A Compact Driving Simulator to Support Research and Training Needs – Hardware, Software, and Assessment

M.S. Thesis Defense
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A Virtual Driving Education Simulation
– Hardware and Software with Pilot Study

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Presentation Outline

• Introduction
• Literature Review
• Tool Features
  – Hardware and Software
  – Track Design
  – Feedback System
  – Scenarios
  – Scoring System
• Pilot Study
• Summary

Basic view of the Clemson Automotive Training System (CATS)
Introduction: Background

- In 2010, 1,963 young people were killed and another 187,000 were injured in automotive crashes in the United States.
- Young drivers, ages between 16 and 23, have more than double the number of car incidents than older drivers.
- Several factors that may cause these drivers to have higher road crash rates:
  - Less experience
  - Not familiar with the road
  - Inaccurately gauge the vehicle speed
  - Easier to be attracted by various factors
  - React improper to hazard situations

Road crashes
Introduction: Background

• The graduated driving license (GDL) was introduced in 1996 and now has been adopted throughout the United States
• Safe driving programs were first developed in 1964, now these courses have spread to many states
• Clemson University Automotive Safety Research Institute (CU ASRI) has cooperated with Petty Safe Driving since 2007 to decrease the crash rates among young drivers
  – In classroom course
  – On-track settings

Petty safe driving program
Introduction: Background

• Virtual driving education has the potential to become an important tool for training young drivers

• CarSim, used in over 30 automotive manufactures and over 100 research institutes and universities, offers advanced vehicle control and vehicle dynamic behavior

• Racing games, such as Grand Turismo 5 and Need for Speed, are examples of driving simulators; they focus on simulating the reality vehicle and the driving environment

• Open source driving simulations are easy to develop and can simulate complex driving scenarios
Introduction: Background

- Clemson Automotive Training System (CATS) was developed based on VDrift, an open source software.
- The purpose of CATS is to educate and train young drivers as a supplemental method in safe driving program.
- Insertion of CATS in Safe Driving Program (SDP):
  - Gain more driving practice
  - Become familiar with SDP modules
  - Increase entertainment

Relationships between SDP and CATS
Driving View Between CATS and SDP

- CATS can simulate the roadway to train young drivers
  - Simulates the same view as driver sitting in the vehicle
  - Create control signs for the road

Comparison in-vehicle driving view between CATS and SDP
• Lee (2007): Best way to train novice drivers is through the GDL program, then use emerging technology to support
• Chan et al. (2010): Driving simulators are effective tools for evaluating novice drivers’ hazard anticipation, speed management and attention maintenance skills
• Crundall and Andrews (2010): Commentary that training improves responsiveness to hazards in a driving simulator
• Vidotto and Bastianelli (2010): Training with a simulator improved hazard avoidance skills in teenagers
• Norfleet et al. (2011): Driving simulator proved helpful in communicating automotive safety lessons, followed by driving exercises to practice and reinforce the educational concept
Tool Features: Hardware

- 17 inch monitor
- Seat belt
- Racing chair
- Seat belt holder
- Steering wheel holder
- Throttle & brake pedal
- Steering wheel
- Speak bar
Tool Features: Software

Create Track

Bob's Track Builder

Blender

CATS

Create Scenarios

C++

Python

Automotive Research Laboratory
Tool Features: Track Design

- Customized track and user interface
  - Create track with customized shape
  - Mountain, bumps, etc.
  - Adjust the track surface coefficient
  - Modify the information display on the screen

- Objects added to environment
  - Add hundreds of objects to track
  - Make unique objects

Track with multiple objects on the road
Tool Features: Feedback System

- **Image feedback system**
  - Face images represent the driving performance to pass this scenario
  - Instructional images give hints about the scenario the driver will meet next

- **Message feedback system**
  - Offer simulated parameters such as driving ratings, reaction time, braking time, braking distance, and deceleration

*Automotive Research Laboratory*
Tool Features: Scenarios and Data Collection

- Create scenarios
  - Stop sign
  - Right lane selection
  - Full stopping module
  - Obstacle avoidance

- Collect parameters
  - Position of vehicle and track
  - Vehicle speed and acceleration
  - Lateral acceleration, yaw angle
  - Numbers of wheels on the track
  - Indirectly values calculated from the above

Collect data such as velocity, acceleration, and other valuable vehicle information.
Tool Features:
Stop Sign Scenario

• Scenario 1: Stop sign
  – A stop sign is placed along the roadway
  – Users are informed to bring their vehicle to a stop

Stop Sign

Automotive Research Laboratory
Tool Features:
Lane Selection Scenario

- Scenario 2: Right Lane Selection
  - Driving lane presented with a two-way split in a driving lane with one path containing an obstacle and the other path clear
  - User must select the clear path

Right Lane Selection
Testing Design Strategy: Braking Scenario

- Scenario 3: Braking
  - Users will be commanded to bring their vehicle to a sudden stop at various locations of the roadway
  - After stopping the vehicle, users will be provided with feedback on their performance

Braking Module
Tool Features: Obstacle Avoidance Scenario

- Scenario 4: Obstacle Avoidance
  - An obstacle is placed in an arbitrary location of the roadway
  - Users must identify the obstacle and maneuver their vehicle appropriately to avoid it
Tool Features: Scoring System

- Driving score will display on the top left of the screen
- User can check his/her driving score immediately while driving
- Driving score will be updated automatically during the simulation
Tool Features: Scoring System

• Four scores listed according to the scenarios, a final score has been put at the bottom of the four scores
• User can check their score status by looking at this list in the game menu
• Click on the “Detail” button; user can see more information for their driving performance
Tool Features: Scoring System

• In each scenario, the scoring system records the description of how the user gets points.
• Left column displays the items used to evaluate the user’s driving performance.
• Right column lists the score and the total points in each category received.

In game, right lane selection menu.
Tool Features: Scoring System in Background Process

- User’s information
- Pre-test score
  - 10 questions
- Score list and items
  - Four scenarios and their items
  - Related scores
- Driving performance
  - “Excellent, Good, Fair, Poor, Dangerous”
- Some basic data statistic
  - Max speed, Average speed
Tool Features: Data Collection

- Data can be collected and analyzed by Matlab

Car trajectory as measured by (x-y) coordinates

Steering wheel angles by the data system
Pilot Study

- A total of 12 students were invited to complete the testing of CATS.
- The driver performance improved an average of 12.75% (novice), 5.67% (young), and 4.31% (seasoned).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Years Driving</th>
<th>Self Rating</th>
<th>Driving Education</th>
<th>Pre Test Score</th>
<th>1st Run Driving Score (DS)</th>
<th>2nd Run Driving Score (DS)</th>
<th>Driver Rating (DR)</th>
<th>Post Test Score</th>
<th>Knowledge Gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>3-5</td>
<td>Excellent</td>
<td>Yes</td>
<td>100</td>
<td>86.75</td>
<td>66</td>
<td>Fair</td>
<td>100</td>
<td>0</td>
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<tr>
<td>2</td>
<td>25</td>
<td>6-10</td>
<td>Excellent</td>
<td>No</td>
<td>100</td>
<td>61.25</td>
<td>80</td>
<td>Good</td>
<td>100</td>
<td>0</td>
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<tr>
<td>3</td>
<td>21</td>
<td>6-10</td>
<td>Good</td>
<td>Yes</td>
<td>80</td>
<td>84.75</td>
<td>80</td>
<td>Good</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>3-5</td>
<td>Good</td>
<td>No</td>
<td>60</td>
<td>45</td>
<td>47.5</td>
<td>Dangerous</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>6-10</td>
<td>Excellent</td>
<td>Yes</td>
<td>100</td>
<td>54.75</td>
<td>61.25</td>
<td>Fair</td>
<td>100</td>
<td>0</td>
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<td>6</td>
<td>23</td>
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<td>Average</td>
<td>Yes</td>
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<td>59.25</td>
<td>55</td>
<td>Dangerous</td>
<td>100</td>
<td>40</td>
</tr>
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<td>79.25</td>
<td>76</td>
<td>Average</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>11-20</td>
<td>Good</td>
<td>Yes</td>
<td>80</td>
<td>74.75</td>
<td>73.75</td>
<td>Average</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>23</td>
<td>0-2</td>
<td>Average</td>
<td>Yes</td>
<td>100</td>
<td>62.25</td>
<td>58.5</td>
<td>Dangerous</td>
<td>80</td>
<td>-20</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
<td>3-5</td>
<td>Good</td>
<td>Yes</td>
<td>100</td>
<td>19</td>
<td>54.25</td>
<td>Dangerous</td>
<td>80</td>
<td>-20</td>
</tr>
<tr>
<td>11</td>
<td>23</td>
<td>0-2</td>
<td>Fair</td>
<td>No</td>
<td>80</td>
<td>21.5</td>
<td>65.5</td>
<td>Fair</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>0-2</td>
<td>Good</td>
<td>No</td>
<td>100</td>
<td>71.25</td>
<td>84.25</td>
<td>Good</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>24.67</td>
<td>5.25</td>
<td>Good</td>
<td>-</td>
<td>88.33</td>
<td>59.98</td>
<td>66.83</td>
<td>Fair</td>
<td>93.33</td>
<td>5</td>
</tr>
</tbody>
</table>

Pilot study results for twelve human test subjects using CATS.
Summary

- Modules developed to instruct and test users safe driving capabilities within a virtual driving environment
- Participants’ overall driving behavior became safer after using the simulator
- Young drivers showed more improvement both on driving knowledge and driving proficiency than veteran drivers
- The simulator proved to be efficient at improving driving skills and knowledge
Questions
Assessment of an Automotive Driving Simulator to Educate Novice Drivers

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Presentation Outline

• Introduction
• Literature Review
• CATS Demo
• Testing Design Strategy
  – Steps
  – Questionnaire
  – Scenarios
• Assessment
• Summary
• Future Work

CATS Station in the Safe Driving Program at Charlotte Motor Speedway (Concord, NC)
Introduction

• Simulators have been widely used in many fields
• A total of 50 participants have been invited to take the testing of the Clemson Automotive Training System (CATS)
• 35 participants were male and 15 participants were female
• Participants’ ages ranged between 23 and 31 years old
• Subjects were classified as novice (0-2 years), beginner (3-5 years), and experienced (5+ years) drivers
Literature Review: Simulator Development and Application

- Ruspa et al. (2007): FIAT auto use virtual driving tool for the **ergonomic assessment** of the external visibility during the **development of new car model**, to compare different geometries
- Kim et al. (2007): Integrate automotive simulator system of a large scale driving simulator with hardware-in-the-loop systems (HILS)
- Piegsa and Rumbolz (2011): Based on different driver habits and various car types and locations, the driving simulator be used to **measure the fuel consumption** and compare the data
- Kandhai and Smith (2011): Apply driving education simulation both in personal PC and **mobile apps**
- Groot et al. (2011): Use driving simulator to investigate whether concurrent bandwidth feedback improves learning of the **lane-keeping task**
CATS Demo

- Demo for CATS
- Click to watch demo from local
- Click to watch demo from youtube
Testing Design Strategy: Steps

• Step 1: Practice driving
  – Become familiar with the equipment such as throttle and braking pedal and then drive the vehicle on a road with no scenarios

• Step 2: Answer pre-test questionnaire
  – Ten questions about safety driving will be posted on the screen and required to answer. A score will be saved and be used to analyze the driving performance later

• Step 3: Drive CATS simulation system for the first lap
  – Four scenarios have been made on the road and students are required to react in the correct way in passing them
  – A system score will be used to collect some data and evaluate the student’s driving performance on each scenario
Testing Design Strategy : Steps

• **Step 4: Watch instruction video**
  – A short video will give purpose to design this track and scenarios and demonstrates the right method to pass each scenario

• **Step 5: Drive CATS simulation system for the second lap**
  – Instruction system will be used to give enough instructions when student is driving on each scenario for the second time

• **Step 6: Answer post-test questionnaire**
  – Ten questions are required to be answered again
Testing Design Strategy: Steps

• Step 7: Evaluation of the driving performance
  – A final score will be created based on the pre-questions answers and the driving performance of the student on the four scenarios
  – Certain value will be made to graphics to show some basic students’ performance
Testing Design Strategy : Questionnaire

• Five attitudinal questions
  – Q1: I love to show off when I'm driving.
  – Q2: If you have good skills, speeding is O.K.
  – Q6: Wearing a seatbelt makes me feel safe.
  – Q8: I'm still learning to be a good driver.
  – Q10: I would get into the car with a reckless driver if I had no other way to get home.

• Five correct / incorrect questions
  – Q3: What is the proper way a seat belt should be worn?
  – Q4: When driving, you should consistently check what?
  – Q5: Coming to a flashing red light, you should?
  – Q7: While driving on a highway, when do you use your turn signal?
  – Q9: When approaching an intersection with a yellow signal light, it is best to...
Testing Design Strategy: Scoring System Items

- Scoring system used to test and give the users’ driving performance is based on results of the pre-questions and four scenarios
  - Answer the ten pre-questions and get the scores
  - Evaluate users’ driving performance and get the scores
  - Add all the scores and get one final score

\[
S_i = \begin{cases} 
\sum_{j=7}^{3} \alpha_{ij} K_{ij} ; & \text{for } (i=1,2,4) \\
\sum_{j=1}^{7} \alpha_{ij} K_{ij} ; & \text{for } (i=3) 
\end{cases}
\]

DS = \frac{1}{n} \left( \sum_{i=1}^{4} S_i - \sum_{\kappa=1}^{3} \beta_{\kappa} N_{\kappa} \right)

DR = \begin{cases} 
\text{Excellent}; & \text{if } 90 \leq DS \leq 100 \\
\text{Good}; & \text{if } 80 \leq DS < 90 \\
\text{Average}; & \text{if } 70 \leq DS < 80 \\
\text{Fair}; & \text{if } 60 \leq DS < 70 \\
\text{Dangerous}; & \text{if } DS < 60 
\end{cases}
Testing Design Strategy: Stop Sign Scenario

- **Event 1: Stop sign**
  - A stop sign is placed along the roadway
  - Users are informed to bring their vehicle to a stop prior to the sign

- **Performance evaluation**
  - A score will be given based on the items below, the total score of this scenario is 25 points

<table>
<thead>
<tr>
<th>Items</th>
<th>Success</th>
<th>Failed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vehicle speed lower than 10 mph</td>
<td>15 points</td>
<td>0 points</td>
</tr>
<tr>
<td>2. Not run off the road</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>3. Drive smoothly</td>
<td>5 points</td>
<td>0 points</td>
</tr>
</tbody>
</table>

25 points 0 points
Testing Design Strategy: Lane Selection Scenario

- Event 2: Right Lane Selection
  - Driving lane presented with a two way split in a driving lane with one path containing an obstacle and other path clear
  - User must select the clear path

- Performance evaluation
  - A score will be given based on the items below, the total score of this scenario is 25 points

<table>
<thead>
<tr>
<th>Items</th>
<th>Success</th>
<th>Failed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Drive on the right lane.</td>
<td>10 points</td>
<td>0 points</td>
</tr>
<tr>
<td>2. Not run off the road.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>3. Drive smoothly.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>4. Vehicle speed lower than 30 mph.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>25 points</td>
<td>0 points</td>
<td></td>
</tr>
</tbody>
</table>
Testing Design Strategy: Braking Scenario

- Event 3: Braking
  - Users will be commanded to bring their vehicle to a sudden stop at various locations of the roadway
  - After stopping in vehicle, users will be provided with feedback on their performance

- Performance evaluation
  - A score will be given based on the items below, the total score of this scenario is 25 points

<table>
<thead>
<tr>
<th>Items</th>
<th>Success</th>
<th>Failed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Has vehicle stopped completely?</td>
<td>10 points</td>
<td>0 points</td>
</tr>
<tr>
<td>2. Stopping distance.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>3. Stopping reaction time.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>4. Stopping time.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td></td>
<td>25 points</td>
<td>0 points</td>
</tr>
</tbody>
</table>
Testing Design Strategy: Obstacle Avoidance Scenario

- Event 4: Obstacle Avoidance
  - An obstacle is placed in an arbitrary location of the roadway
  - Users must identify the obstacle and maneuver their vehicle appropriately to avoid it

- Performance evaluation
  - A score will be given based on the items below, the total score of this scenario is 25 points

<table>
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<th>Failed</th>
</tr>
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<tbody>
<tr>
<td>1. Drive on the right lane.</td>
<td>10 points</td>
<td>0 points</td>
</tr>
<tr>
<td>2. Not run off the road.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>3. Drive smoothly.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td>4. Vehicle speed lower than 30 mph.</td>
<td>5 points</td>
<td>0 points</td>
</tr>
<tr>
<td></td>
<td>25 points</td>
<td>0 points</td>
</tr>
</tbody>
</table>
### Attitudinal Questionnaire Results

#### Attitudinal Questionnaire

<table>
<thead>
<tr>
<th>Attitude Question</th>
<th>PreTest (%)</th>
<th>PostTest (%)</th>
<th>Improvement(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SA</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>Q1: I love to show off when I'm driving</td>
<td>4</td>
<td>16</td>
<td>50</td>
</tr>
<tr>
<td>Q2: If you have good skills, speeding is OK</td>
<td>8</td>
<td>36</td>
<td>34</td>
</tr>
<tr>
<td>Q6: Wearing a seatbelt makes me feel safe</td>
<td>68*</td>
<td>28</td>
<td>4</td>
</tr>
<tr>
<td>Q8: I'm still learning to be a good driver</td>
<td>34*</td>
<td>44</td>
<td>18</td>
</tr>
<tr>
<td>Q10: I would get into the car with a reckless driver if I had no other way to get home</td>
<td>6</td>
<td>28</td>
<td>36</td>
</tr>
</tbody>
</table>
Assessment: Pre-test and Post-test: Driving Knowledge Questionnaire Results

• Correct / Incorrect questionnaire

Q3: 72% agreed to wear the seat belt on the pre-test and 92% on the post-test
Q4: 95% know the proper way to check mirrors before driving
Q5: 74% react correctly when coming to a flash red light on the pre-test and 90% on the post-test
Q7: Over 90% know when to use turn signal on the express way
Q9: 66% know the right method to approach an intersection with a yellow signal light on the pre-test and 82% on the post-test

<table>
<thead>
<tr>
<th>Question</th>
<th>PreTest(%)</th>
<th>PostTest(%)</th>
<th>Improvement(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct</td>
<td>Incorrect</td>
<td>Correct</td>
</tr>
<tr>
<td>Q3</td>
<td>72</td>
<td>28</td>
<td>92</td>
</tr>
<tr>
<td>Q4</td>
<td>94</td>
<td>6</td>
<td>96</td>
</tr>
<tr>
<td>Q5</td>
<td>74</td>
<td>26</td>
<td>90</td>
</tr>
<tr>
<td>Q7</td>
<td>90</td>
<td>10</td>
<td>96</td>
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<tr>
<td>Q9</td>
<td>66</td>
<td>34</td>
<td>82</td>
</tr>
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</table>

Five correct / incorrect questionnaire
## Assessment: 50 Human Test Subjects

- Overall driving improvement is 28% 
- Subject 2 is a novice driver and demonstrated a satisfied improvement

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age</th>
<th>Driving Experience</th>
<th>1st Run</th>
<th>2nd Run</th>
<th>(%)</th>
<th>Driver Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>25</td>
<td>3~5</td>
<td>46.5</td>
<td>75</td>
<td>28.5</td>
<td>Average</td>
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<td>2</td>
<td>M</td>
<td>23</td>
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<td>66.8</td>
<td>80.8</td>
<td>14</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>25</td>
<td>0~2</td>
<td>55.2</td>
<td>81.5</td>
<td>46.3</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>28</td>
<td>3~5</td>
<td>82</td>
<td>82</td>
<td>0</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>23</td>
<td>0~2</td>
<td>73.8</td>
<td>75.5</td>
<td>1.8</td>
<td>Average</td>
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<tr>
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<td>M</td>
<td>20</td>
<td>3~5</td>
<td>39.5</td>
<td>86</td>
<td>46.5</td>
<td>Good</td>
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<td>77.5</td>
<td>75.8</td>
<td>Average</td>
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<tr>
<td>14</td>
<td>M</td>
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<td>86.5</td>
<td>86.5</td>
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<td>Good</td>
</tr>
<tr>
<td>15</td>
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<td>24</td>
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</table>

Table of 50 human test subjects
Assessment: Relationship Between Driving Score and Several Factors

- Driving score improved 28% when $V_{peak}$ decreased 3% and $V_{ave}$ increased 6%

<table>
<thead>
<tr>
<th>Subject</th>
<th>Driving Score</th>
<th>$V_{peak}$</th>
<th>$V_{ave}$</th>
<th>$\delta_{peak}$</th>
<th>$\delta_{ave}$</th>
<th>$\bar{N}_{offRoad}$</th>
<th>$\bar{N}_{doubleLine}$</th>
<th>$\bar{N}_{Speeding}$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>-5.2</td>
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<td>-1</td>
<td>-3</td>
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<td>-4</td>
<td>-6</td>
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<td>-2</td>
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<td>-213</td>
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<td>-4</td>
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<td>-2</td>
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<tr>
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<td>-1.7</td>
<td>2.2</td>
<td>-12.8</td>
<td>1.5</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
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<td>0.8</td>
<td>-1.6</td>
<td>9.4</td>
<td>6.6</td>
<td>4.8</td>
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<td>0</td>
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<tr>
<td>49</td>
<td>-1.8</td>
<td>-1.7</td>
<td>4.8</td>
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<td>-103</td>
<td>-0.1</td>
<td>-0.5</td>
<td>-1</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

Table of relationship between driving score and several factors

*Automotive Research Laboratory*
Assessment: Relationship Between Driving Score and Several Factors

- The average of $N_{\text{offroad}}$, $N_{\text{doubleline}}$, and $N_{\text{speeding}}$ decreased show that the drivers became more cautious of passing corners on the track and they showed a better awareness of controlling vehicle speed below the speed limit.
- Drivers improved their driving performance after achieving familiarity with the track and scenarios on the road.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Novice</th>
<th>Beginner</th>
<th>Experienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td>19.5</td>
<td>14.9</td>
<td>18.1</td>
</tr>
<tr>
<td>$V_{\text{peak}}$</td>
<td>-2</td>
<td>-4</td>
<td>-2</td>
</tr>
<tr>
<td>$V_{\text{ave}}$</td>
<td>1</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>$\delta_{\text{peak}}$</td>
<td>-42</td>
<td>-32</td>
<td>-50</td>
</tr>
<tr>
<td>$\delta_{\text{ave}}$</td>
<td>-24</td>
<td>11</td>
<td>61</td>
</tr>
<tr>
<td>$\hat{N}_{\text{offRoad}}$ (times)</td>
<td>-0.6</td>
<td>-0.5</td>
<td>-0.7</td>
</tr>
<tr>
<td>$\hat{N}_{\text{doubleLine}}$ (times)</td>
<td>-1.3</td>
<td>-0.8</td>
<td>-0.9</td>
</tr>
<tr>
<td>$\hat{N}_{\text{speeding}}$ (times)</td>
<td>-1.7</td>
<td>-1.3</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

Table of relationship between driving score and several factors
Assessment: Self Rating and Test Rating

- Novice drivers over-estimated their driving skills
- Only half experienced drivers achieved good test rating

<table>
<thead>
<tr>
<th>Number of Subjects</th>
<th>Novice (0~2 years)</th>
<th>Beginner (3~5 years)</th>
<th>Experienced (6+ years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>21</td>
<td>9</td>
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</tbody>
</table>

Driver’s Self Rating on Pre-test Questionnaire (Question 4)

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Average</th>
<th>Fair</th>
<th>Dangerous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice (0~2 years)</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Beginner (3~5 years)</td>
<td>4</td>
<td>9</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Experienced (6+ years)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
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</tbody>
</table>

CATS Driver Rating, DR

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Average</th>
<th>Fair</th>
<th>Dangerous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice (0~2 years)</td>
<td>0</td>
<td>9</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Beginner (3~5 years)</td>
<td>0</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Experienced (6+ years)</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Comparison table between self-rating and test-rating
Summary

• Novice drivers demonstrate significantly greater potential in enhancing their driving skills and absorbing traffic rules than experienced drivers

• An increase in driving score correlates with a decrease in peak velocity, but an increase in average velocity

• A large proportion of drivers do not realize the potential risks created by driving over the speed limit

• An average improvement of 28% in the driving score indicates that CATS succeeded in improving driver’s performance
Future Work

- Add force feedback function into CATS
- Design and build more realistic tracks
- Implement Artificial Intelligence (AI) vehicles and interact with player vehicle
- Develop more friendly user interface
- Design a strategy to better evaluate driver’s performance
Questions