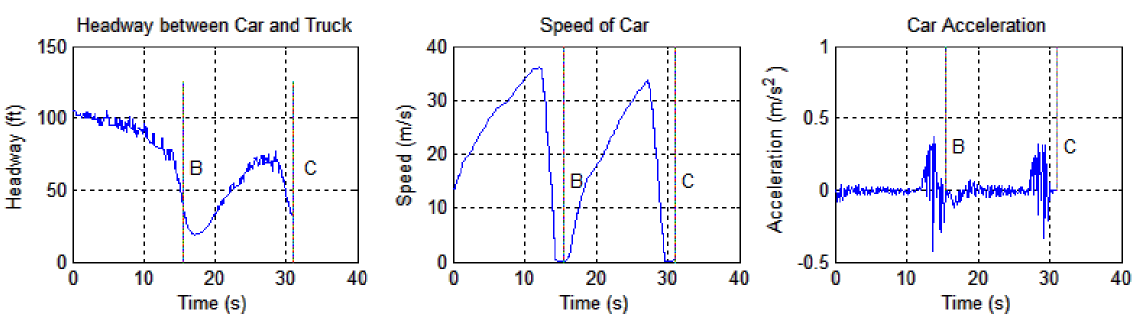

Figure D.3: Example of a bad driver's headway distance, speed, and acceleration during the in-vehicle tailgating module

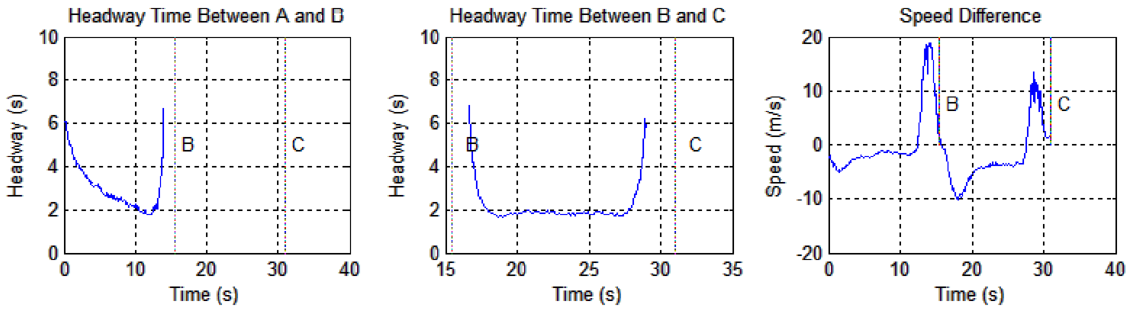

Figure D.4: Example of a bad driver's headway time and speed relative to truck during the in-vehicle tailgating module

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