Assessment of the Use of a Driving Simulator for Traffic Engineering Studies

FINAL REPORT

Authors: Dr. Harold Klee and Dr. Essam Radwan
University of Central Florida
School of Electrical Engineering and Computing Science
P.O. Box 25000
4000 Central Florida Blvd.
Orlando, FL 32816-2450
Phone: 407-823-2786
Email:klee@mail.ucf.edu

Technical Report Documentation Page

<table>
<tr><td>1. Report No.</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Assessment of the Use of a Driving Simulator for Traffic Engineering and Human Factors Studies</td><td>5. Report Date
Feb 04</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author/s
Dr. Harold Klee and Dr. Essam Radwan</td><td>8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Center for Advanced Transportation Systems Simulation
University of Central Florida
P.O. Box 162450
Orlando, FL 32816-2450</td><td>10. Work Unit No. (TRAIS)</td></tr>
<tr><td>11. Contract or Grant No.
BC096/RPWO#18</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Organization Name and Address
U.S. Department of Transportation
Research and Special Programs Administration
400 7th Street, SW
Washington, DC 20590-0001</td><td>13. Type of Report and Period Covered
Final Report</td></tr>
<tr><td>14. Sponsoring Agency Code</td></tr>
<tr><td colspan="3">15. Supplementary Notes</td></tr>
<tr><td colspan="3">16. Abstract
The goal of this project was to design one or two studies involving traffic engineering and human factors that could be conducted in the UCF driving simulator instead of relying on actual field test data. Two separate projects were chosen. The first involved the subject of gap acceptance by drivers. Published data for gap acceptance for a specific type of merging maneuver was compared to the experimental results obtained in the driving simulator under similar merging conditions. The second study was a human factors investigation of a radar based safety warning system using in-vehicle voice and text warnings to alert drivers about the presence of impending conditions requiring their attention.</td></tr>
<tr><td>17. Key Words
driving simulator, traffic engineering, human factors</td><td colspan="2">18. Distribution Statement
No restrictions-this report is available to the public through the National Technical Information Service, Springfield, VA 22161.</td></tr>
<tr><td>19. Security Classification (of this report)
Unclassified</td><td>20. Security Classification (of this page)
Unclassified</td><td>21. No. Of Pages
52

22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) **Reproduction of form and completed page is authorized.**

Final Report Summary

PROBLEM STATEMENT

Driving simulators have been used predominantly for training specific target audiences such as novice drivers, law enforcement officers, truck drivers, etc. Visual databases and traffic scenarios have been developed to support the training mission. The steady improvements in simulator technology has opened the door to the possibility of using driving simulators in research applications involving both human factors and traffic operations. For example, the driving simulator at the University of Massachusetts was used in a National Cooperative Highway Research Program (NCHRP) project to identify the best traffic signal display for protected/permissive left-turn control.

The University of Central Florida driving simulator is a high fidelity simulator mounted on a motion base capable of operation with 6 degrees of freedom. It includes 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation, an audio and vibration system, steering wheel feedback, operator/instructor console with graphical user interface, sophisticated vehicle dynamics models for different vehicle classes, a 3-dimensional road surface model, visual database with rural, suburban and freeway roads plus an assortment of buildings and operational traffic control devices, and a scenario development tool for creating real world driving conditions.

This project was undertaken to see if UCF's driving simulator could be used to support research in the area of traditional traffic engineering and human factors.

OBJECTIVES

The goal of this project was to design one or two studies involving traffic engineering and human factors that could be conducted in the UCF driving simulator instead of relying on actual field test data. Two separate projects were chosen. The first involved the subject of gap acceptance by drivers. Published data for gap acceptance was compared to the experimental results under similar merging conditions. The second study was a human factors investigation of a radar based safety warning system using in-vehicle voice and text warnings to alert drivers about the presence of impending conditions requiring their attention.

FINDINGS AND CONCLUSIONS

Findings from the gap acceptance study contradicted published AASHTO (2001) data which suggests that the minimum acceptable gap for a left turn from a minor road on to a major road is independent of the traffic speed on the major road. The simulator results indicated the acceptable gap was reduced as the major road speed increased.

In the human factors study, responses from the subjects indicated that the safety warning system accomplished the intended purpose of informing drivers and raised their perceived awareness levels to potential road hazards without confusing or distracting them. However, the subjects were undecided as to any perceived safety benefits.

This project demonstrated the feasibility of using the UCF driving simulator to conduct applied research in traffic engineering and human factors. However, the research team underestimated the time required to make changes to the simulator's visual database and develop appropriate traffic scenarios. Future studies will allocate more development time to accomplish these tasks.

More studies are needed to identify limitations on the scope of research conducted in the simulator as a result of performance limitations associated with the visual system (update rates, polygon counts, etc) and the traffic management software (number of moving models, control of external vehicles, etc).

BENEFITS

Based on the two limited pilot studies, the UCF driving simulator has the potential to be used as an experimental testbed to conduct traffic engineering and human factors related research. The driving simulator should be considered for future FDOT research involving areas such as traffic operations, sign recognition, geometric design, age related studies, etc. because it offers a safe alternative to field testing and its an economical platform for conducting the research.

Executive Summary

In the driving simulator, a number of test subjects were asked to merge into traffic along a major road by making a left turn from a stopped position on a minor road. Driving scenarios were created which enabled monitoring of a driver's minimum acceptable gap at major road speeds of 25 mph and 55 mph. Descriptions of the scenarios and data logging of pertinent variables in real-time are included in the report.

Experimental results showed that the average critical gap for the 25 mph speed major traffic was 7.31 sec and the critical gap for the 55 mph speed major traffic was 5.78 sec. The difference in mean acceptable gap for 25 mph major road traffic speed and 55 mph was statistically significant. AASHTO (2001) recommends a 7.5 sec value for the minimum acceptable gap independent of major road traffic speed. Consequently, results from the driving simulator experiments contradicted AASHTO recommendations by suggesting speed is an important factor affecting gap acceptance.

A second study using the driving simulator involving human factors is also reported. UCF was subcontracted by The Georgia Tech Research Institute (GTRI) to conduct experiments for evaluating a radar based Safety Warning System (SWS) which provides advanced warnings to drivers as they approach potentially hazardous situations. GTRI was the primary contractor for a US Dept of Transportation study. Text and voice messages alerted drivers in the simulator to the presence of school buses, railroad crossings and work zones. Traffic scenarios were created to test a driver's response with and without the SWS system. Subjects responded to a questionnaire about the SWS system at the end of their session.

Overall, the responses from the subjects indicated that the SWS accomplished the intended purpose of informing drivers and raised their perceived awareness levels to potential road hazards without confusing or distracting them. However, the subjects were undecided as to any perceived safety benefits and were undecided if they would recommend the system to a friend. Finally, there was no statistical evidence to indicate that males vs. females and the under 40 vs. 40 and over population responded differently to any of the questions asked.

The final report consists of two separate sections. The first was prepared by the principal investigator and other CATSS researchers affiliated with the project. It describes the traffic engineering Gap Acceptance study. The second report was written by a researcher from GTRI using a description of the UCF driving simulator and logged data provided by UCF researchers.

SECTION I - GAP ACCEPTANCE STUDY

1. Introduction

Due to recent advances in computer technology, driving simulators are now widely used not only for training but also for research. They enable researchers to conduct multi-disciplinary investigations and analyses on a wide range of issues associated with traffic safety, highway engineering, Intelligent Transportation System (ITS), human factors, and motor vehicle product development (Blana, 1999). Many researches (Alicandri, 1986 and Stuart, 2002) indicated that simulator measures are valid for sign detection and recognition distances, speed, accelerator position changes and steering wheel reversals, because of a high correspondence between real world and simulator data sets.

The driving simulator housed in the Center for Advanced Transportation Systems Simulation (CATSS) is an I-Sim Mark-II system. It is mounted on a motion base capable of operation with 6 degrees of freedom. It includes 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation, an audio and vibration system, steering wheel feedback, operator/instructor console with graphical user interface, sophisticated vehicle dynamics models for different vehicle classes, a 3-dimensional road surface model, visual database with rural, suburban and freeway roads plus an assortment of buildings and operational traffic control devices, and a scenario development tool for creating real world driving conditions. The output data include steering wheel, accelerator, brake, every car’s speed and coordinates, and time stamp. The sampling frequency is 30Hz.

This research concentrated on two scenarios of gap acceptances for left turn maneuvers from a stop sign controlled minor road to a major road with speed limits of 25 and 55 mph. In gap acceptance experiments, dependent measures focus on the following variables: critical gap acceptances, left turn time, average steering angle velocities, separation between vehicles, average acceleration rates of the simulator vehicle, and speed reduction and the decelerations rate used by major-road vehicles.

The objectives of this study were to

- determine the distribution of critical acceptable gaps in major-road traffic (for 25 mph and 55mph) that are accepted by the minor-road drivers
- to qualify the effect of major road traffic speeds on gap acceptance of left turners
- to analyze drivers' behavior model at intersections
- to compare field data and simulator results

2. Background Information

Gap is defined here as the time headway between two vehicles on the major road into which a minor-road vehicle may choose to turn. Gap-acceptance data is not only used to determine intersection sight distance, but also analyze capacity, queue length, and delay at unsignalized intersections (Fitzpatrick, 1991). Gap acceptance scenarios are provided by AASHTO (2001) for various levels of intersection control and the maneuvers to be performed. There are six scenarios (A to F) in the manual, and the one replicated in this study is defined as Case B1_Left turn from the minor road.

According to AASHTO (2001), the gap acceptance model is based on the assumption that gap acceptance does not vary with approach speed on the major road. It adopted 7.5 seconds as a constant value of critical gap acceptance for left turn from the minor road, independent of approach speed. An analysis of variance by Kyte et al. (1996) also found that the critical gap does not vary with approach speed. However, in a simulator experiment for left crossing from a major road (Jennifer et al, 2002), the velocity of the on-coming traffic was the variable that had the greatest effect on the median accepted gap size. This result corresponds to those of other previous studies involving gap acceptance, which have shown that drivers accept a smaller gap at higher approach velocities (Darzentas et al. 1980a).

3. Experimental Methodology

3.1 Experiment Sample Size

A total of 63 subjects were recruited for this research. Age and sex structure of the subject sample is shown in Table 1. Every participant has a full Florida drivers license with a minimum of 1-year driving experience. They were paid $20 for their participation.

Table 2: Age and sex structure of the subject sample

Age	18-55 years old	56-83 years old	Total
Male	25	10	35
Female	24	4	28
Total	49	14	63

3.2 Experimental Design

A long straight undivided East-West two-lane collector was selected as the major road. Its length is around 3000 m and lane width is 3.6 m. A two-lane minor road with stop signs (see Figure 1) was selected to test gap acceptances for Case B1-Left turns from the minor road. All subjects were tested in two scenarios, one in which the major road speed was 25 mph and the another where the major road speed was 55 mph.

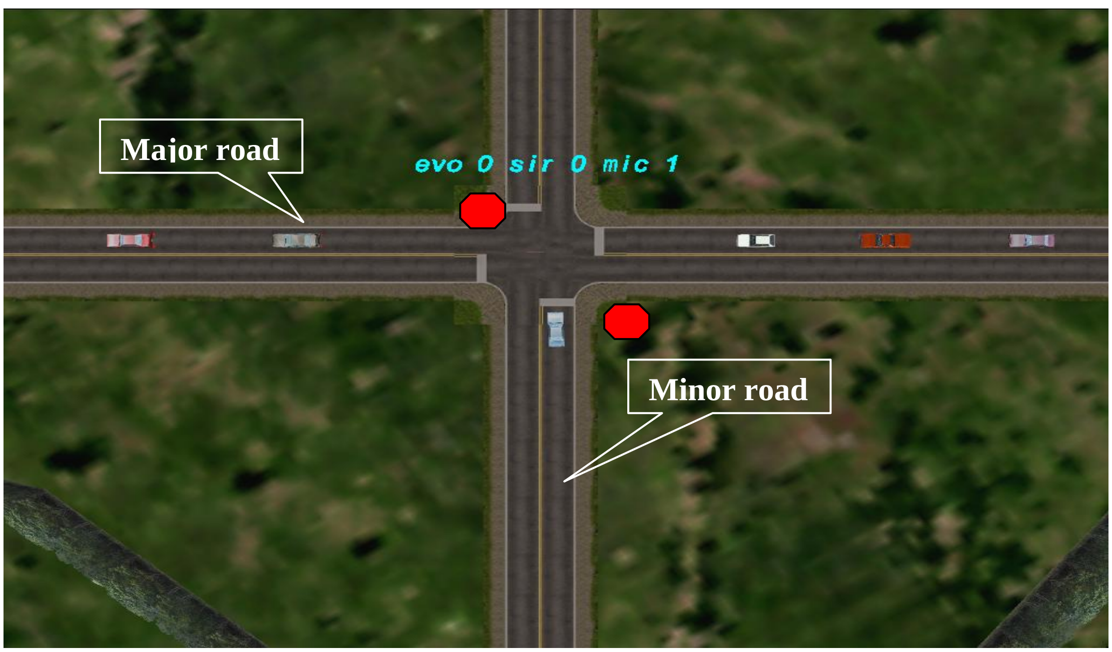

Figure 1: Four-leg Intersection with STOP signs on Minor Road

A major challenge in designing this experiment was how to make the drivers perform their left turn maneuver with the same minimum gap as in the real world. This was accomplished by generating traffic on the major road from the right composed of two classes of intermingled gaps to make the traffic appear random. One gap classification was very small gaps (less than 3 seconds) that were unlikely to be accepted by the participants. The other class consisted of increasing gaps in which the subsequent gap was one second larger than the previous one. This pattern assured the selected gap would be close to the driver's minimum acceptable gap. The uniformly increasing gaps ranged in duration from one sec to sixteen sec, a large enough variation to accommodate all drivers. This concept is illustrated in Figure 2.

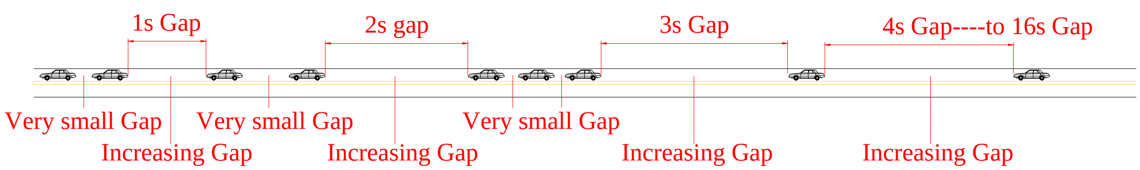

Figure 2: Design for oncoming traffic on the major road

Whenever a car on the major road approached the intersection, it was automatically reclassified from a “record vehicle” to a “normal vehicle”. “Record vehicles” travel along a fixed path with constant speed from the start point to the end point, while the “normal vehicles” moved intelligently along the given route. Although the normal vehicles move at the design speed, they could decelerate, accelerate, and pass slower moving vehicles according to the traffic. Therefore, major road vehicles decelerated from the posted major road design speed, if necessary, to allow the simulator vehicle to negotiate the left turn. Consequently, the likelihood of abnormal collisions at a downstream point from the intersection was minimized, however collision were still possible, especially if the simulator vehicle entered the major road too slowly or selected an unusually small gap. Because the vehicles on the major road become intelligent once they approach the intersection, the no-collision algorithm was overridden and the major road vehicles adjusted their speeds to keep a safe gap.

3.3 Experiment Procedure

Before the formal experiments began, all subjects were required to test-drive the simulator for a period of three minutes to become familiar with this system. The subjects were immersed in one of two driving scenarios. Scenario A corresponded to major road traffic traveling at 25 mph. In scenario B the traffic was moving at 55 mph. The scenarios are presented in sequence A-B-A-B-A-B or B-A-B-A-B-A and repeated three times for each driver. There was a short break (approximately 2 min) between scenarios. In order to avoid driver bias, the participants were informed that the objective of the study was to assess the fidelity of the simulator.

4. Dependent Measures

Speed and position of all vehicles in the system were logged every 1/30-second. In addition, the simulator's acceleration, braking and steering were also monitored at the same rate.

4.1 Acceptable Gap

The speed of each vehicle on the major road was fixed at the posted speed limit, 25 or 55 mph and remained constant unless it became necessary to slow down near the intersection to allow the merging vehicle access to the major road. The acceptable gap was computed from the separation of the lead and following vehicle divided by the major road design speed (See Figure 3).

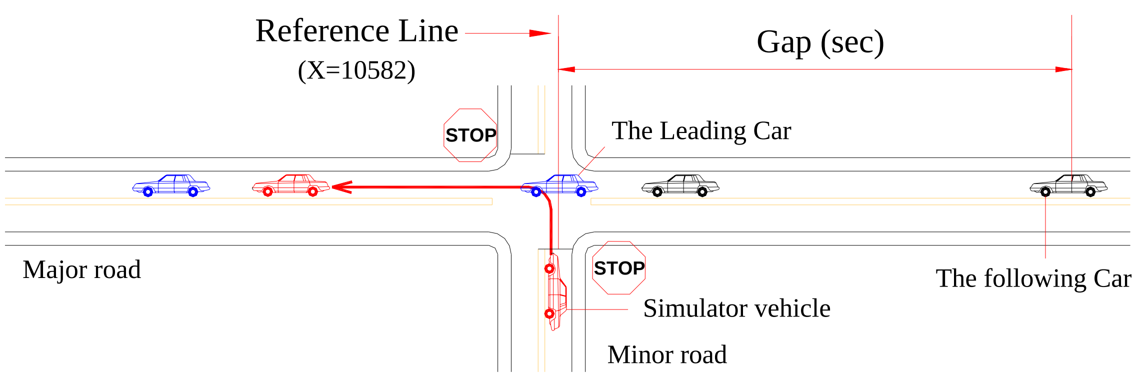

Figure 3: Illustration of Minimum Gap Measurements

4.2 Left Turn Time and Average Steering Angle Velocity

Time stamped values of the simulator steering wheel angle were recorded. The left turn time (LTT) interval was computed as the difference between the time when the simulator began to move and the time at which it reached the reference line (see Figure 4). The average steering angle velocity (SAV) was calculated based on the total steering angle difference and the left turn time. The LTT and SAV are measures of driver behaviors associated with steering control.

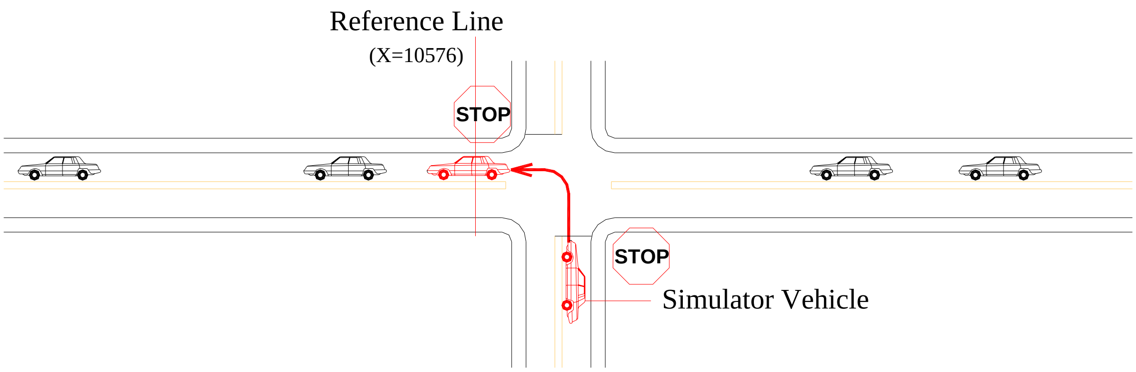

Figure 4: Measurement of Left Turn Time and Average Steering Angle Velocity

4.3 Minimum Clearance Distance, Speed Reduction and Deceleration

Clearance distance is the separation between the left turning simulator vehicle and the major-road following vehicle. As the following car on the major road approached the intersection, the distance between the merging simulator and the following major-road vehicle got progressively smaller until a minimum clearance distance between the two vehicles occurred. At that same time the following car's speed reduction from the posted speed limit was a maximum. The deceleration experienced by major-road vehicles from road design speed to some minimum speed were also computed.

Figure 5 illustrates the typical relationships between the merging and following vehicles. The simulator vehicle begins merging slightly after 100 sec from the beginning of the scenario. The major road following vehicle starts to decelerate a few seconds later and eventually reduces its speed to just under 40 mph, the same as the merging vehicle. The clearance is a minimum (see Figure 5) and remains constant as the two vehicles accelerate in similar fashion back to the major road design speed of 55 mph.

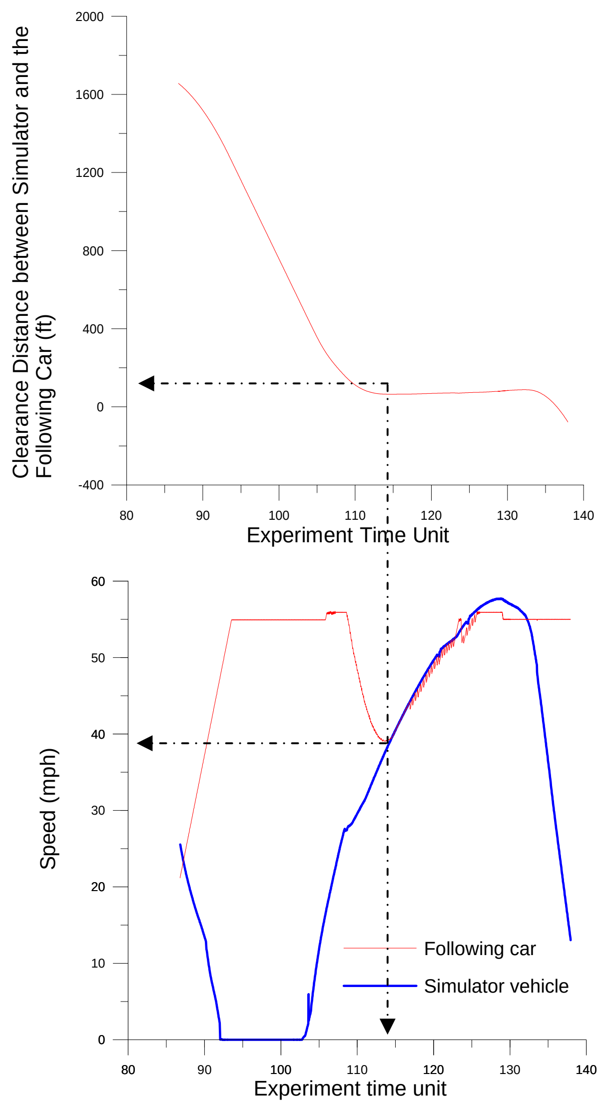

Figure 5: Relationship Between Clearance Distance and Speeds of the Simulator Vehicle and the Following Car

The left turn maneuver is successfully completed as soon as the two vehicles are traveling at the same speed with minimum clearance. Minimum clearance distance, speed reduction, and deceleration of the following vehicle were logged for every simulation run.

5. Experimental Results

Every subject had three chances to select an acceptable gap for scenario A and B. Results of a statistical analysis of gap acceptance and related traffic parameters are shown in Table 3.

Table 3: Statistical analysis of gap acceptance and related traffic parameters

Scenario A_25 mph major road speed								
	Gap (sec)	MCD (ft)	SR (mph)	SRR (%)	ACC (ft/sec^2)	DEC (ft/sec^2)	LTT (sec)	SAV (rad/sec)
Sample	63	63	63	63	63	63	63	63
Mean	7.45	178.08	0.40	2	5.65	0.37	4.22	3.06
Median	7.02	185.53	0.04	0	5.61	0.00	3.98	3.00
Std. Deviation	2.10	60.60	0.80	3	1.71	0.68	0.91	0.80
Minimum	4.38	67.13	0.00	0	1.71	0.00	2.83	1.47
Maximum	13.70	342.19	4.22	17	9.02	3.41	6.71	6.33
Scenario B_55 mph major road speed								
	Gap (sec)	MCD (ft)	SR (mph)	SRR (%)	ACC (ft/sec^2)	DEC (ft/sec^2)	LTT (sec)	SAV (rad/sec)
Sample	63	63	63	63	63	63	63	63
Mean	5.87	81.06	13.26	24	4.53	3.54	4.19	3.00
Median	5.84	69.49	12.24	22	4.66	3.12	3.87	3.09
Std. Deviation	1.44	43.53	7.38	13	1.12	2.44	1.07	0.83
Minimum	3.00	44.32	0.00	0	1.54	0.00	2.76	1.27
Maximum	10.72	320.60	32.53	59	7.02	13.94	7.85	5.21

Note for the name of traffic parameter:

GAP (sec): Gap time accepted by the driver
LTT (sec): Left turn time
SAV (rad/sec): Average steer angle velocity during left turn time
MCD (ft): Minimum clearance distance
SR (mph): Maximum speed reduction of the following car
SRR (mph): Maximum speed reduction rate of the following car
DEC (ft/sec^2): Deceleration of the following vehicle
ACC (ft/sec^2): Average acceleration during the whole left turn maneuver

According to the Paired T-Test the 95% Confidence Interval for the difference in mean acceptable gap, $\mu_{25} - \mu_{55}$ ranges from 1.24 sec to 1.92 sec. The simulator experiment results strongly suggest that gap acceptances for left turns are significantly higher for lower traffic speeds, i.e. drivers tend to accept smaller gaps at higher approach velocities.

AASHTO (2001) recommends a 7.5 sec value for the minimum acceptable gap independent of major road traffic speed. This is consistent with the measured simulator average gap of 7.45 sec when the major road speed was 55 mph. It follows that the gap acceptance criterion of AASHTO is a bit conservative compared with the simulator results which indicated the acceptable gap was reduced as the major road traffic speed increased.

From Table 3, the average deceleration rate of major-road vehicles from 25 mph to the point where the minimum speed occurs is 0.37 ft/sec^2, implying a very gentle deceleration.. For Scenario B (major road traffic equal to 55 mph), the deceleration experienced by major road vehicles was 3.54 ft/sec^2. Hence the vehicles turning left on the minor road had minimal effect on the major road vehicles at the lower major road speed. The opposite was true at the higher major road speed of 55 mph. Using results of field studies, Harwood (1999) reported an average deceleration of 2.2 ft/sec^2 for major road speeds between 35 mph to 55mph. The field study deceleration rate of 2.2 ft/sec^2 lies between the values 0.37 ft/sec^2 and 3.54 ft/sec^2, the values obtained from simulator experiments with 25 and 55 mph major road traffic speeds.

6. Conclusions

Simulator experiment results showed that the critical gap for the 25 mph speed major traffic is 7.31 sec and the critical gap for the 55 mph speed major traffic is 5.78 sec. According to the Paired T-Test comparison, there is a significant difference between values of gap acceptances for the 25 mph speed major traffic and the 55 mph speed major traffic. In contrast with AASHTO recommendations, the simulator experiments suggested that speed is an important factor affecting gap acceptance.

References:

1. Alicandri, E; Roberts, K; Walker, J, 1986. A VALIDATION STUDY OF THE DOT/FHWA HIGHWAY SIMULATOR (HYSIM). STAFF STUDY FINAL REPORT, Report No: FHWA/RD-86/067; FCP 22N3-132, 02/00/1986, Federal Highway Administration.
2. American Association of State Highway and Transportation Officials, 2001. A Policy on Geometric Design of Highways and Streets Washington, D.C.
3. Blana, E, 1999. Driving simulators as research and training tools for improving road safety, Progress in System and Robot Analysis and Control Design, Lecture Notes in Control and Information Sciences Vol.243, 1999, Pages 289-300.
4. Darzentas, et al., 1980. J. Darzentas, M.R.C. McDowell and D. Cooper, Minimum acceptable gaps and conflict involvement in a simple crossing maneuver. Traffic Engineering and Control 21 2 (1980), pp. 58-61.
5. Fitzpatrick, Kay, 1991. Gaps Accepted at Stop-Controlled Intersections. Geometric Design Considerations. Transportation Research Record, 1303. Page 103-112.
6. Harwood et al., 1999. D.W. Harwood, J.M. Mason and R.E. Brydia , Design policies for sight distance at stop-controlled intersections based on gap acceptance. Transportation Research Part A: Policy and Practice **33** 3-4 (1999), pp. 199¯216.
7. Jennifer Alexander, Philip Barham and Ian Black, 2002. Factors influencing the probability of an incident at a junction: results from an interactive driving simulator, Accident Analysis & Prevention, Volume 34, Issue 6, November 2002, Pages 779-792.
8. Kyte, M., Tian, Z., Mir, Z., Hameedmansoor, Z., Kittelson, W., Vandehey, M., Robinson, B., Brilon, W., Bondzio L., Wu, N., Troutbeck, R., 1996. Capacity and Level of Service at Unsignalized Intersections, Final Report: Volume 1-Two-Way Stop-Controlled Intersections. National Cooperative Highway Research Program 3-46.
9. Stuart T. Godley, Thomas J. Triggs and Brian N. Fildes, 2002. Driving simulator validation for speed research, Accident Analysis & Prevention, Volume 34, Issue 5, September 2002, Pages 589-600.

SECTION II
SAFETY WARNING SYSTEM HUMAN FACTORS STUDY

Introduction

This report outlines the key points of the Safety Warning System (SWS) effectiveness human factors simulation study. The SWS radar system provides an inexpensive and efficient warning system for drivers. It uses well-established radar technology allowing specially equipped SWS radar detectors to display and enunciate via synthesized voice over 64 different warning messages. Over the last several years more than 4 million SWS enabled radar detectors were sold in the United States. The SWS system can provide warning to drivers, potentially having a crash reduction impact.

The true effectiveness of the Safety Warning System is determined by how the system increases safety on the road for drivers. Ultimately, this is measured by the reduction of crashes and crash severity over a long period of time. Most of the research to date has involved the measurement of actual traffic patterns. Actual traffic patterns have a large amount of variability in the measurements due to other vehicles interacting with one another and outside factors such as time of day and day of week. Therefore, a simulator study that was able to precisely control all of the variables was conducted.

Note that in general, the driving simulator is not a perfect representation of actual driving conditions. Therefore, the absolute values of the speeds for a given road geometry may not be the same as in the real world, however, it is generally accepted that the relative trends in simulator studies accurately track to the real world.

This study used the University of Central Florida driving simulator to evaluate driver responses and behavior to SWS warnings under various scenarios and traffic incidents.

Study Objectives

The objective of this study is to explore whether driver reaction and performance is affected by SWS warnings, especially at low driver awareness levels. If the information provided by the SWS warnings is useful the driver should have shorter reaction times and make better decisions.

The study is designed to answer the following questions:

1. Does the warning SWS tone and context sensitive message improve driver awareness when compared with no information?
2. Does SWS affect older and younger drivers equally?

   Driver awareness will be evaluated using measured variables such as driver reaction time, average speed, etc.

University of Central Florida Driving Simulator

The University of Central Florida's driving simulator consists of a reconfigurable simulator from GE Capital I-Sim, which includes a late model truck cab and an interchangeable Saturn S-series passenger vehicle cab mounted on a MOOG motion base capable of operation with 6 degrees of freedom. It includes 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation, an audio and vibration system, steering wheel feedback, operator/instructor console with graphical user interface, sophisticated vehicle dynamics models for different vehicle classes, a 3-dimensional road surface model, an existing visual database with rural, suburban and freeway roads plus an assortment of buildings and operational traffic control devices, and a scenario development tool for creating real world driving conditions.

The simulator is housed in the specially designed high bay simulation lab in the College of Engineering and Computer Science Building. The facility's capability for conducting research in driver training, human factors, traffic operations, intelligent traffic systems, etc. is unsurpassed by any organization in the country with the exception of the National Advanced Driving Simulator belonging to The National Highway Traffic Safety Administration (NHTSA) located at the University of Iowa. The Saturn cab was used for this particular study. The cab is shown in Figure 1 on top of the yellow MOOG motion platform. An example of the graphics capabilities of the system is shown in Figure 2. A view of the wide field of view of the simulator is shown in Figure 3. Finally, a view from inside the simulator is shown in Figure 4.

Figure 1. Saturn cab on motion control platform (at bottom)

Figure 2. Example overhead view of a driving scenario

Figure 3. Simulator screens showing wide field of view

Figure 4. View from inside the simulator

Method

Subjects

A total of 96 subjects were expected to participate in the study. The subjects were divided up into four populations, males 18-40, females 18-40, males over 40 and females over 40. The group was expected to be segmented so that a balanced study was conducted with each of the age groups and genders evenly represented. However, it was discovered early on in the study that many of the older subjects experienced simulator sickness. Therefore, a larger number of younger subjects were used in the study. Data on 93 people were actually collected. Table 1 displays the assignment of the subjects into the test groups.

Table 1 – Subject Assignment

Group	Males 18-40	Females 18-40	Males 40+	Females 40+	Number of Subjects
Total	33	39	14	7	93

The average age of the males from ages 18-40 was 26.7 years. The average age of the females from ages 18-40 was 26.6 years. The average age of the males over 40 years old was 48.1 years. The average age of the females over 40 years old was 49.4 years. The average age for all subjects from ages 18-40 was 26.6 years and the average age for all subjects over 40 was 48.6 years.

Experimental Design

Three different SWS messages were selected for study, “Train Approaching Crossing,” “School Bus Loading/Unloading Ahead,” and “Highway Work Crews Ahead.” For each of these three messages two different identical scenarios were built, one where the SWS message would be activated and a second where there would be no message. The non-SWS scenario and SWS scenarios can then be compared to determine if driver behavior changes when the SWS message is present. All six scenarios are listed in Table 2.

Table 2. Scenario Events

Events	***Description***
(#1) Train/SWS	Train approaching crossing such that gates start down before driver reaches crossing forcing driver to make decision on “beating the train” or stopping. SWS present.
(#2) Roadside Parked School Bus/No SWS	School bus with flashing lights simulating picking up children. No SWS present.
(#3) Work Zone/No SWS	Two lane rural highway. Work zone is located after a curve or hill such that there is limited line of sight. NO SWS present.
(#4) Roadside Parked School Bus/SWS	School bus with flashing lights simulating picking up children. SWS present.
(#5) Train/No SWS	Train approaching crossing such that gates start down before driver reaches crossing forcing driver to make decision on “beating the train” or stopping. No SWS present.
(#6) Work Zone/SWS	Two lane rural highway. Work zone is located after a curve or hill such that there is limited line of sight. SWS present.

All subjects were presented the same set of 3 driving scenarios, denoted *A*, *B* and *C* shown in Table 3. The scenarios were presented in different orders (ABC, BCA, or CAB chosen at random) so that the data collected in later scenarios were not biased by learning from earlier scenarios. There was a short delay (~ 5 min) between each of the scenarios. A list of the simulator scenarios is shown in Table 3.

Table 3. Simulator Scenarios

Scenario	*Events*	*Elapsed Time to Event*
A	(#1) Train/SWS (#2) School Bus/No SWS End Scenario	1 min 5 min 6 min
B	(#3) Work Zone/No SWS (#4) School Bus/SWS End Scenario	2 min 5 min 6 min
C	(#5) Train/No SWS (#6) Work Zone/SWS End Scenario	1 min 4 min 5 min

Display Conditions

An SWS receiver was mounted on the vehicle windshield, as shown in Figure 5. One of two SWS conditions was in effect for each event. They are

1. No SWS: Control condition with no SWS warnings
2. SWS: SWS context sensitive message using synthesized speech

Figure 5. View of SWS receiver mounted on the middle of the windshield

The control condition did not broadcast any SWS messages. The control condition was used to determine if the SWS message positively or negatively affects the subject's responses to the simulated scenarios. The second condition used a synthesized voice and LED displayed message to give context sensitive SWS information about the type of hazard the driver is about to encounter.

Procedure

Upon arrival, the subjects were given an informational briefing. In order to avoid driver bias, the participants were informed that the objective of the study was to assess the fidelity of the simulator. Each of the subjects was escorted to the simulator cabin and informed about the SWS receiver during the normal simulator orientation. A short practice period in the simulator (~five minutes) was provided. Each of the three SWS messages were activated in succession and the subject was asked to repeat back the message to ensure that it was understood. This was to assure that the subjects can see/hear the message adequately during the test session and that subjects with hearing and/or sight problems were not included in the study. No subjects were eliminated from the study due to sight or hearing problems.

SWS Integration

The Safety Warning System receiver was mounted in the vehicle in a standard configuration. The activation of the Safety Warning System receiver was performed by the simulator via standard digital I/O lines controlled by the simulator.

The work zone scenario will broadcast the message, “Highway Work Crews Ahead.” The railroad crossing scenario will broadcast the message, “Train Approaching at Crossing.” The school bus scenario will broadcast the message, “School Bus Loading or Unloading.”

Dependent Measures

The statistical analysis will focus on driver reaction to incoming SWS warnings and the environmental cues provided by the simulator.

Accelerator Behavior

The raw accelerator input was recorded at a 30 Hz sample rate. This variable, coupled with the brake input data and SWS message activation data, provides a measure of the subject’s reaction time to the scenario.

Braking Behavior

The raw brake input was recorded at a 30 Hz sample rate. This variable, coupled with the accelerator input data and SWS message activation data, provides a measure of the subject's reaction time to the scenario.

Steering Behavior

The raw steering input was recorded at a 30 Hz sample rate. The variability of this data during the scenario provides a measure of evasive action taken by the subjects.

X,Y Coordinates

The X,Y coordinates of the vehicle was recorded at a 30 Hz sample rate. From this data, the velocity and acceleration of the vehicle can be derived. The data will be used to compare velocity and acceleration profiles between SWS and non-SWS instrumented scenarios.

Data File Output

SWS Message and Timing

The SWS messaging will be recorded at a 30 Hz rate, with a 0 being used for no message, 1 for "Highway work crews ahead," 2 for "Train approaching at crossing," and a 3 for "School Bus Loading or Unloading." This data will provide timing markers used to correlate the other dependant measures listed above. Each line in the data file will represent one sample of data sampled at a 30 Hz rate stored in a binary format. The format will be as follows:

```
X_position, Y_position Steering_input Accelerator_input Brake_input SWS_message
```

Scenario Details

A maps showing the geometry and path that the subjects follow for the three scenarios is shown in Figure 6.

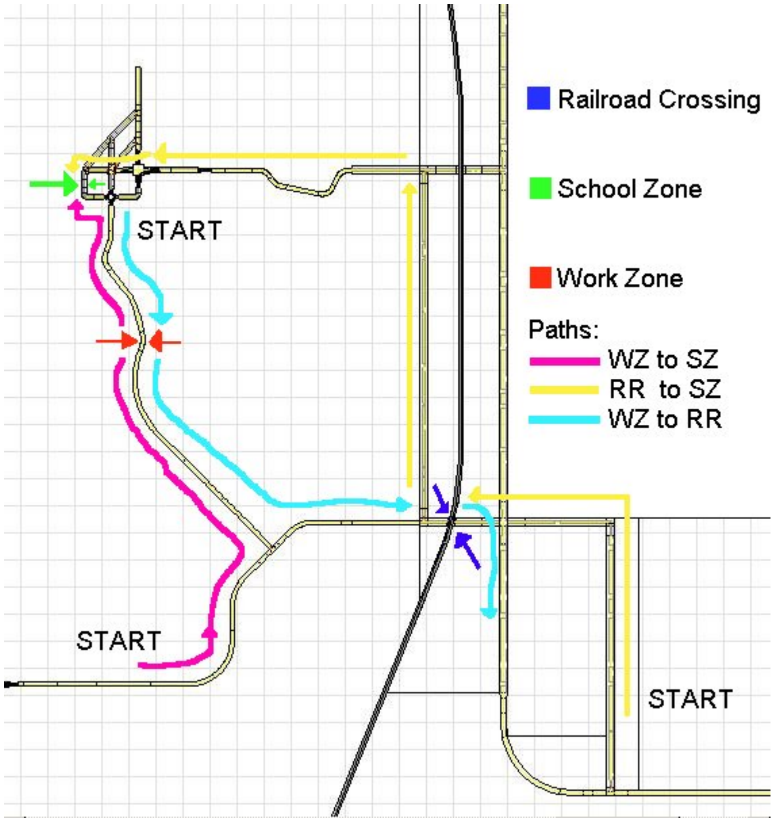

Figure 6. Map of scenarios

A picture showing an overhead view of one of the train scenarios is shown in Figure 7 and a view of the work zone scenario is shown in Figure 8.

Figure 7. Overhead view of Train Approaching at Crossing scenario

Figure 8. Overhead view of Work Zone Ahead scenario

Data Analysis & Results

The data will be analyzed by examining and comparing several driving parameters before the SWS event and after the SWS event and looking for any changes to driver behavior. For every scenario there is a nearly identical replicate of the scenario, only without the SWS message, that is used as a baseline for comparison.

The goal is to compare driver behavior between the SWS and baseline (non-SWS) scenarios and see if the presence of an SWS message causes a measurable and statistically significant change. The scenarios are analyzed by looking at driving behavior before the SWS message and after the SWS message. In the baseline scenario, a marker is placed where the SWS message would normally be activated so that a similar analysis can be performed.

If the driving behavior before and after the message location are the same between the SWS and baseline scenarios, then we can say that driver behavior was the same going into the message location, and the results after the message location can be compared. However, if driving behavior differs going into the message location, then the SWS and baseline scenarios were not recreated identically and the data after the message location cannot be compared between the SWS and baseline scenarios.

The data was analyzed by deriving speed, velocity, and acceleration out of the recorded position data. Also, the brake input was measured and analyzed as well. Data was examined at time intervals of 5 and 20 seconds before and after the message location. The 5 second time interval gives an indication of driver behavior immediately before and after the message location. The 20 second time interval gives an indication of how the drivers respond over a longer time window.

Data reduction was achieved by examining the means and standard deviations of speed, velocity, acceleration, and brake input over the time window of interest. The means are meant to reveal any trends in the data and the variances are meant to reveal any erratic or transient behavior.

An initial analysis of the data indicated that the school bus scenario drastically differed between the SWS and baseline event. After further analysis, the presence of a stop sign was detected just before the school bus in the baseline event that was not present in the SWS event. Therefore, the two scenarios were significantly different enough that the results are not meaningful. However, the Work Zone Ahead and Train Approaching at Crossing scenarios were successful.

After initial analysis and data reduction, hypothesis testing was conducted to determine first of all if driving behavior was statistically the same before the message location between the SWS and baseline events as well as to determine if driving behavior changed as a result of the SWS message. A standard t-test with a 95% confidence interval was used for statistical validation of the results. The null hypothesis was that the calculated values were equal.

In addition to the graphs of the values, statistical box plots will be shown as well. The box plot shows the median of the values (by a straight line), the 25^{th} and 75^{th} quartiles (the upper and lower edges of the box), the rest of the data (represented by the "whiskers" coming out of the plot), as well as any outliers in the data (plus signs). All columns on the box plot map directly to the column on the preceding graph. In all of the box plots the columns are the following.

Table 4. Column Definition for Box Plots

Column	
1	Mean of quantity of interest before SWS location for baseline condition
2	Mean of quantity of interest before SWS location for SWS condition
3	Mean of quantity of interest after SWS location for baseline condition
4	Mean of quantity of interest after SWS location for SWS condition
5	Average variance of quantity of interest before SWS location for baseline condition
6	Average variance of quantity of interest before SWS location for SWS condition
7	Average variance of quantity of interest after SWS location for baseline condition
8	Average variance of quantity of interest after SWS location for SWS condition

Work Crew Ahead Scenario- 5 seconds before and after

The mean and standard deviation of the vehicle velocities for 5 seconds before and after the message event are shown in Figure 9. The associated box plot is shown in Figure 10.

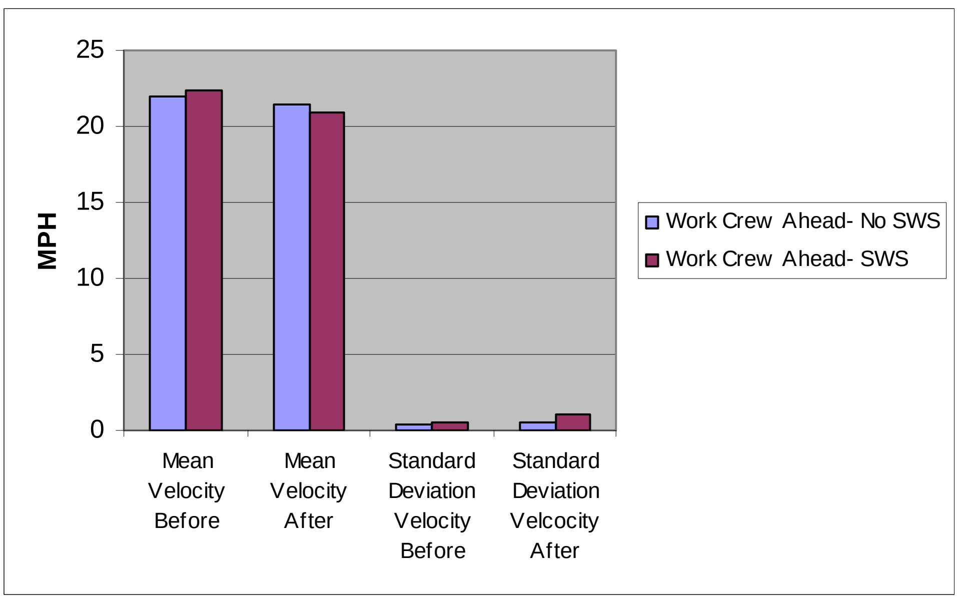

Figure 9. Comparison of velocities for Work Crew Ahead scenario for 5 sec. before and after

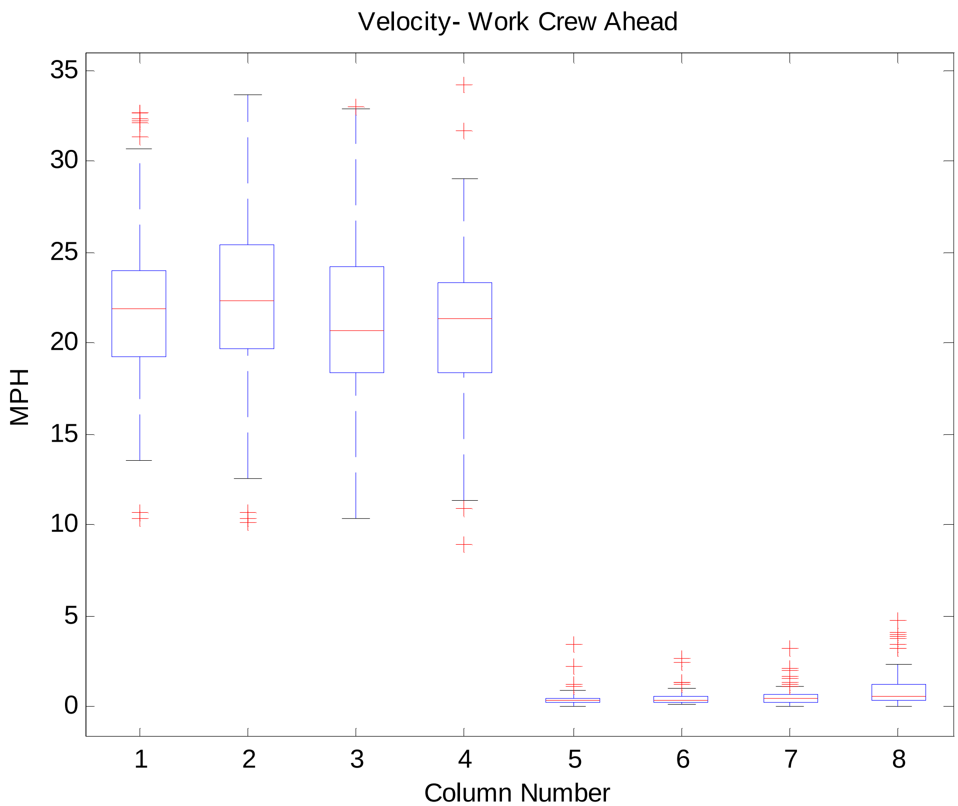

Figure 10. Box plot for velocities shown in Figure 9.

The "mean velocity before" for both the SWS and baseline events are around 22 mph. The velocities are close enough that the t-test indicates that the null hypothesis (means are equal) cannot be rejected. Therefore, the vehicles were at approximately the same velocity approaching the SWS message location. However, the mean velocities after the message location are also close together and can be considered statistically equal as well. Therefore, the SWS message did not cause a statistically significant decrease in speed.

The "standard deviation of the velocity before" is nearly identical between the SWS and baseline conditions and are not statistically different as measured by the t-test. However, the "standard deviation of the velocity after" does statistically differ. However, the difference between the standard deviation before and after the SWS message is only a couple of tenths of a mile per hour, which is a value barely perceivable on the road. Therefore, the presence of the SWS message did not cause a significant change in the standard deviation of the velocity.

The mean and standard deviation of the vehicle acceleration for 5 seconds before and after the message event are shown in Figure 11. The associated box plot is shown in Figure 12.

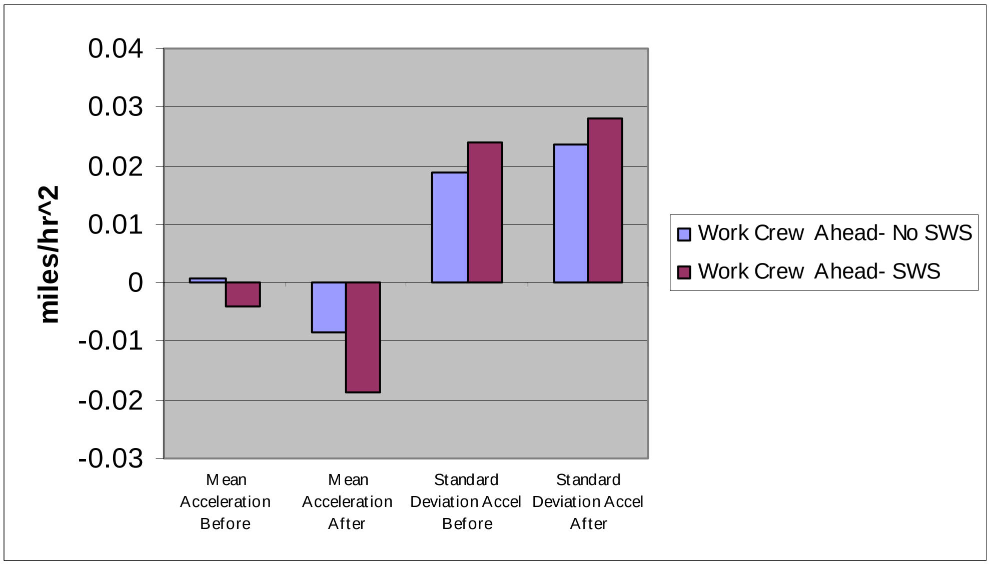

Figure 11. Comparison of acceleration for Work Crew Ahead scenario for 5 sec. before and after

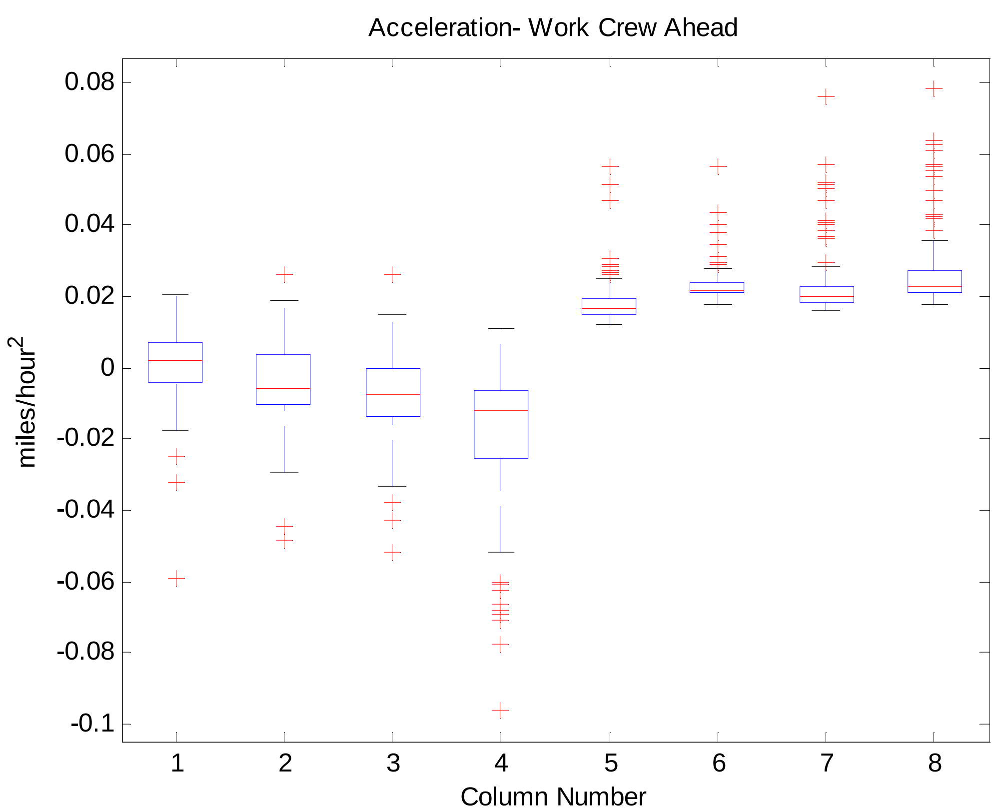

Figure 12. Box plot for Figure 11

The "mean acceleration before" for both the SWS and baseline events differ, but are small values. However, the t-test indicates that the means are statistically different. Therefore, the mean accelerations cannot be meaningfully compared.

The "standard deviation of acceleration before" is also statistically different. Therefore, the mean accelerations cannot be meaningfully compared.

The mean and standard deviation of the brake input for 5 seconds before and after the message event are shown in Figure 13. The associated box plot is shown in Figure 14.

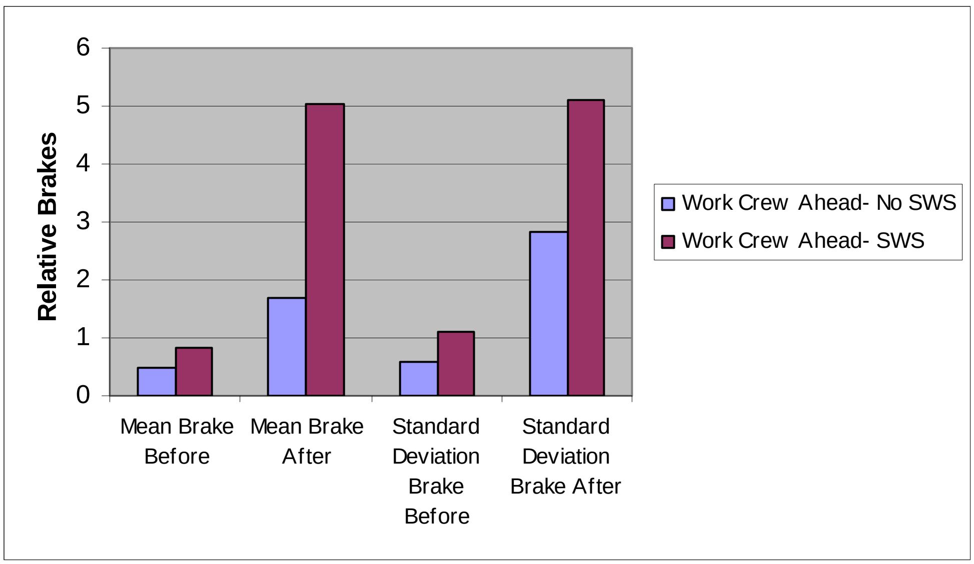

Figure 13. Comparison of brake input for Work Crew Ahead scenario for 5 sec. before and after

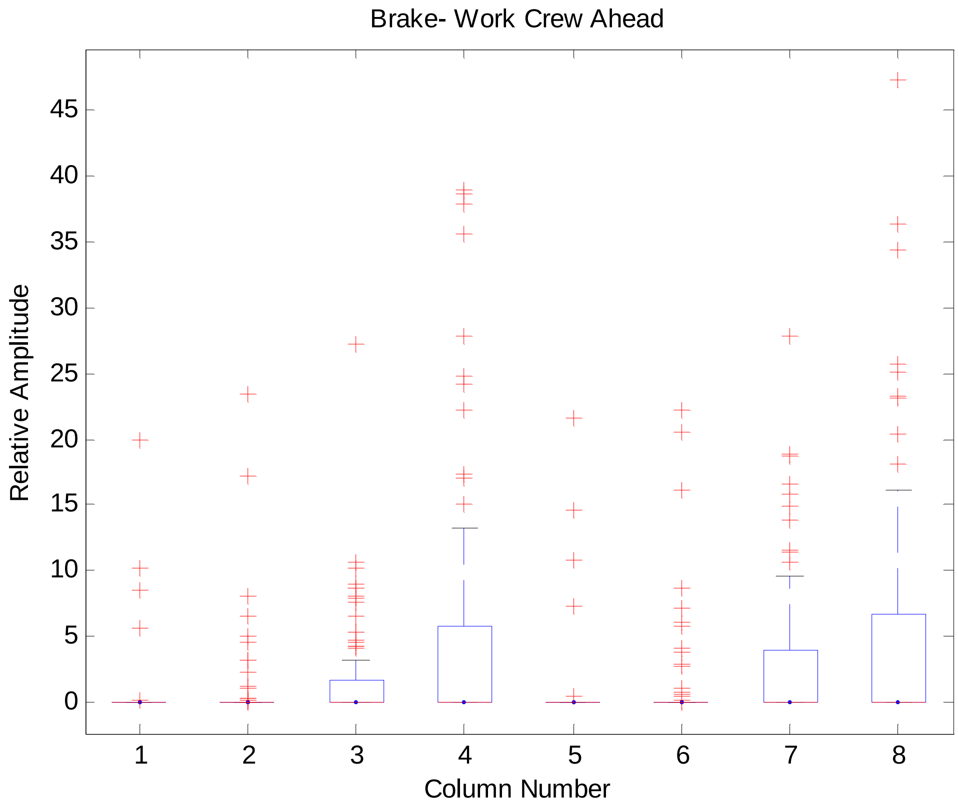

Figure 14. Box plot for Figure 13

The "mean brake input before" for both the SWS and baseline events means are statistically equivalent according to the t-test. However, the brake input changes when looking at the "mean brake input after" data and comparing the SWS to the baseline scenario. In the case where the SWS message is present the average brake input is statistically higher and significantly so. The same is the case with the standard deviation of the brake input as well. Therefore, it can be said that the subjects used the brake more in the SWS event scenario than in the baseline scenario.

Work Crew Ahead Scenario - 15 seconds before and after

The mean and standard deviation of the vehicle velocities for 15 seconds before and after the message event are shown in Figure 15. The associated box plot is shown in Figure 16.

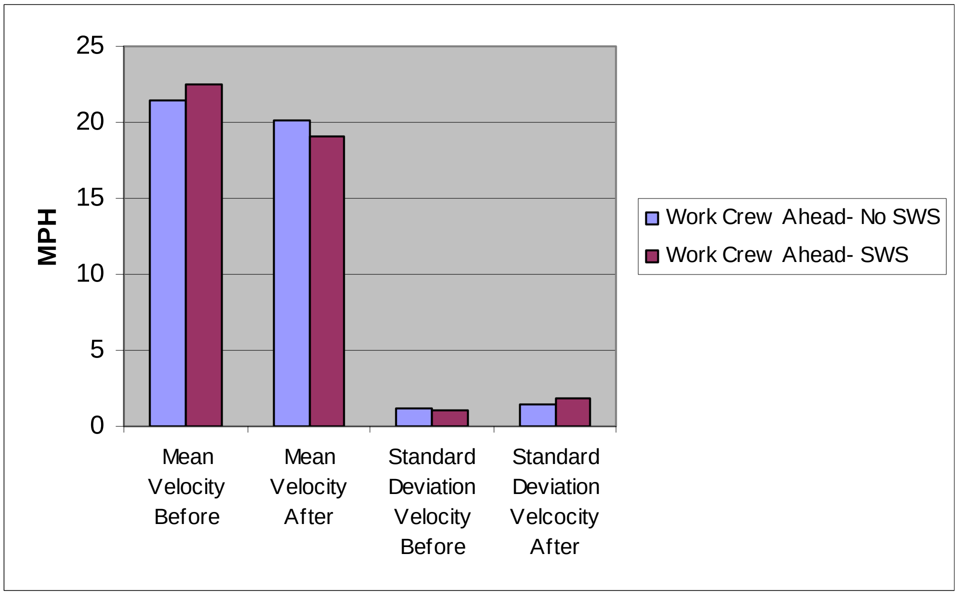

Figure 15. Comparison of velocities for Work Crew Ahead scenario for 15 sec. before and after

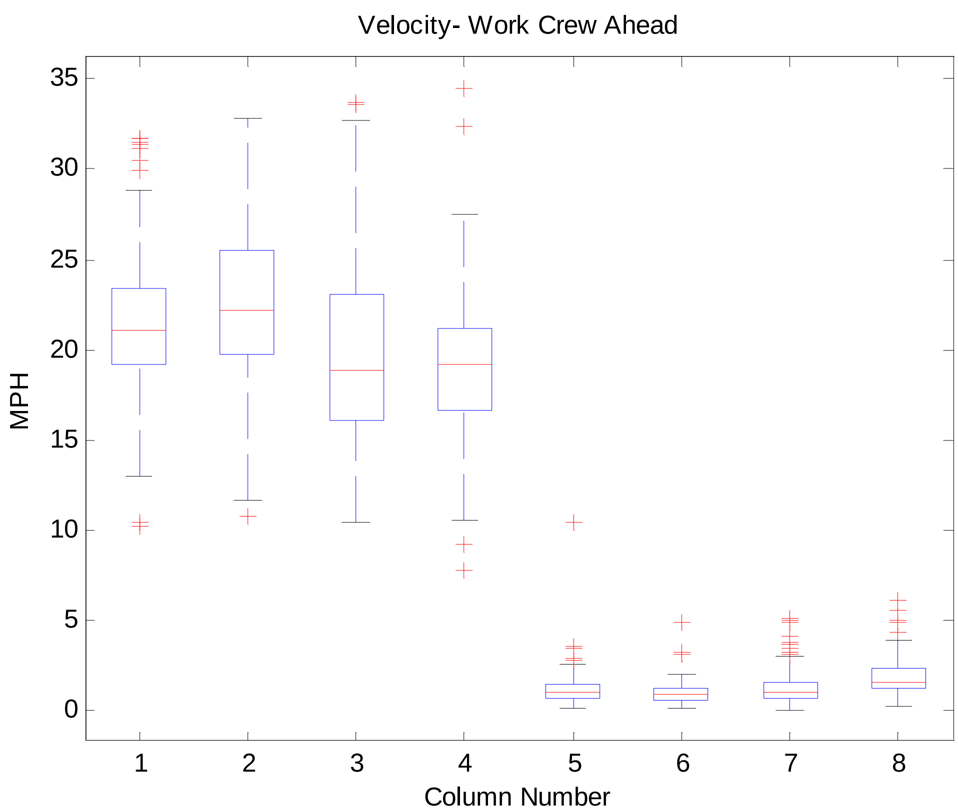

Figure 16. Box plot for Figure 15

The "mean velocity before" for both the SWS and baseline events are around 22 mph. The velocities are close enough that the t-test indicates that the means can be considered statistically equal. However, the "mean velocity after" the message location are also close together and can be considered statistically equal as well. Therefore, the SWS message did not cause a statistically significant change in speed over a 15 second interval.

The "standard deviation of the velocity before" is nearly identical between the SWS and baseline conditions and are not statistically different as measured by the t-test. However, the "standard deviation of the velocity after" does statistically differ. However, the difference between the standard deviation before and after the SWS message is only a couple of tenths of a mile per hour, which is a value barely perceivable on the road. Therefore, the presence of the SWS message did not cause a significant change in the standard deviation of the velocity.

The mean and standard deviation of the vehicle acceleration for 20 seconds before and after the message event are shown in Figure 17. The associated box plot is shown in Figure 18.

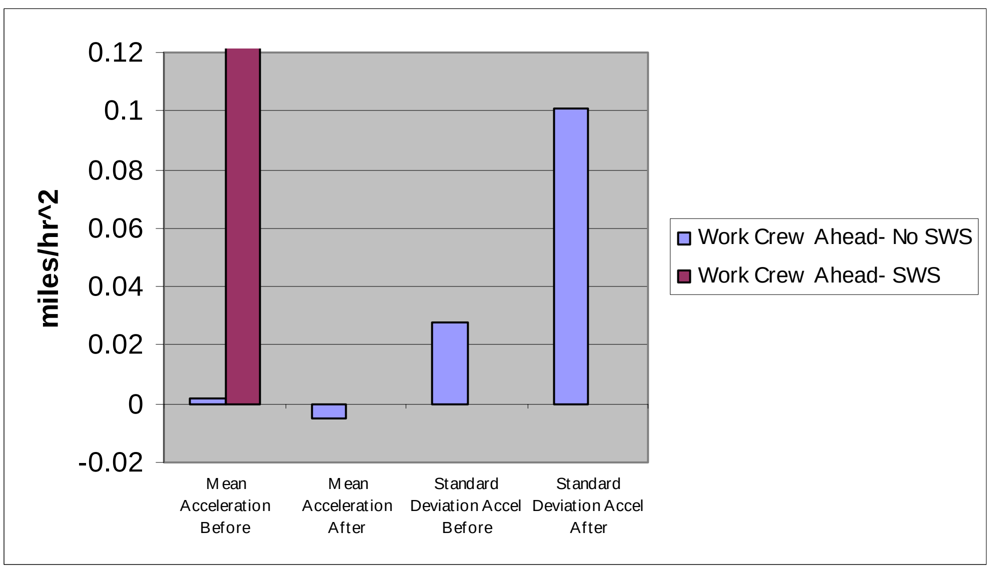

Figure 17. Comparison of acceleration for Work Crew Ahead scenario for 15 sec. before and after

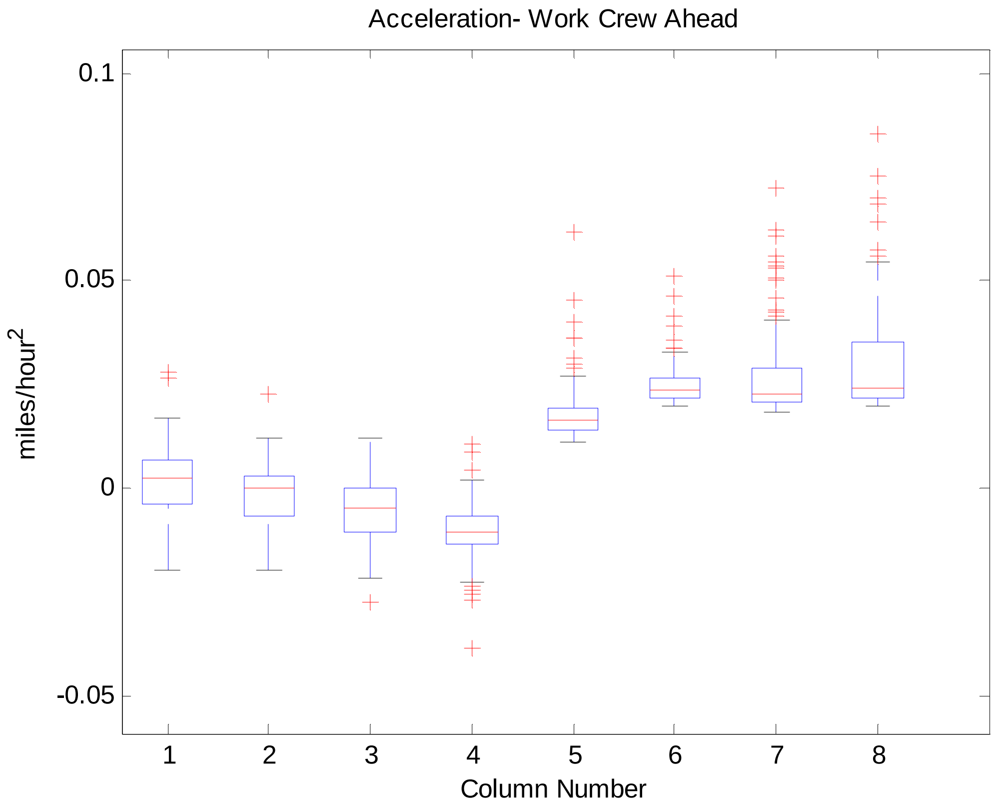

Figure 18. Box plot for Figure 17

The “mean acceleration before” between the SWS and baseline events statistically differ as measured by the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, even though the “mean acceleration after” is significantly lower in the SWS event after the message, the mean accelerations cannot be meaningfully compared.

The standard deviation of acceleration before for both the SWS and baseline events differ with the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, the standard deviation of the accelerations cannot be meaningfully compared.

The mean and standard deviation of the brake input for 15 seconds before and after the message event are shown in Figure 19. The associated box plot is shown in Figure 20

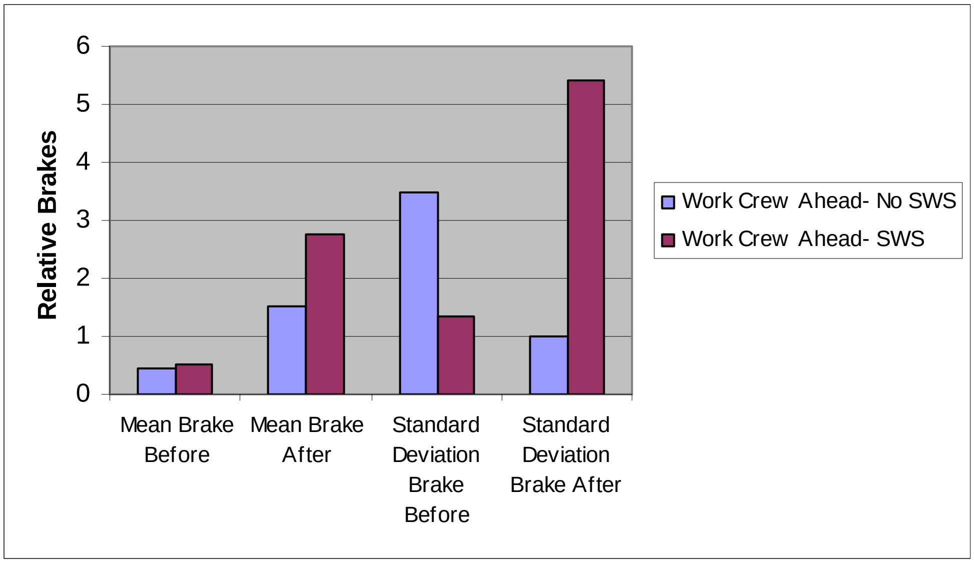

Figure 19. Comparison of brake input for Work Crew Ahead scenario for 15 sec. before and after

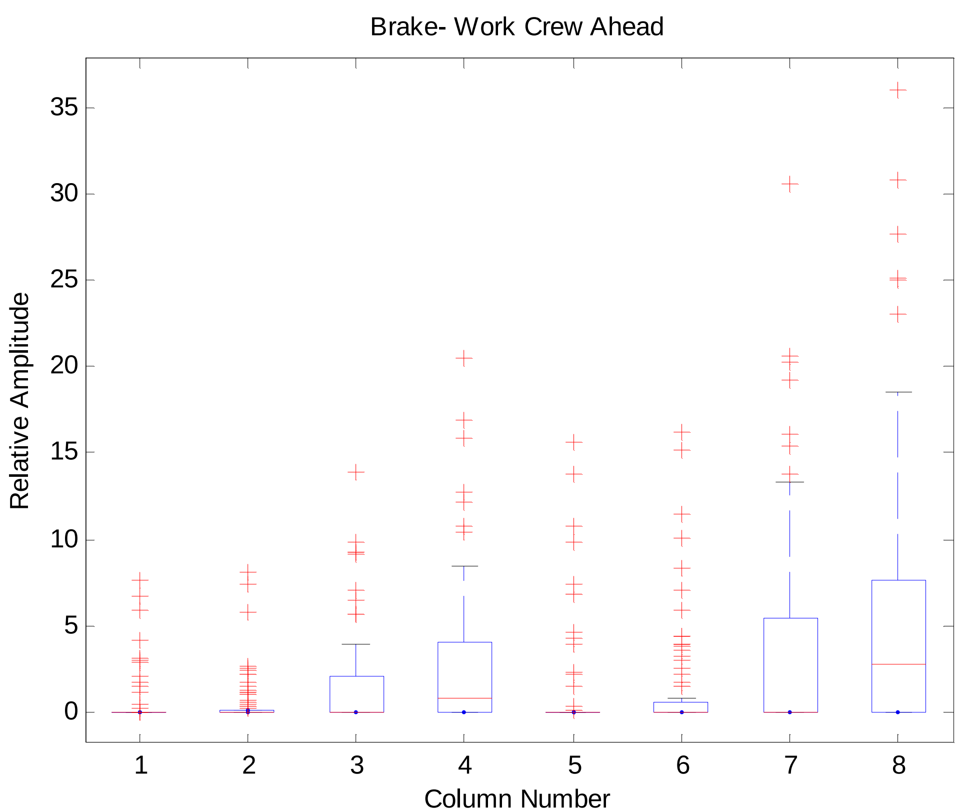

Figure 20. Box plot for Figure 19

The "mean brake before" for both the SWS and baseline are both small and can be considered statistically the same as measured by the t-test. Therefore, the vehicles are approaching the SWS message with approximately the same brake input. However, the brake input changes when looking at the “mean brake after” data. In the case where the SWS message is present, the average brake input is statistically higher. Therefore, the subjects are braking more when exposed to the SWS message.

With the standard deviation of the brake input, the variability is high enough with the measurements that “standard deviation brake before” as well as the “standard deviation brake after” null hypothesis (means are the same) cannot be rejected. Therefore, no statistically conclusive results can be obtained by looking at the standard deviation of the brake input.

Conclusions - Work Zone Scenario

The conclusions for the work zone scenario is that after the subjects were hit with the message, they tended to take their foot off of the accelerator and slightly tap the brakes. However, the brake tapping was not enough that it caused a statistically significant change in the mean or standard deviation of the vehicle velocity. Therefore, it could be inferred that driver awareness levels were raised by the SWS message and that the drivers were prepared to slow down or stop. Also, the braking done by the drivers was not drastic or evasive.

Train Approaching at Crossing Scenario- 5 Seconds Before & After

The mean and standard deviation of the vehicle velocities for 5 seconds before and after the message event are shown in Figure 21. The associated box plot is shown in Figure 21.

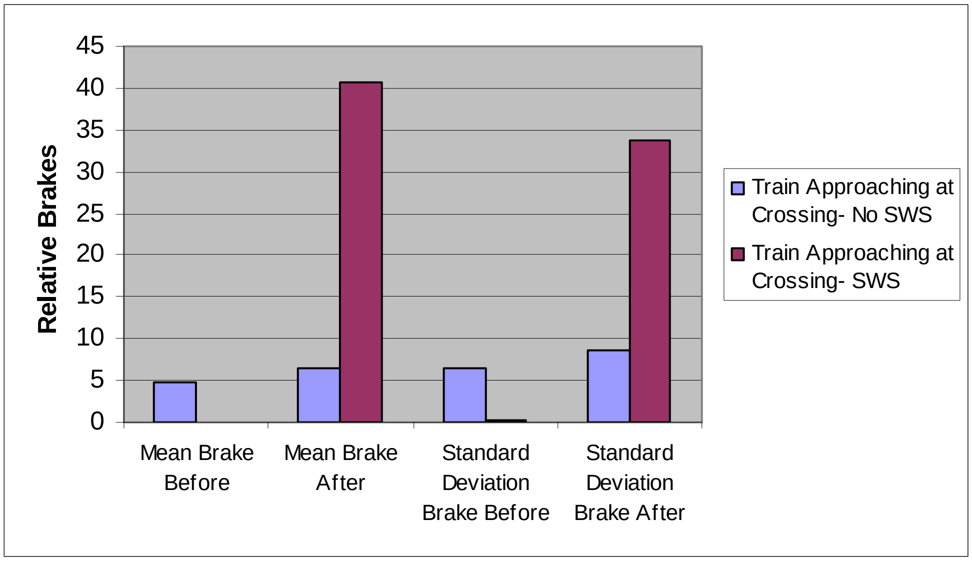

Figure 21. Comparison of velocities for Train Approaching at Crossing scenario for 5 sec. before and after

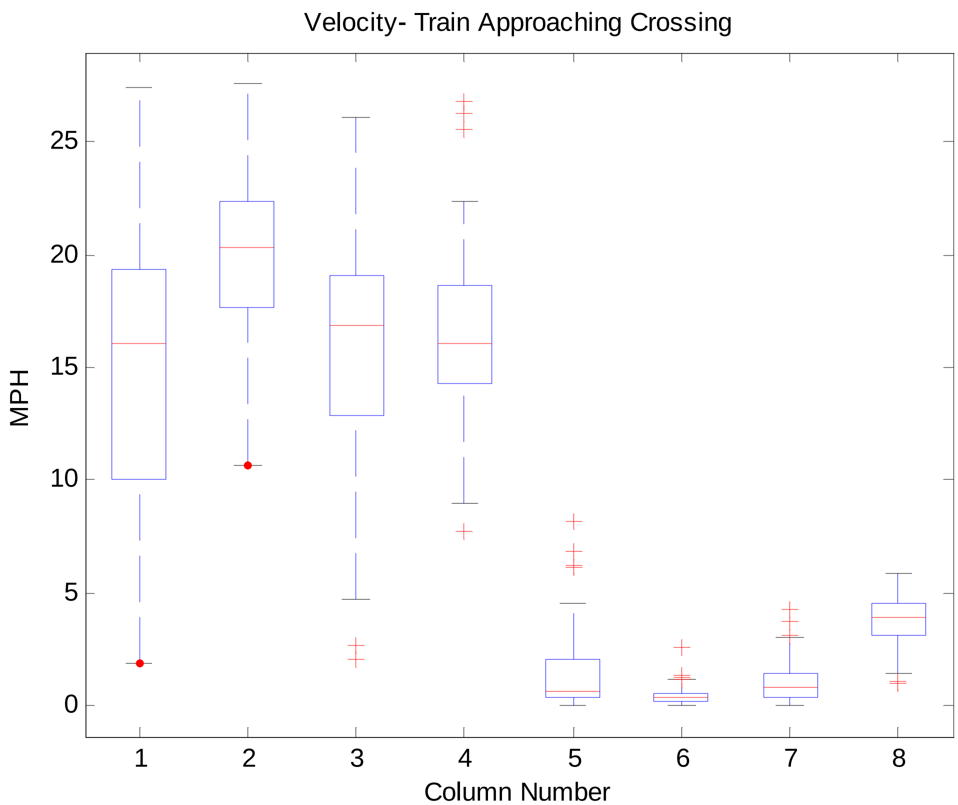

Figure 22. Box plot for Figure 21

The "mean velocity before" for both the SWS and baseline events differ with the t-test indicating that the mean of the velocity before the SWS message is statistically different. Therefore, even though the "mean velocity after" is significantly lower in the

SWS event after the message, the mean velocities cannot be meaningfully compared because the vehicles were not approaching the message at the same speeds.

The "standard deviation of acceleration before" for both the SWS and baseline events differ with the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, the standard deviation of the velocity cannot be meaningfully compared.

The mean and standard deviation of the vehicle acceleration for 5 seconds before and after the message event are shown in Figure 23. The associated box plot is shown in Figure 24.

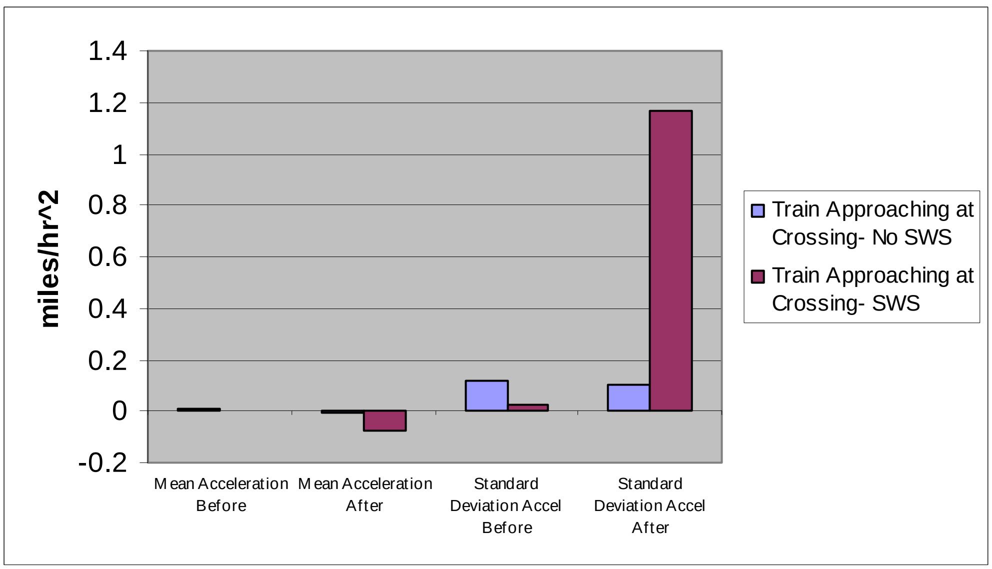

Figure 23. Comparison of acceleration for Train Approaching at Crossing scenario for 5 sec. before and after

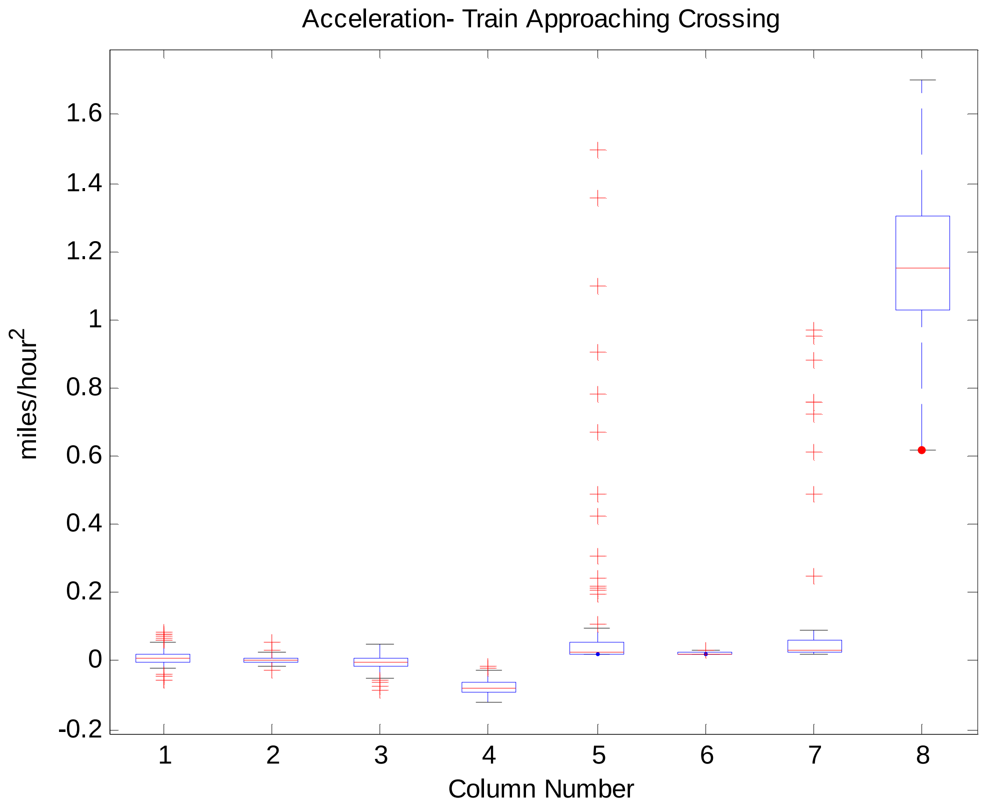

Figure 24. Box plot for Figure 23

The "mean acceleration before" for both the SWS and baseline events are considered statistically the same using the t-test. However, the "mean acceleration after" is statistically different between the baseline and SWS conditions with the SWS condition seeing a larger deceleration. Therefore, subjects are slowing down at a faster rate when the SWS message is present.

The "standard deviation of acceleration before" for both the SWS and baseline events differ with the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, the standard deviation of the accelerations cannot be meaningfully compared.

The mean and standard deviation of the brake input for 5 seconds before and after the message event are shown in Figure 25. The associated box plot is shown in Figure 26.

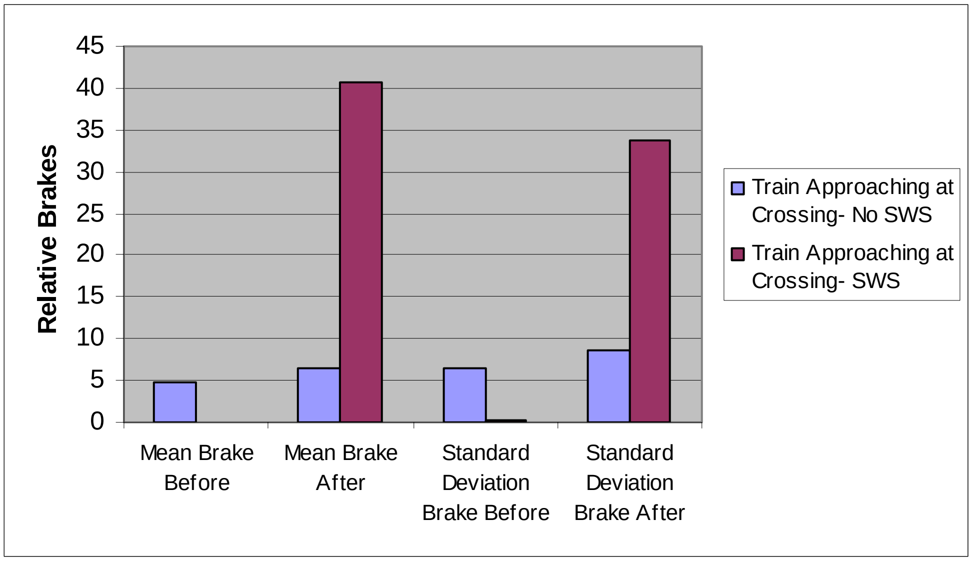

Figure 25. Comparison of brake input for Train Approaching at Crossing scenario for 5 sec. before and after

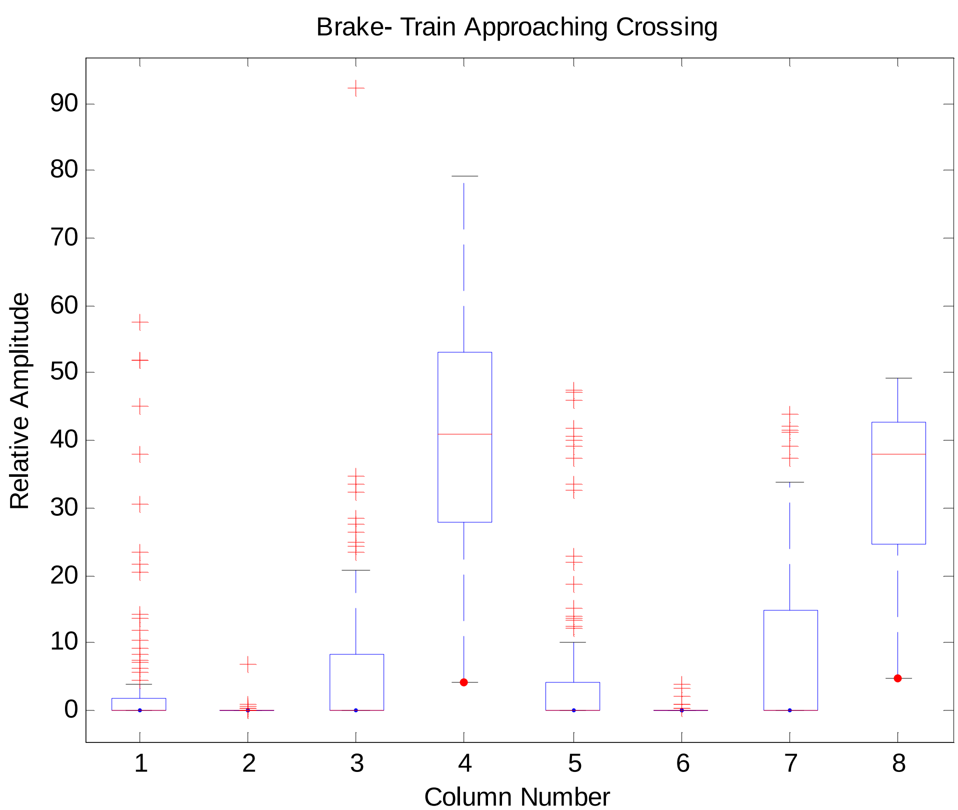

Figure 26. Box plot for Figure 25

The "mean brake before" for both the SWS and baseline events differ with the t-test indicating that the mean of the brake input before the SWS message is statistically different. Therefore, even though the "mean brake after" is significantly lower in the SWS event after the message, the mean accelerations cannot be meaningfully compared.

The "standard deviation of acceleration before" for both the SWS and baseline events differ with the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, the standard deviation of the accelerations cannot be meaningfully compared.

Train Approaching at Crossing Scenario- 15 Seconds Before & After

The mean and standard deviation of the vehicle velocities for 5 seconds before and after the message event are shown in Figure 27. The associated box plot is shown in Figure 28.

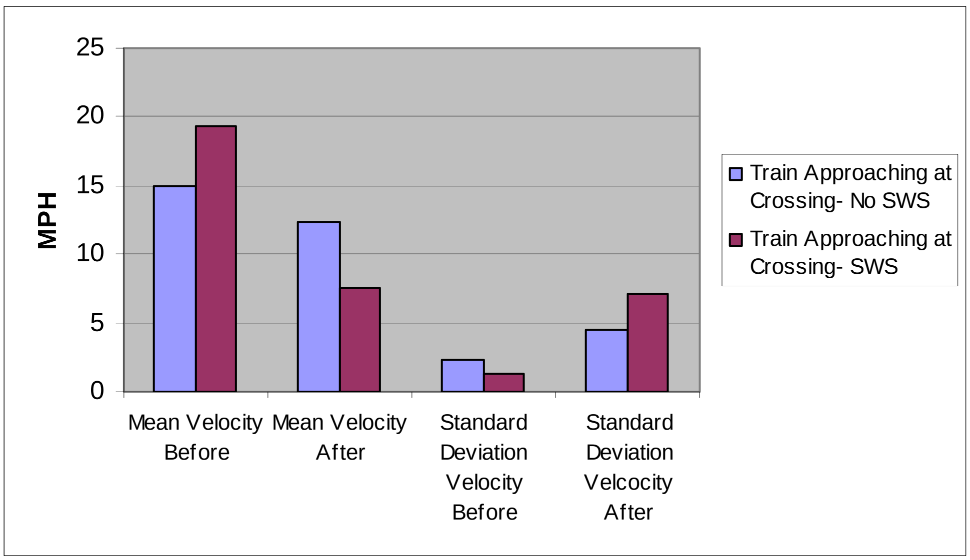

Figure 27. Comparison of velocities for Train Approaching at Crossing scenario for 5 sec. before and after

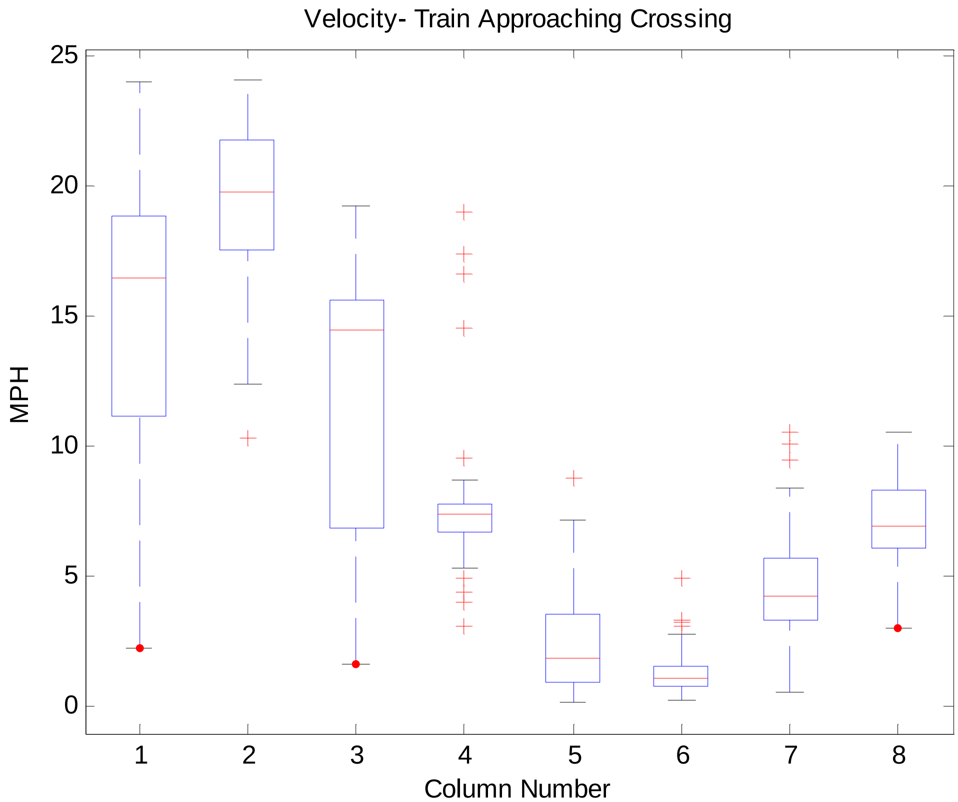

Figure 28. Box plot for Figure 27

The "mean velocity before" for both the SWS and baseline events differ with the t-test indicating that the mean of the velocity before the SWS message is statistically different. Therefore, even though the "mean velocity after" is significantly lower in the SWS event after the message, the mean velocities cannot be meaningfully compared.

The "standard deviation of velocity before" for both the SWS and baseline events differ with the t-test indicating that the mean of the velocity before the SWS message is statistically different. Therefore, the standard deviation of the velocity cannot be meaningfully compared.

The mean and standard deviation of the vehicle acceleration for 15 seconds before and after the message event are shown in Figure 29.

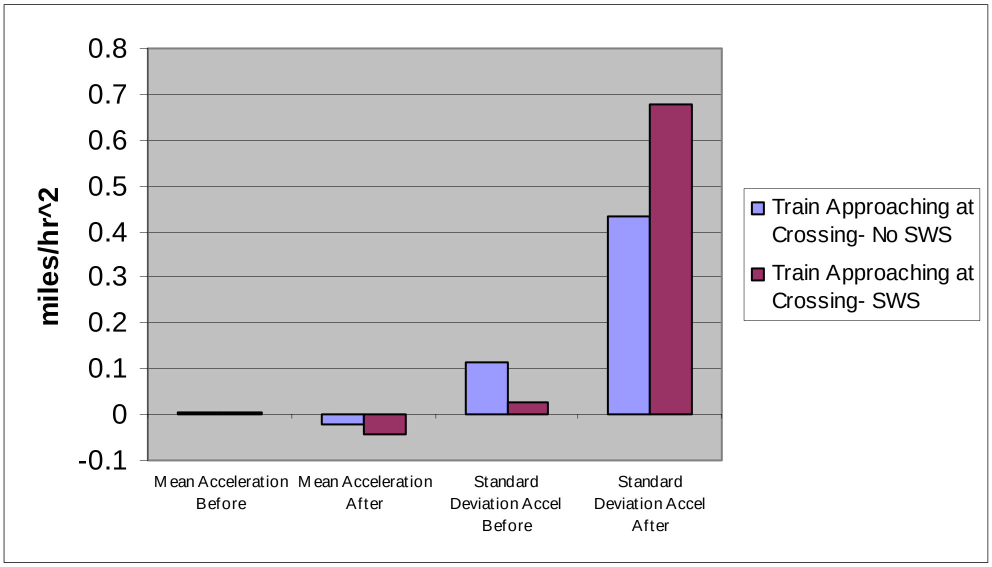

Figure 29. Comparison of acceleration for Train Approaching at Crossing scenario for 20 sec. before and after

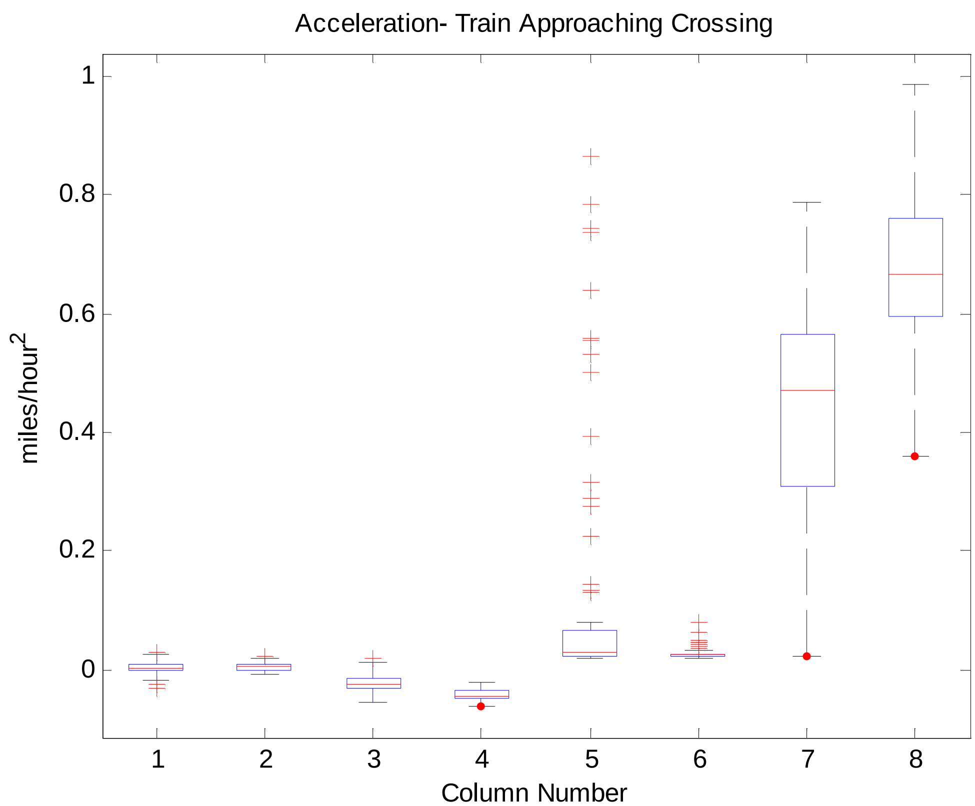

Figure 30. Box plot for Figure 29

The "mean acceleration before" for both the SWS and baseline events do not statistically differ when measured with the t-test. The "mean acceleration after" is statistically different when measured using the t-test. Therefore, more slowing is seen in the SWS event than in the baseline event.

The “standard deviation of acceleration before” for both the SWS and baseline events differ with the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, the standard deviation of the accelerations cannot be meaningfully compared.

The mean and standard deviation of the brake input for 15 seconds before and after the message event are shown in Figure 31.

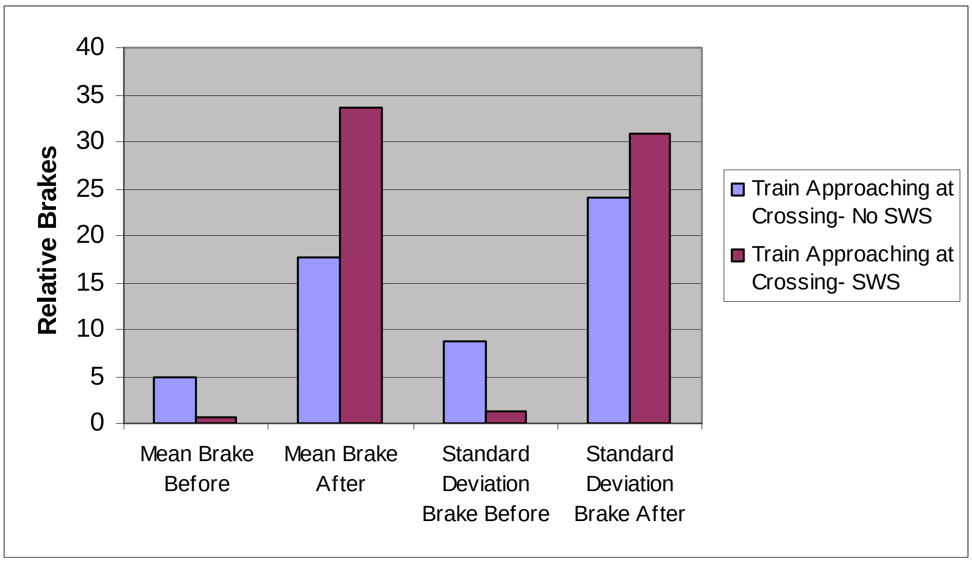

Figure 31. Comparison of brake input for Train Approaching at Crossing scenario for 20 sec. before and after

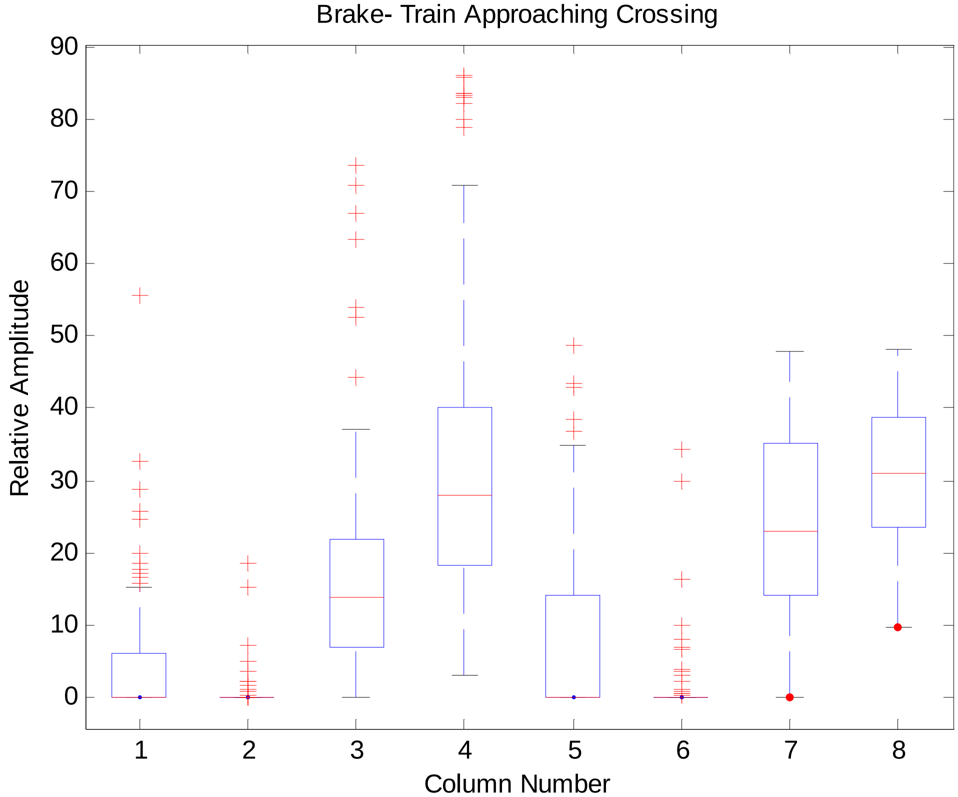

Figure 32. Box plot for Figure 31

The "mean brake before" for both the SWS and baseline events differ with the t-test indicating that the mean of the brake input before the SWS message is statistically different. Therefore, even though the "mean brake after" is significantly higher in the SWS event after the message, the mean accelerations cannot be meaningfully compared.

The "standard deviation of acceleration before" for both the SWS and baseline events differ with the t-test indicating that the mean of the acceleration before the SWS message is statistically different. Therefore, the standard deviation of the accelerations cannot be meaningfully compared.

Conclusions - Train Approaching at Scenario

In general, most of the data was highly variable amongst the subjects leading to a lack of statistical power in the results when measured using the standard t-test. However, most of the data did contain trends corroborating the results of the first scenario where a larger amount of braking was seen after the SWS message when compared with the baseline condition. The main difference between this scenario and the first scenario is that the a statically significant change in the deceleration was seen when the SWS message was present, however, this could be due to a higher average speed when entering the message area.

Overall Conclusions

It was the researcher's expectation in advance of the study that the presence of an SWS message would cause individuals to slow down. However, the results of this study have shown that the tendency of individuals is not to significantly slow down, but to lightly tap the brake and maintain speed. It appears from these results, as well as the post-simulation questionnaire detailed in the following sections, that the SWS system increased driver awareness but did not cause any unsafe driving maneuvers, such as slamming on the brakes.

Post-simulation questionnaire

Upon completion in the simulator, the drivers were presented with a questionnaire regarding their impressions of the SWS system and its usefulness.

The subjects were asked to answer questions rating each on a scale from 1 to 5.

1. Strongly disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly Agree

The following questions were asked.

1. When the SWS system was activated, it provided me a warning of potentially hazardous driving conditions.
2. When the SWS system activated, it raised my driving awareness level.
3. When the SWS was activated, it confused me.
4. The SWS system made me feel safer.
5. I don't think the SWS provided me with any meaningful information.
6. I would recommend the SWS system to others.
7. The SWS system distracted me from driving.
8. I often encounter driving conditions where the SWS system would be useful.
9. I don't think others would benefit from having an SWS receiver.
10. The SWS information provided to me was clear and easy to understand.

Questionnaire Results

The subjects were divided up into several different population groups to determine if different demographics felt differently about the SWS. Therefore the results were tabulated for each of the following population groups: all subjects, males, females, under 40 years old, and 40 years and older. The numerical responses were averaged together to calculate a mean value for each of the population groups for each of the ten questions. Table 5 shows the responses for all population groups.

Table 5. Average Response for All Population Groups for each of the 10 Questions

	All	**Males**	**Females**	**<40**	**>40**
1. When the SWS system was activated, it provided me a warning of potentially hazardous driving conditions.	4.2	4.1	4.2	4.2	4.0
2. When the SWS system was activated, it raised my driving awareness level.	4.1	4.1	4.1	4.1	4.1
3. When the SWS was activated, it confused me.	2.0	2.1	2.1	2.1	2.1
4. The SWS system made me feel safer.	3.3	3.2	3.3	3.2	3.4
5. I don't think the SWS provided me with any meaningful information.	2.1	2.1	2.0	2.1	2.0
6. I would recommend the SWS system to others.	3.6	3.6	3.4	3.5	3.7
7. The SWS system distracted me from driving.	2.1	2.1	2.3	2.2	2.1
8. I often encounter driving conditions where the SWS system would be useful.	3.7	3.6	3.6	3.6	3.8
9. I don't think others would benefit from having an SWS receiver.	2.2	2.2	2.2	2.2	2.3
10. The SWS information provided to me was clear and easy to understand.	4.0	4.0	3.9	4.0	3.8

Next, the data were plotted together on a single bar chart in order to compare the results graphically, as shown in Figure 33. It is apparent from examining both the table and the figure that the responses did not vary much between the populations. The next step was to perform a statistical test to determine if any of the responses for the population groups differed in a statistically significant manner.

A standard t-test was used to determine if there was any difference in the way the questions were answered between males vs. females and between persons under 40 vs. 40 and over. The total population size was 94 people. There were 40 females, 54 males, 21 people aged 40 and over and 73 people under the age of 40.

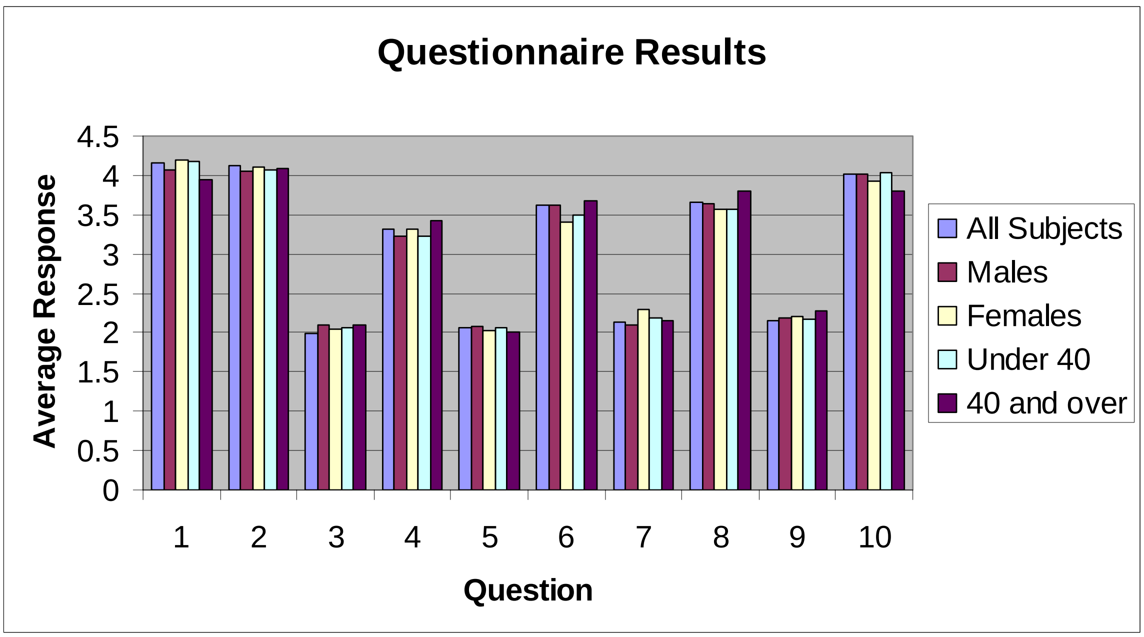

Figure 33. Bar chart display of survey results

Analyzing the responses between the males vs. females as well as the under 40 vs. 40 and over groups found that there was not enough evidence to support that the populations answered any of the questions differently from one another. Therefore, there was no evidence that any single population group responded differently to the SWS than any other group for the questions asked. Therefore, each population group does not need to analyzed separately and the conclusions will be drawn from the results of the entire population.

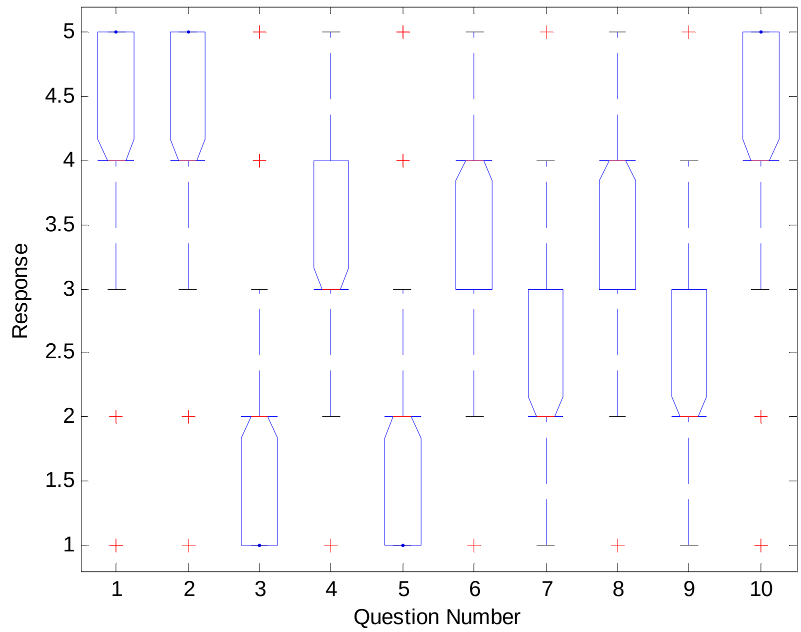

Figure 34. Box plot for the responses from the entire population

A statistical box plot is shown in Figure 34 for the entire population for each of the 10 questions. The line at the tapered edge of the box represents the sample median. The box encompasses from the 25th to the 75th percentile of all the data. The lines extending out from the box represents the extent of the rest of the data. The plus signs represent data outliers.

Analysis

From these results, it can be seen that the high values for questions 1 and 2 showed that the subjects agreed the SWS was providing information to them on potentially hazardous driving conditions and that the system raised their driving awareness level. The responses to question 3 indicated that the subjects felt that the SWS system did not confuse them and the response to question 7 showed that it did not distract subjects from the driving task. The response to question 5 showed the subjects believe the SWS provided meaningful information. Finally, the subjects agreed with question 10 which indicated that the SWS information was clear and easy to understand.

Therefore, from these responses it can be concluded that all populations readily comprehended and understood the SWS message that was given them. It can also be concluded that the subjects believed the SWS provided them with useful information and raised their driving awareness levels, both of which are important factors in highway safety. However, note that these results are the subject's opinion of what they have experienced, and any real changes to driving behavior due to the SWS will be borne out through quantitative analysis of the actual simulator data.

The response to question 4 showed that the subjects were undecided as to if the SWS made them feel safer. In a similar vein, the subjects were somewhat undecided as to if they would recommend the SWS to a friend with a slight bias towards recommending the system. In responding to question 8, about the subject's encountering scenarios where the SWS would be useful, again the subjects were somewhat undecided with a slight bias towards finding the SWS useful.

Some of these responses could be explained through the artificial nature of the simulator and the fact that there were duplicate scenarios in the simulator where the SWS did not sound an alert. These "non-SWS" scenarios were used in order to obtain a baseline to measure the difference in driving behaviors between a scenario instrumented with and without the SWS system. Therefore, the subjects may have thought that the SWS was not working in some of the cases.

Another possible explanation is that although the SWS system provided information and raised driver awareness levels, the subjects may have found the system irritating and would not desire a similar system in their vehicles.

A final possible explanation is that the fifteen minutes of driver simulator time was not enough time to make a judgment on the perceived safety and usefulness of the system and most drivers were left in the undecided category.

Conclusions

Overall, the responses from the subjects indicate that the SWS accomplished the intended purpose of informing drivers and raised their perceived awareness levels to potential road hazards without confusing or distracting them. However, the subjects were undecided as to any perceived safety benefits and were undecided if they would recommend the system to a friend. Finally, there was no statistical evidence to indicate that males vs. females and the under 40 vs. 40 and over population responded differently to any of the questions asked.