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Using driving simulators to assess driving safety

ABSTRACT

Changes in drivers, vehicles, and roadways pose substantial challenges to the transportation safety community. Crash records and naturalistic driving data are useful for examining the influence of past or existing technology on drivers, and the associations between risk factors and crashes. However, they are limited because causation cannot be established and technology not yet installed in production vehicles cannot be assessed. Driving simulators have become an increasingly widespread tool to understand evolving and novel technologies. The ability to manipulate independent variables in a randomized, controlled setting also provides the added benefit of identifying causal links. This paper introduces a special issue on simulator-based safety studies. The special issue comprises 25 papers that demonstrate the use of driving simulators to address pressing transportation safety problems and includes topics as diverse as neurological dysfunction, work zone design, and driver distraction.

Prologue to special issue

The need for simulator-based studies is acute. More than any time in the past, driving and traffic safety is facing rapid and profound changes. Some of these relate to driver characteristics and others to technology and vehicle design. In the US and in other parts of the world, the aging of the baby boom generation (persons born between 1946 and 1964) will shift the demographics over the next decade. In the US alone, over 72 Million people are projected to be over the age of 65 by the year 2030 compared to 40 Million in 2010 (Based on 2000 US Census Bureau data).

This population shift will increase the prevalence of age-related cognitive impairment and prescription drug use for treating conditions such as Alzheimer and Parkinson's disease. Increasing urbanization will also bring vehicles to areas that have limited road infrastructure with potentially huge impacts to driver safety. In developing countries such as China and India, the dramatic increase in motorized vehicle use has been associated with a substantial increase in traffic fatalities, more than in developed countries. One projection shows that driving-related fatalities will increase 66% by 2020, with fatalities in developed countries declining 28%, but dramatically increasing in countries such as China (by 92%) and India (by 147%) (Koppits and Cropper, 2005).

These changes in driver demographics coincide with dramatic changes to vehicle and roadway technology. The recent concerns associated with cell phone and text-messaging distractions are likely to multiply as drivers and manufacturers integrate more internet-enabled infotainment into vehicles. Driver support systems (e.g., speed control and lane keeping) are also emerging to mitigate these distractions by warning or guiding drivers to more responsible driving habits. Such technology will increasingly automate driving such that the basic infrastructure of the vehicle will change as drive-by-wire and vehicle designs are likely to change more in the next 10 years than they have in the past 40.

The changes in drivers and technologies will likely have important consequences for driving safety that may not be immediately observed in crash data as exemplified in initial studies of driver distraction (Neyens and Boyle, 2008; Ghazizadeh and Boyle, 2009; Stutts et al., 2001). The effect of new technology only emerges after crashes accumulate and the cause of these crashes may not be easily identified. Even naturalistic driving data, which uses extensive instrumentation to provide detailed descriptions of driver behavior, fails to provide the timely and complete description of driver response to the coming changes. Because crash and naturalistic driving data provide no experimental control and every event is unique, establishing causality will always represent a fundamental challenge. In contrast, driving simulators make it possible to replicate scenarios as often as needed in a very controlled setting. Driving simulators provide a more proactive and precise description of driver performance.

Just as computer technology has begun to change vehicles, it has also made high-fidelity driver simulators increasingly affordable. Even as the prices decline, simulators have increasingly realistic vehicle dynamics and can render highly representative driving scenes. Portable desktop simulators are now able to model the vehicle dynamics associated with vehicle suspensions, power trains, and tire–roadway interactions. As an example, the National Advanced Driving Simulator (NADS) couples a particularly sophisticated multi-body dynamics model with models of individual subsystems. The resulting simulator can capture the subtle differences between specific vehicle makes and models (Salaani et al., 2007). This powerful modeling capability is now available as a desktop simulator.

Such capabilities make it possible for many more researchers and designers to benefit from driving simulators. This is reflected

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in the dramatic increase in the number of papers published on the topic. Based on the ISI bibliometric database, 124 papers (3.7 papers per year) published between 1965 and 1999 included "driving simulator" in the title, abstract, or topic. This compares to 572 papers published between the years 2000 and 2009 (63.5 papers per year). Driving simulators have become a widely used tool for examining the impact of individual driver differences, vehicle technology, and roadway design, as well as the efficacy of safety interventions.

This special issue contains 25 papers that show the power of driving simulators to address many of the looming challenges facing the traffic safety community. The special section begins with two papers that highlight some of the challenges and unique opportunities (Brooks et al.; Behr et al.). Simulator sickness has long been a challenge for researchers and may emerge as an even greater challenge as technology makes it possible to immerse drivers in an ever more richly detailed virtual environment. The second paper demonstrates the capacity for a detailed understanding of drivers' neuromuscular response to imminent collision situations. The postural and muscular response to crash situations are often much more representative of actual driving situations than one might expect given that drivers in the simulator are exposed to no actual danger.

The next section of the special issue centers on studies related to individual differences and driver state. Topics addressed by these papers include medical and physical impairments, age-related differences, and alcohol and drug use. Examining these individual differences in a controlled environment helps provide insights into situations that are difficult to measure in a naturalistic driving study such as differences in visual search as influenced by day, night, and rain while controlling for roadway demands (Konstantopoulos et al.) or differences in driving performance among drivers with and without ADHD while controlling for the demands associated with different secondary tasks (Reimer et al.).

The remaining papers of the special issue demonstrate how simulators can guide the design of advanced driver support systems and road improvements under various traffic and road situations, Examining advanced systems in a controlled environment provides a more precise understanding of situations that trigger collision warnings or driver support systems such as electronic stability control (Papelis et al.). Simulators can be used to describe how drivers respond to these rare and otherwise difficult to observe situations. A naturalistic study of a forward collision warning system observed only 28 true forward collision warning alerts in an 18-month data collection period consisting of approximately 4 weeks of driving data from each of 66 drivers (NHTSA, 2002). This contrasts with a simulator-based study that captured the response of 120 drivers to a total of 240 true forward collision alerts (two alerts per driver) over a one-month data collection period (Lee et al., 2002). Hence, simulators can provide a very efficient means of studying rare events.

Although there are challenges with naturalistic studies, there are also challenges with driving simulator studies. All research questions cannot be answered with just one approach and future studies will need to integrate data from naturalistic and simulator studies. Naturalistic studies can provide insights into the frequency and context of safety critical events not easily identified in crash data and simulator studies can provide insights into the underlying mechanisms (e.g., eye glance patterns in looked-but-did-not-see crashes). These two research approaches currently operate independently, but valuable insights can be gained from their integration. For example, the circumstances of events identified in naturalistic studies can then be controlled and manipulated in simulator experiments to evaluate novel technology that might mitigate the effects of the safety-critical event. Such a strategy would also increase the degree to which simulator data are representative of actual roadway situations.

In summary, simulator studies provide insights into how driver, vehicle, and roadway characteristics influence driving safety. The studies presented here show how road safety improvements affect driver performance and how advanced vehicle technologies can mitigate the effects of distraction, reduce speeding, and enhance vehicle control. Applications range from pharmaceuticals and information technology to pavement markings and workzone configuration. The diversity of simulator applications highlighted in this special issue provides a preview of the future challenges and opportunities in driving research and an indication of how simulators can help address them.

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Appendix A. Supplementary data

Example of Vehicle Dynamics at National Advanced Driving Simulator (courtesy of U. Iowa - NADS) can be seen here doi:10.1016/j.aap.2010.03.006.

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