Speed Perception Fidelity in a Driving Simulator Environment

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Abstract

Speed is a basic parameter of traffic operations, a critical element of traffic safety, and as a result remains the focus of myriad research efforts. The emergence of driving simulator technology has advanced traditional transportation research efforts; however the level of fidelity associated with drivers' speed perceptions in a fixed-base driving simulator environment warranted consideration. The current research effort evaluated the relationship between the driver speed selection and perception processes in both real-world and simulated environments. To complete the study, a three mile open road loop course with roadways of varying functional classification and land use was replicated in the driving simulator in the Human Performance Laboratory at the University of Massachusetts-Amherst. As part of the evaluation, drivers completed both courses and were asked to report their perceived speed at 20 predetermined checkpoints, with the speedometer occluded. Researchers recorded both the driver-reported speed and the actual vehicle speed, to identify differences. A direct comparison between actual and perceived speeds and both environments was completed. The results are significant as they provide baseline performance measures for the application of simulator technology on future speed-related research efforts.

Introduction

Roadway speed is consistently one of the most critical elements in traffic operations and safety, and as a result has become the focus of numerous research efforts. From a safety perspective, speed is regularly attributed as one of the greatest detriments to roadway safety. For the five-year period from 1999 to 2003 the National Highway Traffic Safety Administration (NHTSA) estimated that speed was a contributing factor in approximately 30 percent of all fatal crashes, accounting for 64,921 fatalities at an estimated cost of $177 billion dollars (1). As a result, all facets of speed, including the processes by which drivers select and are able to accurately perceive a travel speed, are of concern to transportation professionals.

Although speeds are readily measured by drivers in a vehicle's cabin, questions remain as to the manner in which drivers select a given travel speed. A number of variables contribute to drivers' speed selection, articulating each is a monumental task; however, using a number of "grouped" real-world scenarios to determine what environmental factors impact the speed selection process would benefit researchers, transportation professionals and law enforcement officials.

This research initiative addresses the potential use of driving simulator technology to facilitate speed related research. To the extent this application of technology can be validated, transportation researchers will have the ability to evaluate drivers speed selection process in a cost effective and timely fashion. As a result, researchers would have the ability to accurately employ driving simulator technology for simulated scenarios and research experiments where the associated variables (either dependent or independent) are based upon a driver’s/vehicle’s speed attributes.

Background and Problem Statement

In 2005, Knodler and Dulaski completed a field-based study that considered the driver speed selection process as a function of a roadway’s functional classification (xx). Although the study was primarily centered upon the speeds along roadways of varying functional classifications and subsequently speed limits, additional roadway and demographic elements were also considered.

The field-based study (field evaluation) was conducted on a three-mile loop, traversing local, collector, and arterial roadways with varying adjacent land use. There were 20 “checkpoint” locations established along the route, and at each checkpoint, a researcher in the back seat asked the driver to respond to the question, “At what speed are you traveling now?” The instrument panel was occluded from the driver by a curtain, but visible to another researcher sitting in the front passenger seat, who recorded both the actual and perceived speeds of the driver at each location. The course direction and time of day were chosen to ensure that were few vehicles on the roadways such that the driver was selecting their own speed, and not influenced by other vehicles (2).

The research resulted in several conclusions and recommendations, including:

- Drivers had a tendency, when the instrument cluster was occluded, to underestimate their travel speed. This underestimation was more noticeable on roadways without a posted speed limit;
- Male drivers were more accurate in approximating their travel speed in comparison to their actual speed;
- Driver speeds, both perceived and actual, increased as the roadway alignment changed (tangents - curves) and as the functional classification increased (local to arterial); and
- Both male and female drivers tended to travel below the prima facie speed limit on roadways that did not have a posted speed limit. Admittedly, this may be a result of the characteristics for roads that are or are not typically speed-zoned.

The current research effort described herein builds upon the initial stages of this research and is focused on evaluating differences between drivers perceptions of operating speeds in both the real world and simulated environments.

Methodology

The driving simulator evaluation was conducted with the use of a fixed-base, fully-interactive, dynamic driving simulator, housed in the Human Performance Laboratory (HPL) at the University of Massachusetts. The simulator includes a fully instrumented 1995 Saturn Sedan, three mounted overhead projectors, three projection screens, and a Bose surround sound audio system. The projected images which make up the virtual roadway adjust according to the drivers actions. The visual road is composed of three separate images projected onto the screens in front of the vehicle producing a 150-degree semicircular field-of-view. The images produced are refreshed at a rate of 60 Hz and have a resolution of 1024 x 768 dpi. The HPL driving simulator and a simulated scenario are pictured in Figure 1. In the simulator, drivers control steering, braking, and accelerating in a fashion similar to what drivers would expect in the field.

Figure 1 UMass HPL Driving Simulator and Simulated Scenario.

The simulated roadway environment was constructed in Designers Workbench (DWB), developed by Coryphaeus Software, Inc. The driving components are controlled with Real Drive Scenario Builder (RDSB) software created by Monterey Technologies, Inc.

Development of Simulation

The simulated environment experienced by drivers was designed to be consistent with the 3-mile course used in the field evaluation. The simulated environment was constructed to scale and accurately replicated the roadway alignments (horizontal and vertical curvature), roadway widths, pavement markings, and speed limits. In addition, particular attention was given to assure consistent replication of land use (houses and vegetation), and access points (driveways and side streets) to emulate the field evalaution.

The same 20 "checkpoint" locations used in the field evaluation were established in the simulated environment. Figure 2 presents the location of the checkpoints while

Table 1 includes key information regarding significant features for each of the checkpoints. In this evaluation, drivers from the field evaluation were asked to navigate the virtual world. During this simulator evaluation the same procedure was used as was in the field study, namely asking, reporting, and recording perceived and actual speeds.

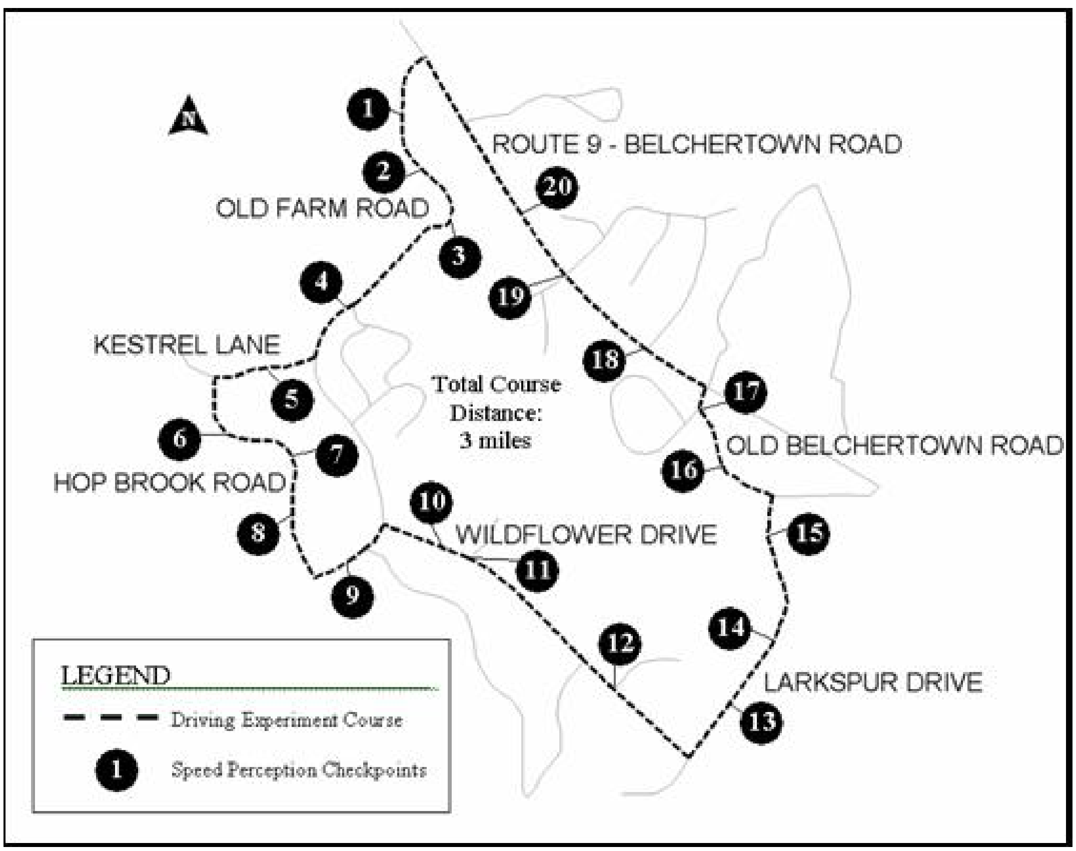

Figure 2 Field Evaluation Course.

Table 1 Description of Key Attributes by Checkpoint.

CPs[a]	Functional Class	Speed Limit[b] (mph)	Road Width[c] (ft)	Pavement Markings[d]	Additional Attributes
1 - 4	Local	30 (P)	30	CL	3 is on horizontal curve
5 - 9		30 (PF)	24	None	
10 & 11		30 (P)		CL	Both on vertical upgrade
12					On vertical downgrade
13 - 15					15 is on horizontal curve
16 & 17	Collector	40 (PF)	30	CL & EL	17 is on horizontal curve
18 - 20	Arterial	45 (P)	38		

[a] Checkpoints 1 to 20
[b] Speed limit where (P) is posted and (PF) is prima facie unposted
[c] Road width from curb to curb
[d] Pavement markings where CL indicates presence of centerline and EL indicated presence of edge lines

Results and Analysis

Eight drivers from the original field evaluation, were recruited to drive in the replicated simulator environment. A breakdown of the general driver demographics are reported in Table 2. In total, the experiment generated 320 unique data points, consisting of a *perceived* and an *actual* speed for each of 8 drivers across all 20 checkpoints.

Table 2 Recorded Driver Demographics.

Driver Number	Age	Sex	Years Driving	Miles Driven in Previous Year
1	22	Male	6	10,000 to 20,000
2	28		12	>20,000
3	31		6	<10,000
4	35		19	10,000 to 20,000
5	24	Female	8	
6	27		12	
7	28		10	<10,000
8	58		40	>20,000

The average of the reported perceived and actual speeds at each checkpoint from the field evaluation is presented in Figure 3. As shown, the average of reported speeds resulted in an underestimation of drivers actual speed at 13 of the 20 checkpoints. Averaging the algebraic differences across all 20 checkpoints results in drivers overestimation in travel speed by 0.30 mph; however when the average of the absolute difference in the perceived versus actual speed is calculated the magnitude of the average estimation error is 2.37 mph. Furthermore, the average difference in the two recorded speeds ranged from –4.50 mph (overestimation) at checkpoint 3 to 4.25 (underestimation) at checkpoint 19.

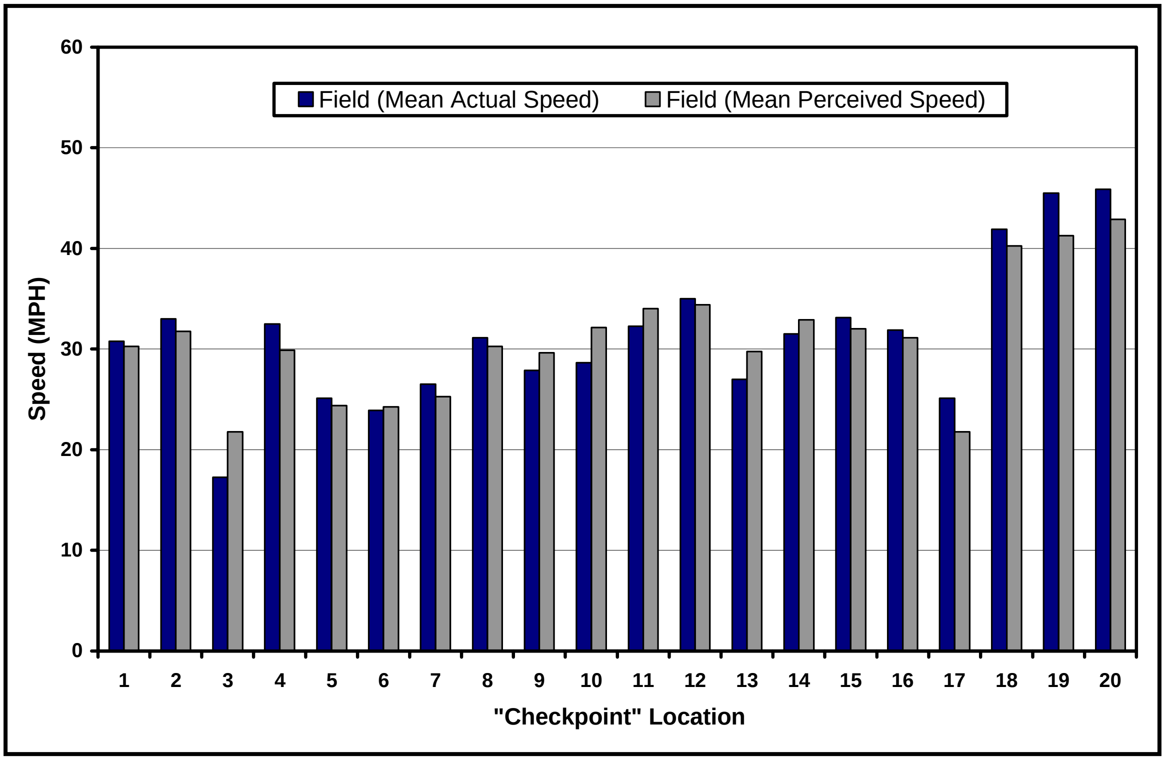

Figure 3 Mean Actual and Perceived Speeds in the Field by Checkpoint.

In the driving simulator environment, the average of drivers perceived speeds was lower than the actual speed at all 20 checkpoints as shown in Figure 4; drivers consistently underestimated their speeds in the simulator environment. The average difference in speeds across all 20 checkpoints was 6.28 mph, and when the average of the absolute difference speeds is considered the difference in speeds is 7.58 mph. The differences in the average perceived versus actual speeds ranged from 0.81 at checkpoint 10 to 15.13 at checkpoint 17.

Figure 5 and Table 3 present a side-by-side comparison of the average of the differences in both experimental mediums across checkpoints. As shown in Figure 5, at only two checkpoints (10 and 13) was the magnitude of the difference in speeds lower in the simulated environment. To determine statistical significance, a paired t-test was performed on the difference between the actual speed and perceived speed in both the simulator and field portions. Several noteworthy findings are evident from the data presented in Table 3, including:

- Checkpoints 3 and 17 resulted in the greatest differences in speed estimates for the simulator and field evaluation (12.31 and 11.75 mph, respectively). It is noteworthy to mention that both of these check point were on sharp horizontal curves. The p-values for the difference in actual and perceived speeds in the simulator when compared to the field were 0.020 and 0.010, respectively;

- Checkpoint 12, had the third largest absolute difference in responses (difference of 10.94 mph when comparing the simulator with the field). This location occurs on a vertical downgrade. A paired t-test indicated that there is a statistically significant difference between the actual and perceived speeds ($p = 0.010$); and
- Checkpoint 20 had significant values of underestimation in both experimental mediums. This checkpoint is located in the middle of a long tangent section on the high speed arterial roadway;

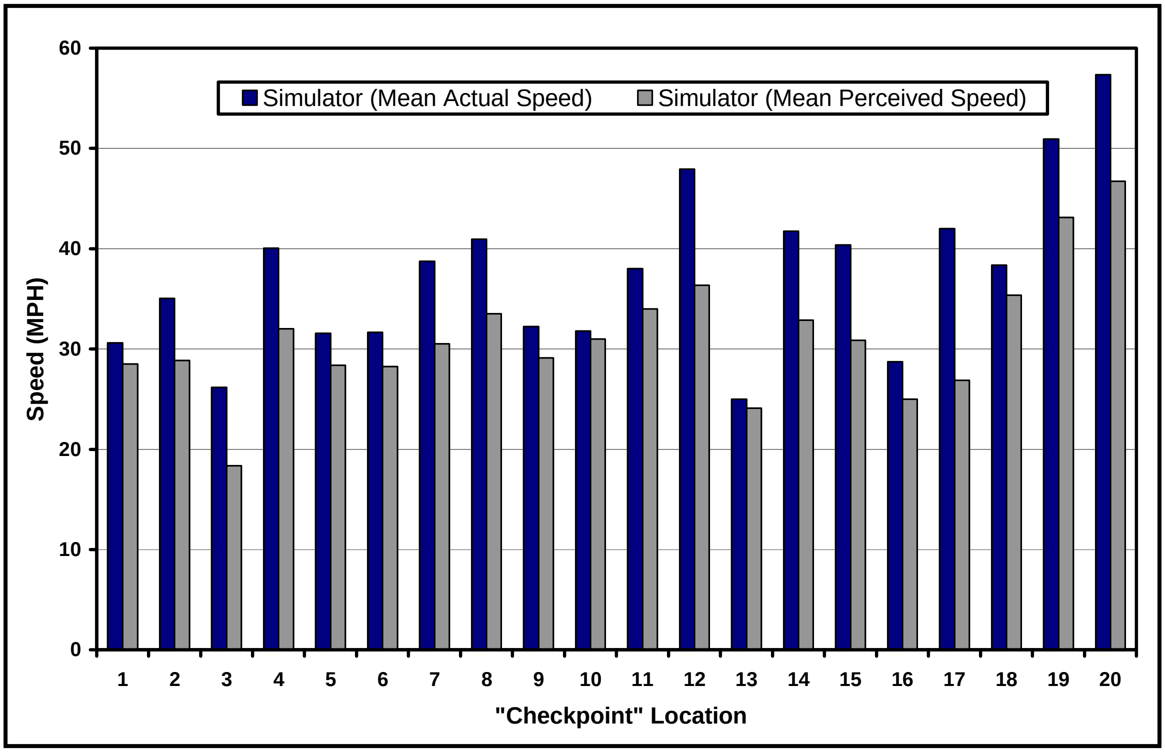

Figure 4 Mean Actual and Perceived Speeds in the Simulator by Checkpoint.

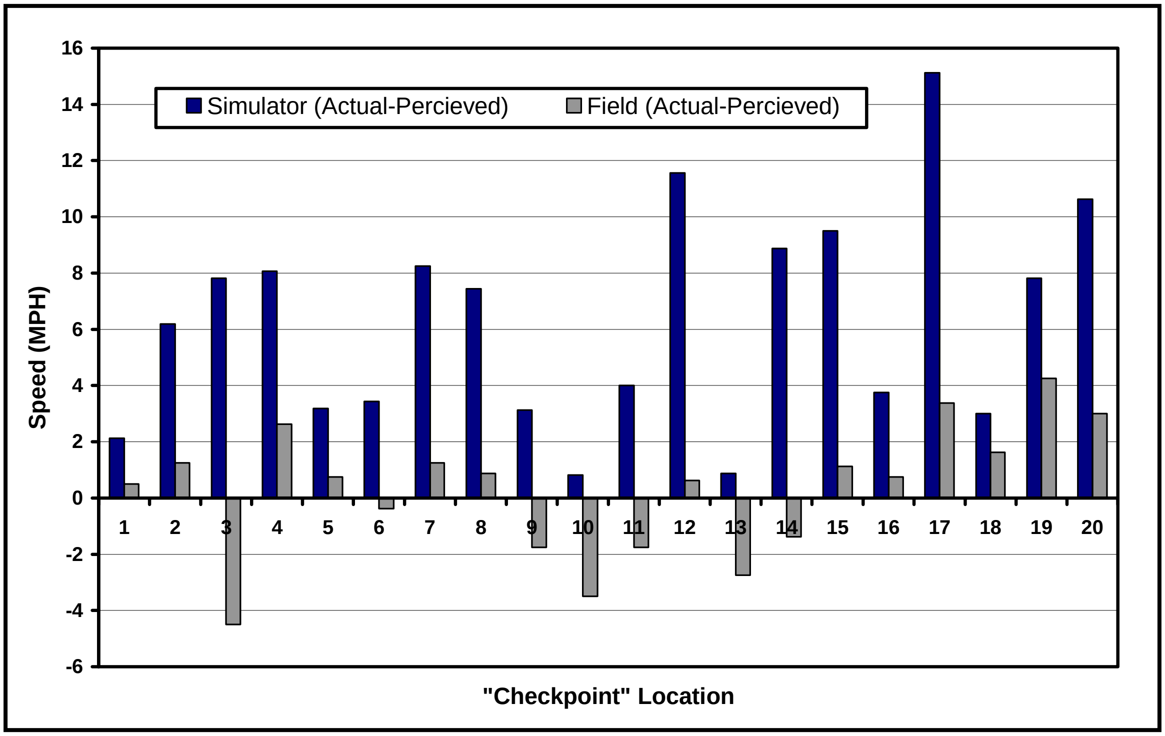

Figure 5 (Actual – Perceived) Speeds in the Simulator and Field Experiments.

Table 3 Statistics for Avg Difference in Actual and Perceived Speed by Checkpoint.

Check Point	Average		Variance		Std Dev		High Value		Low Value		Range		P Value
	Sim	Field	Sim	Field	Sim	Field	Sim	Field	Sim	Field	Sim	Field	
1	2.22	1.00	37.13	21.50	6.09	4.64	15	5	-8	-8	23	13	0.484
2	4.94	1.33	55.40	23.25	7.44	4.82	19	9	-5	-5	24	14	0.358
3	6.94	-4.00	62.65	26.00	7.92	5.10	20	1	-8	-16	28	17	0.020
4	8.06	2.67	32.65	4.75	5.71	2.18	20	7	-0.5	0	20.5	7	0.010
5	3.28	0.44	21.57	5.03	4.64	2.24	9	5	-5	-2	14	7	0.119
6	3.06	-0.56	41.90	7.03	6.47	2.65	14	4	-10	-5	24	9	0.066
7	7.11	0.78	46.55	11.69	6.82	3.42	21	5	-2	-5	23	10	0.013
8	6.06	1.00	28.03	8.50	5.29	2.92	12	5	-5	-4	17	9	0.051
9	2.78	-1.33	13.88	14.75	3.73	3.84	9	4	-3	-9	12	13	0.016
10	0.94	-3.11	36.40	13.86	6.03	3.72	7	0	-10	-10	17	10	0.036
11	3.83	-1.44	21.56	12.03	4.64	3.47	12	3	-3	-8	15	11	0.012
12	11.67	0.89	104.81	23.61	10.24	4.86	35	8	2	-6	33	14	0.031
13	0.50	-2.78	27.63	14.44	5.26	3.80	10	1	-7	-10	17	11	0.034
14	9.06	-1.56	28.15	13.28	5.31	3.64	20	2	2	-7	18	9	0.002
15	10.11	1.00	51.92	3.25	7.21	1.80	22	5	0.5	-1	21.5	6	0.007
16	3.44	0.56	27.97	15.78	5.29	3.97	12	7	-5	-8	17	15	0.183
17	14.44	2.67	82.47	24.75	9.08	4.97	35	12	7	-5	28	17	0.010
18	2.56	1.44	22.53	11.78	4.75	3.43	10	8	-3	-3	13	11	0.613
19	8.06	4.22	83.03	22.94	9.11	4.79	24	10	-10	-5	34	15	0.326
20	10.83	3.00	135.19	19.00	11.63	4.36	32	8	-10	-5	42	13	0.080
AVG	5.99	0.31	48.07	14.86	6.63	3.73	17.90	5.45	-4.15	-6.10	22.05	11.55	0.12

Conclusions and Recommendations

The study allowed for a preliminary comparison of driver speed perception in a field and driving simulator environment. The purpose was to expand upon the existing understanding of the driver speed perception process, and to evaluate the potential application of driving simulator technology in speed related research. Based on the findings, there is initial evidence to suggest that drivers tend to underestimate their travel speeds in both environments and more so in the simulator. Also, there appears to be a consistency in the trends associated with both the speeds selected and perceived. For example, in both environments drivers were operating and perceiving higher speeds on roadways with higher speed limits. Additional conclusions include the following:

- Based on initial findings it appears that drivers are more accurate perceiving their travel speed in the field. On average, the order of magnitude is approximately 5 mph difference in the simulator versus the field;
- It is also apparent that driver performance was affected at certain "checkpoint" locations. An initial inspection draws a strong correlation between horizontal curvature and speed perception. Although drivers tended to have greater difficulty estimating speed on horizontal curves, this difference appears to be more pronounced in the driving simulator;
- It is apparent that speed perception is an attribute that varies between drivers, (i.e. some drivers are more accurate or precise in their perception of speed) regardless of the experimental medium employed; and
- There is preliminary evidence which suggests that differences may exist in drivers perceptions of speed along downgrades in the simulator environment.

The results discussed herein are encouraging, but should be expanded upon and/or further validated. Potential next stages of evaluation may include the following:

- Larger sample sizes would help to strengthen the statistical significance of future results;
- In the field experiment, it was requested that drivers were evaluated while in their personal vehicles, to promote a level of comfort with the vehicles unique operational characteristics (i.e. acceleration, breaking, traction, etc.) To replicate this more accurately, drivers could participate in standardized training to better acclimate themselves to the operational characteristics of the simulator.
- Possible changes in simulator operational mechanics should be considered to better replicate real world vehicle control. For example, the rates of acceleration, brake pressure requirements, or steering wheel stiffness may translate to more accurate operational attributes; and
- Further exploration of changes in the visual field, including elements related to either textures or the environment could also be explored.

Characteristics which have the strong influences over the driver speed perception process must continue to be evaluated. It appears that the trends are similar in both the real-word and the simulator - drivers underestimate their speeds. Given this, it appears that the simulator is a valuable research tool for speed related research. Ideally, the magnitude of difference between the real world and the simulator (approximately 5 mph higher) would reduce as research continues to evolve to address some of the above findings.

References

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