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DRIVING SIMULATOR TECHNOLOGIES

University of Central Florida

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DRIVING SIMULATOR TECHNOLOGIES

Final Report

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The UCF Driving Simulator

Work was initiated at UCF in 1989 on a project to develop what was then called a "low cost" driving simulator. Using the shell of a 1983 Dodge Aries station wagon, the engine and drive train were removed, and sensors to acquire inputs from the steering wheel, transmission selector, ignition switch, brake and accelerator pedals were installed. A PC/AT system served as a control console for the simulator, by providing I/O to the simulator displays and controls, frame timing for sequencing software calls, data logging of test runs as required, and by serving as the host computer for the vehicle dynamics model. Another PC/AT machine served as the visual display computer for the simulator. A flat screen located directly in front of the vehicle displayed relatively simple scenes at a rate of 30 frames per second.

In 1995, a joint UCF research team began a project to enhance the capabilities of the simulator to incorporate modern hardware and software technology. A Silicon Graphics Onyx Reality Engine with two 200 MHz MIPS processors and 192 MB of memory was acquired and installed as the central host computer for the system. The system runs a real-time version of the Unix operating system and is sufficiently powerful to control system I/O, integrate a sophisticated vehicle dynamics model, perform data logging operations, and run a 3-channel color video display with 640 x 480 fixed resolution on each channel. Three video projectors were acquired, and a wrap around curved screen providing a 160-degree field of view was installed. The UCF Driving Simulator is shown in Figure 1.

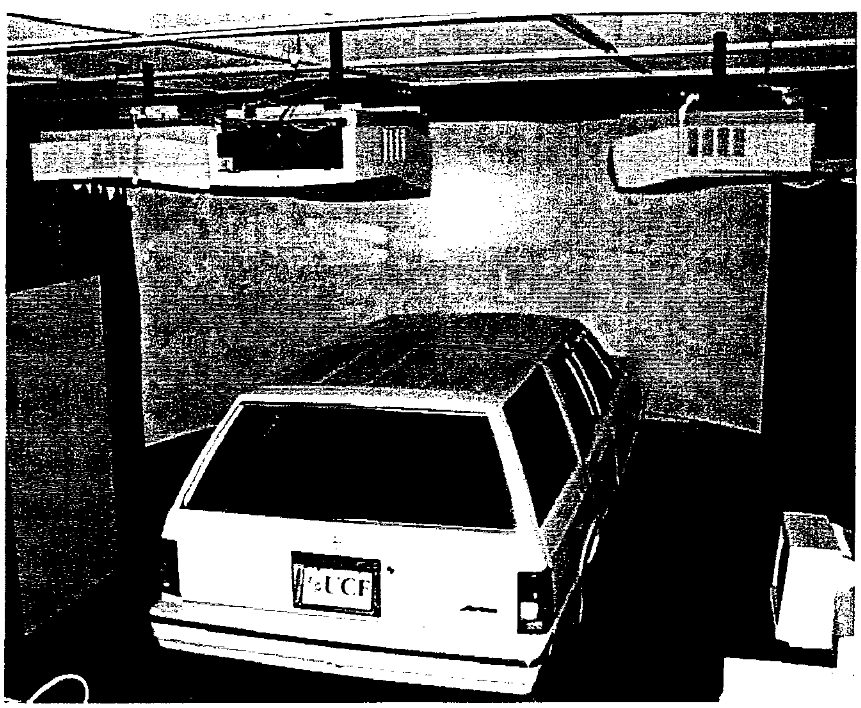

Figure 1 The UCF Driving Simulator

A block diagram of the simulator components is shown in Figure 2.

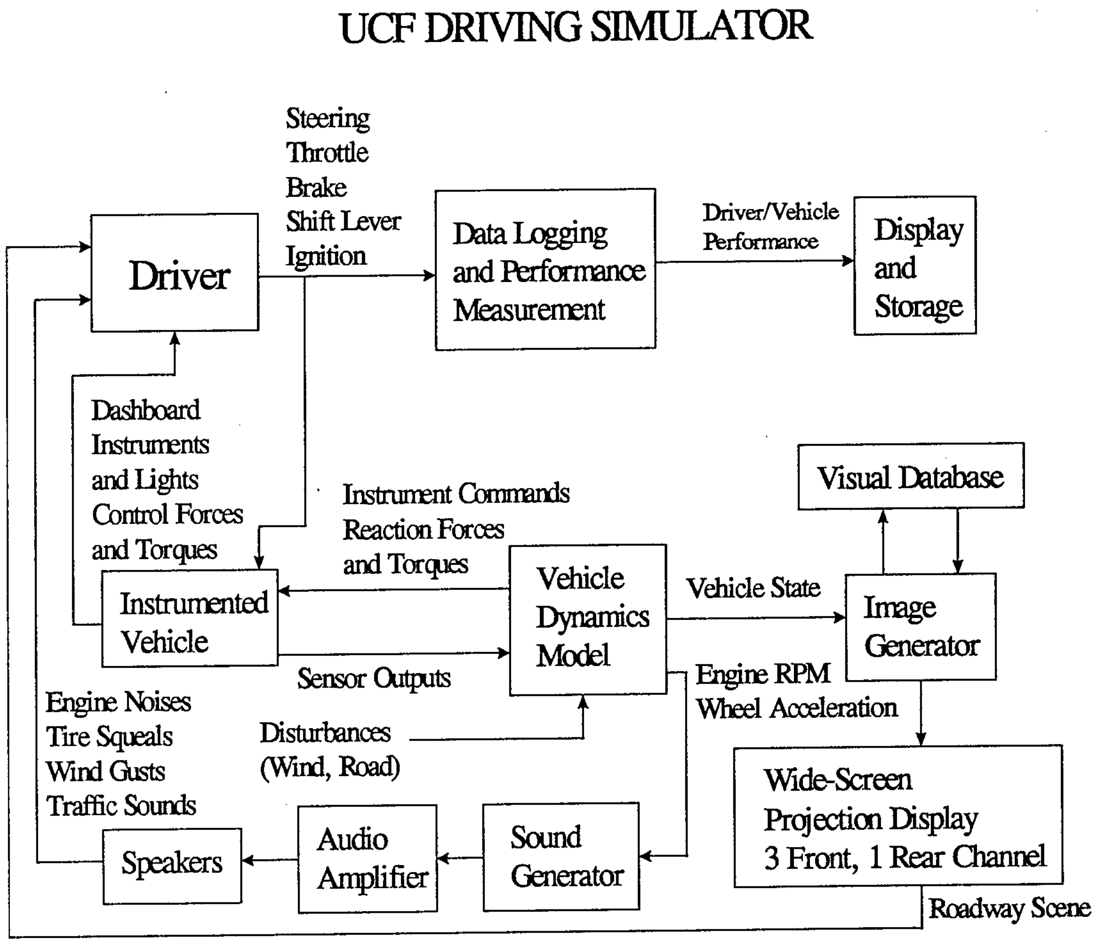

Figure 2 Block Diagram of Simulator Components

Visual data base generation from the system is now done using the MULTIGEN Software System and its associated ROAD TOOLS accessory. This software provides an interactive environment for constructing complex visual data bases with a library of useful macro functions controlled by on-screen icons selected by a mouse. A feature of the software which has proven to be very useful is its ability to synthesize objects in a visual scene by selecting geometric shapes such as rectangular solids and "pasting" texture maps on the sides of these objects. With this technique, the incorporation of buildings and other large objects into the data base becomes a simple task of taking photographs of these objects and scanning the images into the computer for use as the texture maps. The use of a digital camera allows direct input to the computer without the need for intermediate photographic processing. The operational goal of the 2nd generation simulator project was to have the capability of representing real-world driving environments. Several views through the front windshield in the simulator are shown in Figures 3 and 4.

Figure 3 View Through Windshield in Simulator Cab

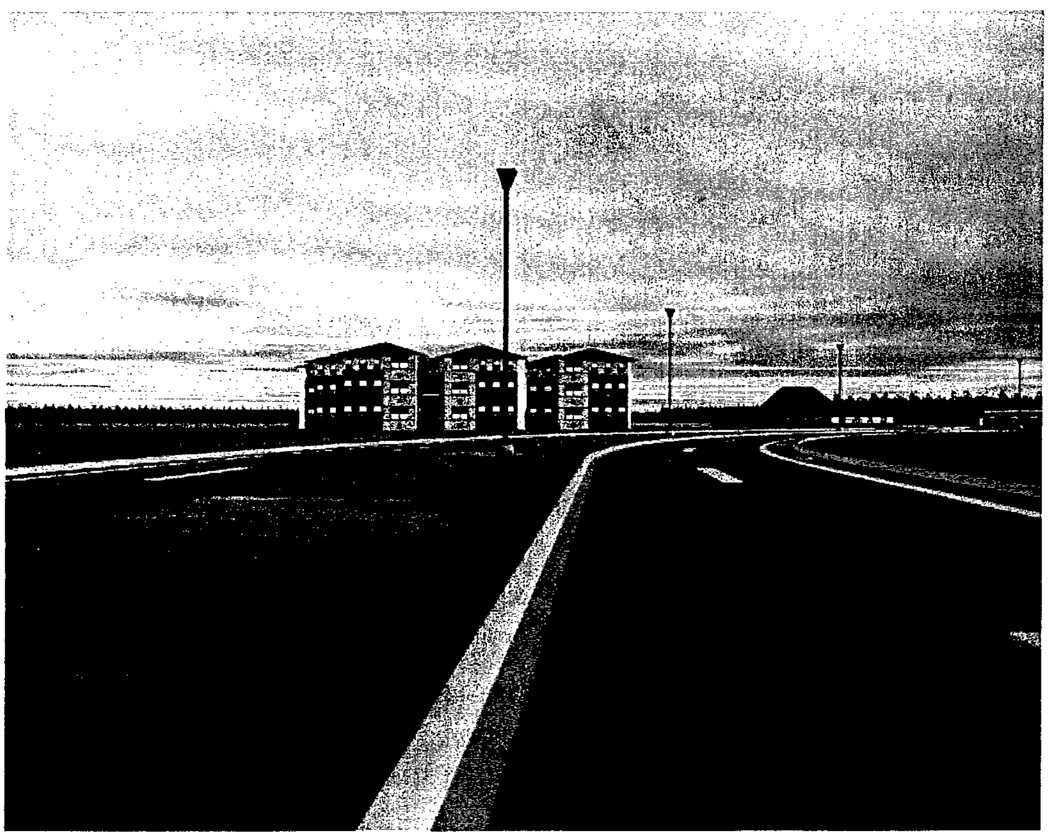

Figure 4 A Different View From the Simulator Cab

Simulator Validation

Early simulator validation studies focused more on fidelity and its effect on the transfer of training. The behavioral validity of a driving simulator according to Blana[1] is defined as "the comparison of driving performance indices from a particular experiment on a real road with indices from an experiment in a driving simulator which is as close as it can be to the real environment". The paper cites driving speed, lateral position and steering behavior as the three most prominent dependent variables used in simulator validation studies. It summarizes the results of twenty-one validation studies performed since 1989.

A study using the VTI driving simulator on a simulated and real rural road 7.2 km long and 7m wide with different speed limits (70 and 90 km/h) produced no statistically significant difference in average speed, 79.0 km/h on the road compared to 81.7 km/h in the driving simulator[2].

Description of Experiment

The most commonly used statistical analyses in simulator validation are analysis of variance (ANOVA) and comparison of means. The UCF Driving Simulator validation study described here utilized the latter. Volunteers from a representative sample of the driving population, both male and female, ranging in age from 17 years to the mid-sixties were solicited for participation in the study. No information related to driving history such as accident involvement or traffic violations was required of the subjects. The only requirement was a valid Florida driver's license and proof of liability insurance.

The subjects were selected from students, faculty, staff and visitors to the UCF community. They were asked to drive a university-owned car the entire length of Gemini Blvd. and North Orion Blvd. from Alafaya Trail to McCulloch Road and back (See Figure 5). The only visible instrument in the vehicle was a DMI (Distance Measurement Instrument). The DMI was operated by a member of the research team who was seated next to the driver in the passenger seat. The DMI provided a log of instantaneous speed, cumulative distance and elapsed time at designated points along the route for subsequent analysis.

In order for the logged data to be useful, the drivers must be free to travel at their desired speed (subject to posted speed limits) without interference from existing traffic. Consequently, the test drives were conducted during daylight off-peak periods to avoid morning and evening rush hours, resulting in little or no impact from the normal traffic flow. Other drivers on the road as well as pedestrians were not aware of any unusual conditions on the road.

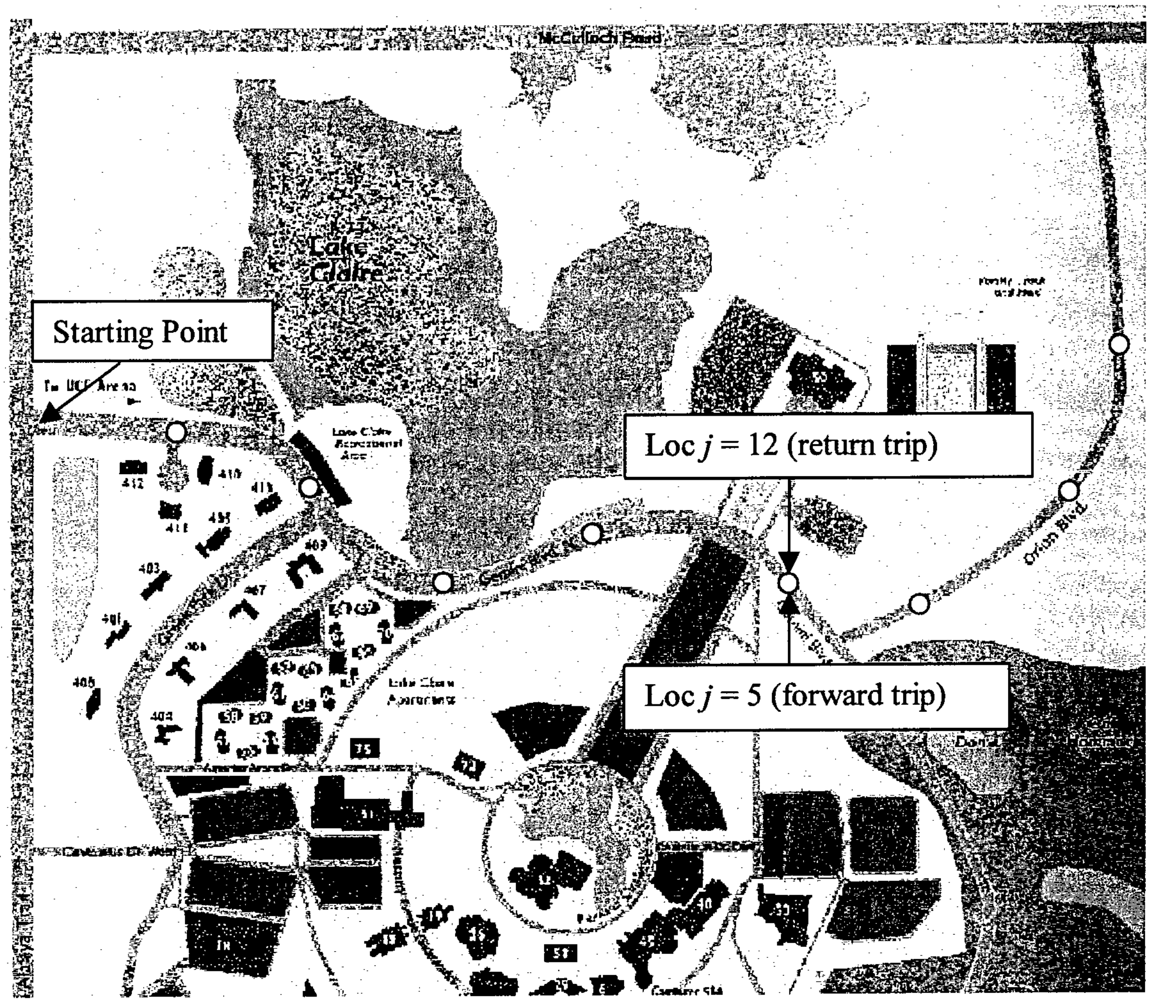

Figure 5 Field Vehicle and Simulator Driving Route
(Locations j=1 to 8 on Forward Trip and Locations j=9 to 16 on Return Trip)

The second phase of the research entailed driving in the UCF Driving Simulator which is located in the Engineering Building. The simulator consists of a complete vehicle cab with a wrap-around screen for displaying computer generated images of a synthetic road and surroundings. Computer generated imagery of the identical road and surroundings were viewable to the subjects in the simulator. The drivers were asked to perform the same task in the simulator as they did in the real driving environment. The same information acquired during field testing was gathered during simulation runs.

Sixteen speed measurements were recorded at eight specific locations corresponding to a two way trip along the test route for each driver in the field and in the simulator. The locations along the roadway (indicated by open circles in Figure 5) were selected based on the local geometry and distance from the starting point. Speed profiles obtained from the DMI and simulator logged data for one of the drivers are shown in Figure 6.

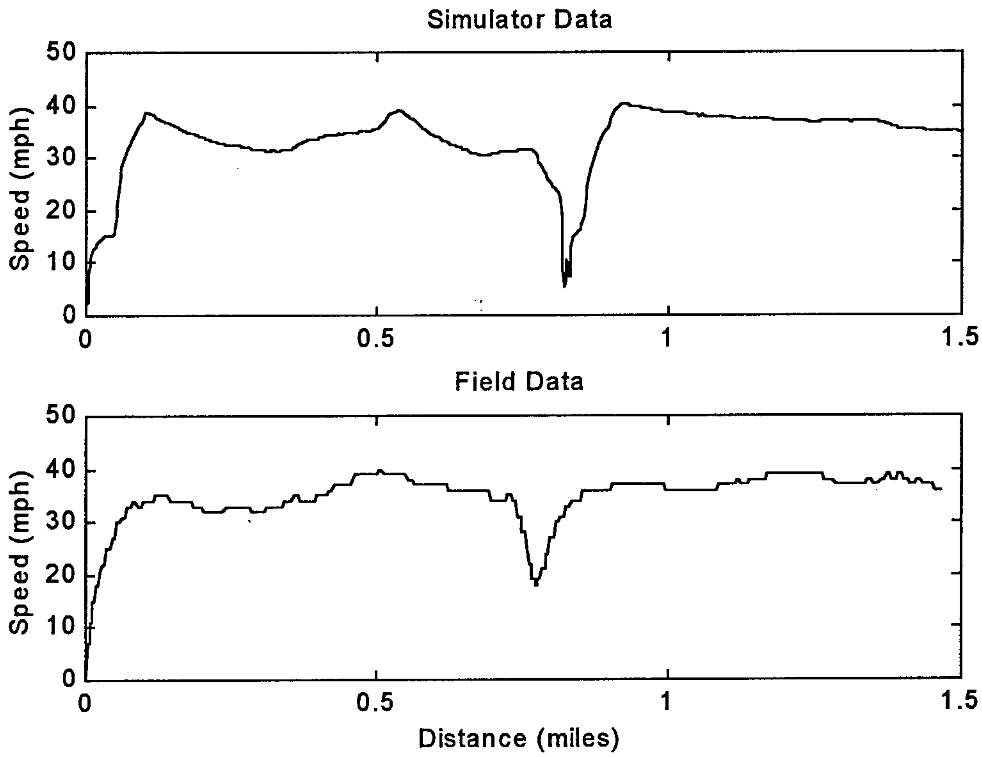

Figure 6 Speed Profiles for Simulator and Real Car for One of the Drivers

The resulting data from the field and the simulator were analyzed to ascertain whether these drivers responded differently, with respect to their forward speed, in the simulator compared to the real driving experience. This simulator validation process is necessary to establish the efficacy of using it in subsequent research involving transportation related issues.

Subjects were allowed to become familiar with the operational aspects of the simulator by driving in it along the test route for several minutes prior to the actual data gathering. A number of subjects, mostly females, were unable to complete the preliminary drive or the actual data gathering phase in the simulator due to symptoms related to simulator sickness. While the original design called for 50% male and female subjects, roughly two thirds of the subjects (21 of 30) who were able to complete the experiment were males. Half of the subjects drove in the simulator first and the other half drove the real car initially.

A description of the statistical analysis used for validation is presented. The following notation is used to describe the test procedure.

Nomenclature

m: Number of roadway locations where speed measurements are taken

n: Number of subjects that drive real car and simulator

i: Subscript denoting a specific driver, i=1,2,3,...,n

j: Subscript denoting a specific location along roadway, j=1,2,3,...,m

d_{ij}: Speed difference between simulator and field for i^{th} driver at location j

$\overline{d}_j$: Average speed difference between field and simulator for all drivers at location j

$\overline{d}_{j,c}$: Critical value for $\overline{d}_j$

F: Superscript denoting field data

S: Superscript denoting simulator data

v: Speed measurement, mph

μ_j^F: Population mean vehicle speed in the field at location j, mph

μ_j^S: Population mean vehicle speed in the simulator at location j, mph

D_j: Speed difference (random variable) between field and simulator at location j, mph

μ_{D_j}: Mean of probability distribution for D_j, mph

$\sigma_{\overline{d}_j}$: Standard error of estimate of $\overline{d}_j$, mph

s_{d_j}: Sample standard deviation (estimator of σ_{D_j}), mph

z_c: Critical value for z

Δ: Threshold for defining alternate hypothesis, mph

α: Probability (risk) of rejecting true null hypothesis

β: Probability (risk) of accepting a false null hypothesis

At the conclusion of the data gathering phase, an $n \times 2m$ table similar to Table 1 was obtained.

Driver # i	Field Speed Location: $j = 1$	Simulator Speed Location: $j = 1$	...	Field Speed Location: $j = m$	Simulator Speed Location: $j = m$
1	$v^F_{1,1}$	$v^S_{1,1}$	...	$v^F_{1,m}$	$v^S_{1,m}$
2	$v^F_{2,1}$	$v^S_{2,1}$	...	$v^F_{2,m}$	$v^S_{2,m}$
3	$v^F_{3,1}$	$v^S_{3,1}$	...	$v^F_{3,m}$	$v^S_{3,m}$
.	.	.	...	.	.
.	.	.	...	.	.
.	.	.	...	.	.
n	$v^F_{n,1}$	$v^S_{n,1}$	...	$v^F_{n,m}$	$v^S_{n,m}$

Table 1 Listing of Experimental Data

Normal populations for field and simulator driving speed along the entire roadway are not assumed. In fact, histograms of logged data in the real car and simulator at two locations, shown in Figures 7 and 8, do not support the assumption of Normally distributed speeds.

A test was designed to determine if differences existed in the mean speed for the two populations at each of the 16 locations where speed data was available. A statistical hypothesis was formulated which stipulated that no difference existed in mean driving speeds in the field and in the simulator. Field and simulator speed data from the table was then used to either substantiate the hypothesis or reject it. Either conclusion has an inherent risk or probability of being incorrect. The sample size n was 30, large enough to make the test statistic, the mean speed difference $\bar{d}$, approximately Normally distributed with acceptable risks of drawing either incorrect conclusion .

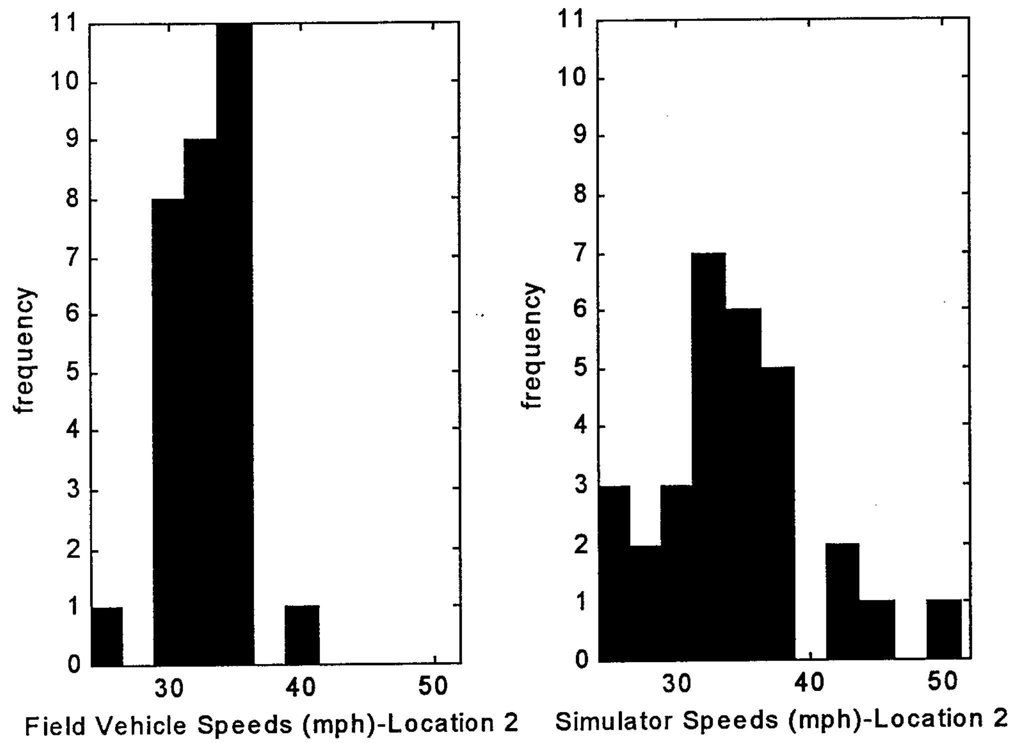

Figure 7 Field and Simulator Vehicle Speeds at Location 2

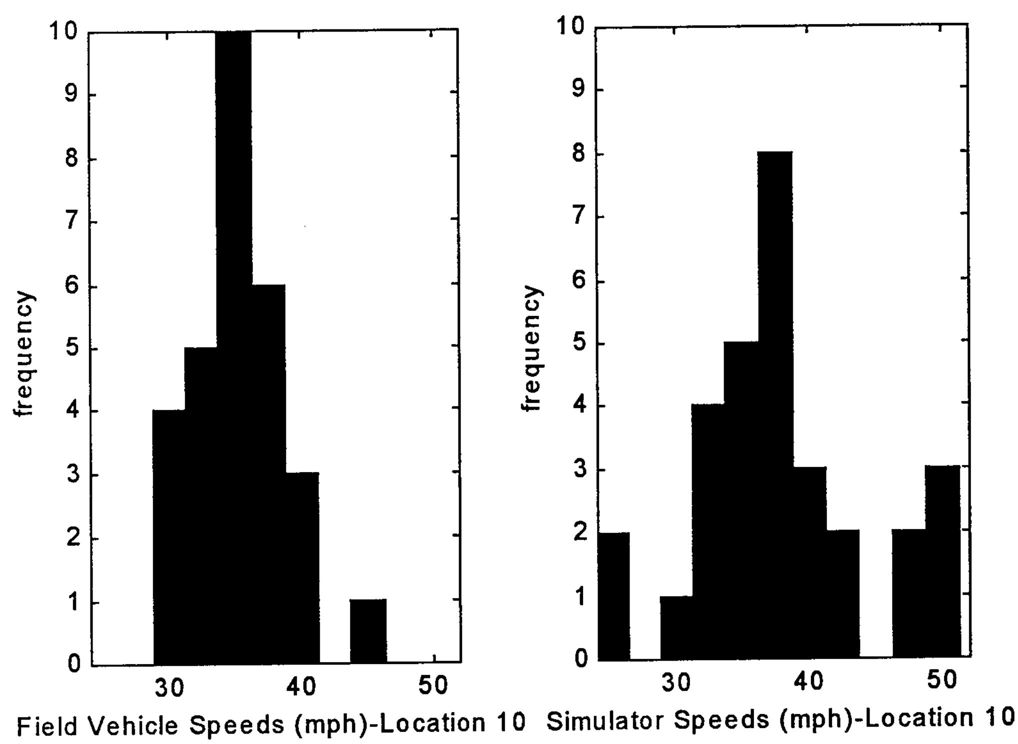

Figure 8 Field and Simulator Vehicle Speeds at Location 10

For each location j=1,2,3…,16 null and alternate hypotheses were formulated.

$$H_0: \mu_{D_j} = \mu_j^{S} - \mu_j^{F} = 0; \quad H_1: \mu_{D_j} = \mu_j^{S} - \mu_j^{F} \neq 0 \qquad j = 1,2,\ldots,16$$

The alternate hypotheses can also be expressed in the form:

$$H_1: \left|\mu_{D_j}\right| = \left|\mu_j^{S} - \mu_j^{F}\right| > \Delta$$

where Δ is a speed threshold used to define the alternate hypothesis.

The average speed difference over all drivers at the j^{th} location was computed as

$$\bar{d}_j = \frac{1}{n}\sum_{i=1}^{n} d_{i,j} = \frac{1}{n}\sum_{i=1}^{n}\left(v^{S}{}_{i,j} - v^{F}{}_{i,j}\right)$$

The standard error of $\bar{d}_j$ is approximated using the sample standard deviation s_{d_j}

$$\sigma_{\bar{d}_j} = \frac{s_{d_j}}{\sqrt{n}}$$

and the critical value $\bar{d}_c$, allowing for a Type I error (rejecting a true Null Hypothesis) to occur with probability α is

$$\bar{d}_c = z_{1-\alpha/2}\frac{s_{d_j}}{\sqrt{n}}$$

The probability of a Type II error (accepting a false Null Hypothesis) is β which can be determined once z_β is calculated from

$$z_\beta = \left(\bar{d}_c - \Delta\right)\frac{\sqrt{n}}{s_{d_j}}$$

A decision rule for accepting the null hypothesis H_0, i.e. no difference in mean speed for the simulator and the real car is

$$\text{Accept } H_0 \text{ if } -\bar{d}_c \leq \bar{d}_j \leq \bar{d}_c \qquad \text{otherwise} \qquad \text{Reject } H_0 \text{ if } \left|\bar{d}_j\right| > \bar{d}_c$$

Results

Table 2 contains measured speed data at one location for all drivers in the real car and the simulator. The sample mean $\bar{d}_7$ = -1.3 and the standard deviation $s_{d_7} = 5.6$

Choosing $\alpha = 0.05$, $z_{1-\alpha/2} = z_{0.975} = 1.96$, the critical value $\bar{d}_c$ is

$$\bar{d}_c = z_{1-\alpha/2}\frac{s_{d_7}}{\sqrt{n}} = 1.96\frac{5.6}{\sqrt{30}} = 2.0$$

Since $-d_c < \bar{d}_7 < d_c$, the Null Hypothesis is accepted at the location corresponding to the recorded data (j=7).

Driver i	Simulator Speed, mph v_i^S	Field Speed, mph v_i^F	$d_i = v_i^S - v_i^F$
1	35	35	0
2	35	29	6
3	42	34	8
4	37	40	-3
5	17	34	-17
6	34	35	-1
7	30	35	-5
8	48	39	9
9	38	40	-2
10	35	34	1
11	35	32	3
12	32	34	-2
13	45	36	9
14	31	34	-3
15	45	39	6
16	33	36	-3
17	41	33	8
18	35	32	3
19	31	36	-5
20	42	35	7
21	38	38	0

22	49	44	5
23	38	37	1
24	325	35	-3
25	39	37	2
26	49	39	10
27	30	33	-3
28	37	34	3
29	36	34	2
30	39	37	2

Table 2 Simulator and Field Speed Data at One Location ($j = 7$)

With $\Delta = 3$ mph as the threshold defining the Alternate Hypothesis,

$$z_\beta = \left(\bar{d}_c - \Delta\right)\frac{\sqrt{n}}{s_{d_7}} = (2.0-3)\frac{\sqrt{30}}{5.6} = -0.98$$

resulting in the probability of a Type II error (accepting a false Null Hypothesis) β of 0.16.

A confidence interval for the true difference between mean speeds μ_{D_j} in the field and simulator is obtained from

$$\bar{d}_j \pm z_{1-\alpha}\frac{s_{d_j}}{\sqrt{n}}$$

In the previous example, 95% and 99% confidence intervals for μ_{D_7} are:

Risk α	Confidence 100(1-α)%	Confidence Interval for $\mu_{D_7} = \mu^S_7 - \mu^F_7$
0.01	99 %	$-1.3 \pm 2.58\frac{5.6}{\sqrt{30}}$ $-3.9 < \mu_{D_7} < 1.3$
0.05	95 %	$-1.3 \pm 1.96\frac{5.6}{\sqrt{30}}$ $-3.3 < \mu_{D_7} < 0.7$

Table 3 Confidence Intervals for Mean Speed Difference At One Location (j=7)

Table 4 summarizes the results for each of the 16 locations where speed data was recorded.

Location j	Accept H_0 with $\alpha = 0.05$ (Y/N)	β Probability of Type II Error	95% C.I. (mph)	99% C.I. (mph)
1	Y	0.42	(-0.2, 5.2)	(-1.0,6.1)
2	Y	0.35	(-3.5, 1.5)	(-4.3,2.3)
3	Y	0.23	(-2.3, 2.0)	(-3.0,2.7)
4	Y	0.23	(-4.3, 0.0)	(-5.0,0.7)
5	N	0.52	(-7.8, -1.6)	(-8.7,-0.7)
6	Y	0.55	(-0.1, 6.2)	(1.1,7.2)
7	Y	0.16	(-3.3,0.7)	(-3.9,1.3)
8	N	0.27	(-4.7,-0.1)	(-5.4,0.6)
9	Y	0.76	(-3.4,6.1)	(-4.9,7.6)
10	Y	0.56	(-5.1,1.4)	(-6.1,2.4)
11	N	0.29	(-4.8,-0.1)	(-5.6,0.6)
12	N	0.59	(-10.0,-3.2)	(-11.1,-2.1)
13	N	0.40	(-6.9,-1.6)	(-7.7,-0.7)
14	Y	0.35	(-4.4,0.6)	(-5.2,1.4)
15	Y	0.22	(-4.0,0.3)	(-4.7,1.0)
16	N	0.38	(-9.1,-3.9)	(-9.9,-3)

Table 4 Summary of Results For All Locations

Conclusions

Based on the preliminary speed validation results in Table 4, subjects appear to maintain similar speeds in the simulator and the real car at the majority of the flagged locations. Of the 6 locations where the Null Hypothesis was rejected, at two of them (locations $j = 8$ and 11), the 95% confidence intervals fall just short of including zero. In fact, the 99% confidence intervals do contain zero at locations $j = 8$ and 11, indicating the Null Hypothesis would have been accepted at a 1% level of significance. At the remaining 4 locations ($j = 5$, 12, 13, and 16) where the Null Hypothesis was rejected at $\alpha = 0.05$, it would also have been rejected at $\alpha = 0.01$ since the 99% confidence intervals exclude zero. Consequently, the result of rejecting the Null Hypothesis is highly significant at those locations.

Qualitative feedback from the majority of subjects who drove in the simulator indicated a requirement for greater scene detail at moderate sight distances. Virtually all drivers slowed down prematurely in the simulator (compared to the field car) when approaching the left turn onto Orion Blvd from Gemini Blvd. Referring to Figure 5, this corresponds to location $j = 5$, one of the four locations where rejection of the Null Hypothesis was highly significant. Location $j = 12$ is the same geographical point traveling in the opposite direction.

The probabilities of making a Type II error (accepting a false Null Hypothesis) are rather large at every location (see Table 4). This can be attributed in part to the value selected for Δ (3 mph). Larger values would reduce the likelihood of erroneously assuming drivers behave similarly (with respect to forward speed) in the simulator and the real car.

From Table 4, most of the confidence intervals for $\mu_{D_j} = \mu_j{}^S - \mu_j{}^F$ are skewed to the left of zero, implying that subjects drove the test route at slower speeds in the simulator compared to the real road. The inability to discern roadway features short distances ahead may have contributed to the conservative driving patterns observed in the simulator.

Future upgrades to the simulator will include improvements in the visual system and a motion platform to provide inertial cueing forces normally present under real driving conditions. Upon completion of these upgrades, a similar validation study comparing driving speeds in the simulator and a real car will be conducted. Additional simulator validation studies are planned which will focus on the lateral control of the vehicle as well as work load effort measured to some extent by steering wheel reversals.

References

1. Blana, Evi, "The Pros and Cons of Validating Simulators Regarding Driving Behavior", Driving Simulation Conference, Lyons, France, Sept., 1997.

2. Tornos, J., Harms, L. and Alm, H., "The VTI Driving Simulator: Validation Studies", Driving Simulation Conference, Lyons, France, Sept., 1997.