Driving simulation to support road safety policy: Understanding crash risks to better inform speed setting guidelines

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Abstract

Currently, selection of the appropriate speed limit for a given road segment is based on road authorities' consideration of a number of environmental criteria. These include: cross section, alignment, and the number and type of abutting developments and traffic; the movement of and potential for conflict with other road users; the road's crash history; and seasonal influences such as holiday traffic. Observed crash data demonstrate a clear lack of uniformity in crash risk across sites within the same speed limit zone, suggesting that, if speed limits were set for safety reasons alone, there are other factor(s) affecting crash risk which are not, currently, being considered.

Driving simulators are often used to evaluate a wide variety of road safety interventions for their effects on driving performance and speeding behaviour. Policy makers and regulators tend to question, however, whether results from simulator-based research can and should be used to reliably predict actual changes in real-world crash risk. This paper reviews issues related to simulator validity and fidelity, and presents three psychological constructs, driver workload, situation awareness, and hazard perception, that can be measured in the driving simulator and are commonly used as 'surrogate' measures of crash risk. Driving simulation offers a safe, low cost method to identify and investigate environmental factors affecting crash risk which are not, currently, included in speed setting guidelines. By providing for a more complete account of the factors that affect crash risk, the inclusion of these features in future speed setting or road design guidelines could be expected to lead to reductions in crash risk and, consequently, enhanced overall road safety.

Keywords

Speeding, driver behaviour, human factors, speed limits

1. Introduction

The risk of a driver being involved in a crash depends on many factors, including characteristics of the road, vehicle, environment, driver, other road users, and finally, opportunity. 'Crash risk' describes the probability of being involved in a collision given one's interaction with the road transport system. The crash risk associated with any one of the above elements is usually calculated by statistical analysis of frequencies of observed road crashes; in particular, through the application of statistical modelling approaches such as factor analysis and logistical regression to databases of police-reported crash statistics.

The selection of speed limits by Australasian road authorities, as well as internationally, is determined through the application of speed setting guidelines found in various traffic engineering manuals [e.g.,1]. These manuals specify criteria that are to be considered when choosing the appropriate speed limit for each segment of road, and include physical road characteristics, the extent and nature of any abutting development, typical movement of road users, the road's crash history, and traffic patterns [1]. The process is also assisted through use of computer speed advisory programs such as ARRB's LIMITS program [e.g., 2]. These programs use general road site characteristics as input data, which are then applied to algorithms to produce recommended speed limits. The aim behind the process is to produce speed zones that take into account safety and mobility needs, and that are recognised as being consistent and fair by motorists.

A MUARC review of 1997-2001 crash rates within 70 and 80 km/h speed zones in Victoria revealed large variations in crash risk across road segments [3], suggesting that there is a range of crash rates within zones of similar speeds (see Figure 1). The large variability in crash risk within the same speed limit zone suggests that there are other factors besides those used in the current speed setting guidelines that contribute to crash risk. Although data in Figure 1 are somewhat dated, the analysis used a complex methodology incorporating road and road segment length *vs.* traffic volume and observed crash rate, and results using more recent data from the same or other jurisdictions would be expected to be very similar. Therefore, a research trial to identify these factors is currently being undertaken by the MUARC Baseline Research Program, a joint undertaking of the Victorian government (VicRoads, the Transport Accident Commission and the Department of Justice, with representation from the Victoria Police) and Monash University to undertake research into road safety issues relevant to Victoria's road safety policy formulation and delivery. Sophisticated statistical models are being developed to estimate the relationship between speed and crash risk, and its interaction with key road environment features. This modelling work will eventually yield multivariate statistical models that identify factors affecting crash risk, and a database of key road environment features that can be used to better inform road design and speed setting guidelines. A key activity of this research will be to validate the statistical models by testing the resultant hypotheses and predictions in a safe and cost-effective manner.

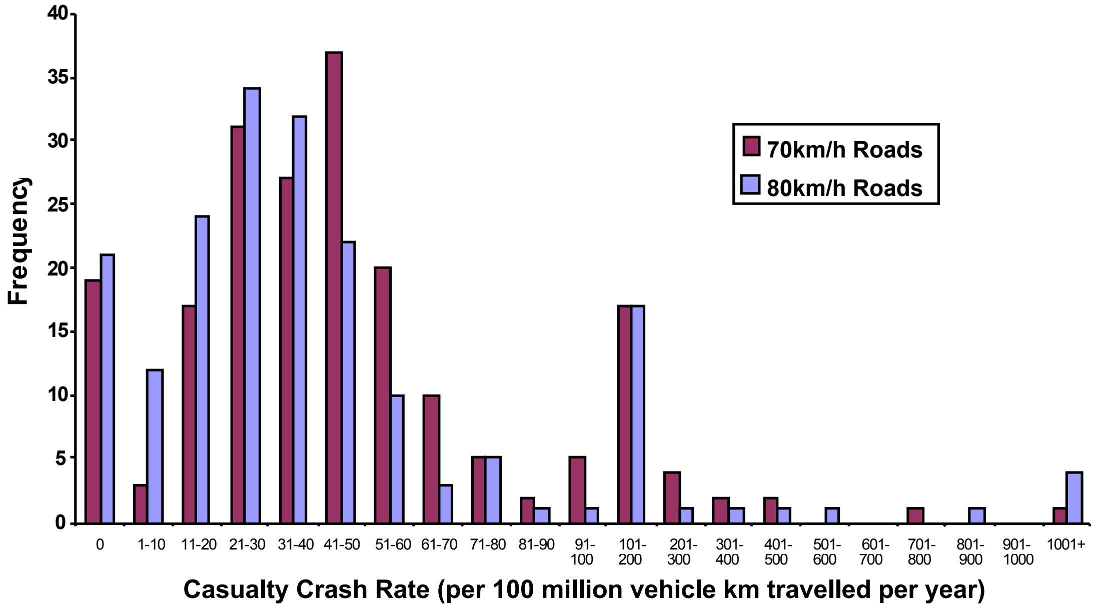

Figure 1: Distribution of Crash Rates in 70 km/h and 80 km/h Speed Zones, Metropolitan Melbourne 1997–2001 [3].

The use of simulation to train operators and to conduct research has been accepted practice within the aviation industry since the early days of flight history [4, 5]. While the use of simulation in aviation can be easily justified on the basis of the very high cost of real world flight operations, it is more difficult to justify the use of simulation for driver training and research based on cost alone. However, in both cases, the use of simulation offers a number of advantages unrelated to cost, the most salient being safety [4, 6-9]. Driving simulation has been around since at least the 1960s [5] and, since then, has undergone many advances in terms of computing, visual display, and vehicle dynamics, capabilities. Today, many universities and institutes involved in road safety research include a driving simulator amongst their array of research tools; however, while popular among students and researchers, the validity of using driving simulation to understand the behaviours predictive of actual crash risk is a critical issue that is not commonly considered [7]. This leads to the overarching aim of the present discussion: to investigate whether driving simulation can, and should, be used to understand and reliably predict changes in actual crash risk, and consequently to potentially inform road design and/or speed-setting procedures.

2. Driving simulation validity / fidelity

The term ‘validity’, when used in the context of behavioural research, refers to how well a study, procedure, or measure does what it is intended to do [10]. The validity of a driving simulator is obviously of great importance to researchers and policy makers alike; however, it is not necessary for *all* elements of a driving simulator to be identical to those associated with a real vehicle. Instead, the choice of whether to use a driving simulator should be based on whether the simulator is sufficiently valid for the specific task or behaviour that is under investigation. As long as the set of cues that is germane to the aspect of driving that is under investigation is valid, results from a simulator may be as compelling as those from a field experiment [6].

Two types of validity that are often discussed in the simulation literature are *physical validity* and *behavioural validity*. Depending on the underlying purpose(s) for using a simulator in a given situation, either of these types of validity can be more, or less, relevant.

Physical validity. The physical correspondence of a simulator’s components, layout, and dynamics with those experienced in a real world setting is referred to as its “fidelity”, or physical validity [7, 11]. The level of simulator fidelity that is ultimately selected by a given lab or research facility is almost always determined by one factor: cost [11]. Lower fidelity simulators, which are often based on personal computers or workstations with add-on steering wheel and pedal components originally designed for video games, provide limited or no kinaesthetic feedback to the driver (“fixed-base”), have limited visual graphic capabilities, and only rudimentary control of vehicle dynamics. Higher fidelity, or ‘advanced’ simulators, like the one housed at MUARC (see Figure 2), offer an added level of concordance between the simulated stimuli and those which would be experienced on an actual roadway by employing even more sophisticated graphics packages. These ‘moving-base’ simulators provide at least a 180 degree field-of-view, and are commonly experienced by participants as very closely reproducing the experience of real driving.

Figure 2: MUARC's advanced driving simulator.

Behavioural validity. A second type of simulator validity relates to the comparison of operators’ performance in the simulator *vs.* that which occurs in the real world. Known as a simulator’s ‘behavioural’ or ‘predictive’ validity, it is often presumed to be closely correlated with a simulator’s fidelity; however, this is not necessarily the case [7]. It is possible, for example, for a high fidelity driving simulator to have the same behavioural validity as a much lower fidelity one, allowing the same conclusions to be drawn from research conducted using both models. At the same time, there may be advantages other than cost that are associated with a lower fidelity model, such as the ease with which it can be programmed and with which data can be extracted. Unfortunately, it is the physical, and not the behavioural, validity of a simulator that is most often reported. A researcher or research organisation considering the purchase of a driving simulator must, therefore, be careful to consider trade-offs that are associated with behavioural *vs.* physical validity as, oftentimes, too much importance is placed on the latter [7, 11].

If results from driving simulation research are to be used as the basis for informing real world road safety policy, including speed-setting guidelines, it is important that a simulator's behavioural validity be assessed and demonstrated to lie within an acceptable range. The most effective way to accomplish this is to compare driving performance in a real vehicle to that observed in a driving simulator, using tasks that are as similar as possible to one another in both environments [12]. This comparison will generate two subsets, or categories, of simulator behavioural validity that are argued to have opposing levels of importance for effective human factors research [13]. The degree to which a simulator generates the same numerical values of driving performance as those observed in the real world is called its *absolute validity.* On the other hand, the degree to which any changes in those measures of driving performance are in the same direction, and have a similar magnitude, as those in the real world is known as a simulator's *relative validity.* Some researchers contend that it is a simulator's relative validity that is of greatest import, as research questions tend to deal with matters relating to the effects of treatment *vs.* control levels of an independent variable. In fact, research validating the use of driving simulators for the assessment of a speed control countermeasure (transverse rumble strips) found that participants driving a high fidelity driving simulator responded to the rumble strips in very similar ways as did participants who drove an instrumented vehicle, which established the relative validity of the simulator [7]. However, participants generally drove faster in the instrumented vehicle than in the simulator, which resulted in the absolute validity of the simulator not being established. The authors concluded that speed is a valid measure for experiments designed to investigate road-based speeding countermeasures conducted on the MUARC driving simulator and, although the simulator would not be appropriate to assess absolute numerical speed values, the relative validity of the simulator makes it a valuable research tool in this area.

In summary, there are several different types of validity that can be applied to driving simulators. A standard design approach for many simulator developers and users is to incorporate the highest possible level of fidelity and to hope for the best possible outcome with respect to the applicability of research results to the real world. This approach is the direct result of the belief that high levels of physical validity, or fidelity, equate to high levels of behavioural validity, despite the fact that there is evidence that suggests this might not be true [11]. Instead, it is more important to focus on the specific goal of the research, and to carefully consider the trade-offs between fidelity and cost; it is quite possible, and even likely, that a lower-fidelity simulator will be entirely adequate for the underlying purpose of a given research program. As Liu et al. [11] point out, the answer to the question of how real does simulation need to be in order to translate the effects of a road safety intervention to the real world, is "it depends" (p.71). Most importantly, it will depend on the underlying purpose for choosing to use simulation in the first place.

3. "Surrogate" measures of crash risk

There are typically a large number of contributory factors that are at play in the lead-up to a crash. Very often, it is road users' behaviour that plays a central role in crash causation [14]. Because, technically, it is not currently possible to have multiple, independent drivers interact in a common driving simulation platform in a way that is similar to real traffic situations, and because traffic crashes are rare occurrences in any environment, it is not possible to experimentally measure crash risk directly. Researchers can measure how often a subject vehicle 'crashes' with other simulated vehicles in the simulator; however, these vehicles, which are part of the simulated ambient traffic, are programmed to behave in a random or semi-random manner, and are not able (in most cases) to interact 'intelligently' with a subject vehicle. Instead, it is common and accepted practice amongst road safety researchers to measure changes in so-called "surrogate" measures of crash risk [15]. Because there is an assumption that any behavioural changes seen in the simulator would translate in a similar way to the real world, they can be assumed to be representative of an analogous change in real world crash risk. Three common measures of surrogate crash risk, driver workload, situation awareness, and hazard perception, are presented here.

Driver workload. Driver workload refers to the amount of effort a driver devotes to the driving task. More generally, workload can be defined as a set of task demands, as effort, and as activity or accomplishment [16], where the task demands are the goal to be achieved, including the time allowed to perform the task, and the performance level to which the task is to be completed [17].

Driver performance on a secondary task is one of the most commonly used dependent measures of workload in driving research. This technique requires the driver to perform the primary task of driving while, at the same time, use any spare attention or capacity to perform a secondary task. The change in performance on the secondary task between different driving conditions is considered to reflect the amount of workload generated by each [17]. One commonly used secondary task is the peripheral detection task, or PDT, wherein a participant driver must press a button, for example, every time a light or other stimulus is presented in the driver's peripheral field of vision. A demonstrated source of increased driver workload is the use of mobile phones while driving [18], which parenthetically is associated with deteriorated performance on the PDT in both simulated [19] and on-road field studies [20].

Vehicle control variables that reflect changes in driver workload and that can be measured with precise accuracy in a simulated environment include speed choice and speed variability, or the standard deviation of speed. Speed variability within a non-distracted, attentive driver who is travelling in 'free-flowing' conditions (unimpeded by other road users) on a given road segment with a consistent speed limit should not, theoretically, be large. Typically, though, if a driver begins to perform a secondary task such as talking on a mobile phone or looking at an in-vehicle device s/he will tend to reduce their speed in order to compensate for the increase in visual and/or cognitive workload [20-22]. If performance of the secondary task is intermittent, then the driver will consequently tend to speed up and slow down, depending on whether or not s/he is actively engaged in the task. Fuller [23] refers to the tendency of drivers to regulate their vehicle speed in order to maintain task difficulty within selected boundaries the 'task capability interface' model of driver behaviour. He postulates that speed is the easiest, and the most common, vehicle control variable that drivers use, when required, to reduce mental workload associated with the driving task.

Another vehicle control variable that is used as a measure of driver workload is vehicle headway time, sometimes referred to as time-to-collision, or TTC. Headway time refers to the time to impact for a (following) subject vehicle to strike a lead vehicle if it were to come to a sudden and complete stop. Most driving training guidelines recommend that drivers maintain a 2.0 s time headway, as this will allow the majority of drivers to react to any expected event(s) in a safe time margin. Driving simulator studies have shown that time headway is a sensitive measure to manipulations that have the capacity to distract drivers and increase mental workload. For example, drivers conversing by either hand held or hands free mobile phones increased their following distance to a lead vehicle by over four percent [18]. The authors concluded that this increase in headway to a lead vehicle was adopted in order to compensate for drivers' increased reaction time, which was slowed by over eight percent compared to baseline. In addition, this slowed reaction time resulted in their being involved in significantly more rear-end collisions, when the leading "pace car" braked unexpectedly.

Subjective estimates of driver workload usually comprise one or more questions presented in a questionnaire format that are designed to probe a driver's experience of workload. One of the most commonly used subjective workload questionnaires used in driving research is the NASA task load index, or TLX [24]. The NASA TLX is a multidimensional rating instrument that uses a 10-point Likert rating scale to explore various aspects of mental workload, such as task demand, the participant's feelings of being rushed, and their feelings of discouragement. An advantage of administering questionnaires like the NASA TLX in a simulated environment is that the simulation can be paused or 'frozen' by an experimenter at any time, enabling the participant to complete the questionnaire in an unhurried, and safe, manner.

Situation awareness. Situation awareness (SA) can be defined as awareness of what is happening around you, and understanding what that information means to you now and in the future [25]. In terms of driving behaviour, situation awareness refers to how attuned a driver is to his or her current roadway surroundings, and how well he or she understands what is about to happen on-road in the near, and less near, future.

The relationship between SA and crash risk is such that, as a driver's level of SA decreases, his or her risk of being involved in a collision increases. If a driver's attention is not focused on the driving task at hand, she or he may still be able to adequately control the vehicle under normal driving conditions; however, it is when unexpected events occur that the likelihood of collision increases. One of the most common ways for drivers' SA to decrease is to become distracted. In fact, the cognitive load involved with talking on a mobile phone while driving, whether it be in hand held or hands free mode, has been demonstrated to decrease drivers' SA when driving [26, 27]. Authors have concluded that mobile phone conversations compete for limited mental resources of drivers, which leads to less attention to, and inaccurate knowledge of, the driving situation [26].

One concept that is significant in terms of its relevance to driving-related SA is *automaticity*. Automaticity occurs when a person's behaviour and reactions become automatic, through experience with a routine task. Automaticity can have a positive effect on SA; for example, when it frees up mental effort for more demanding tasks, such as when experienced drivers are not aware of where their feet are positioned, and can instead concentrate on where they are steering. However, it can also have negative consequences on SA, as when information outside the scope of the 'routinised' sequence might not be attended to; for example, when a new stop sign is erected on a well-travelled route home, and many drivers drive right past it, not even noticing this new and significant piece of information.

The construct of SA has often been investigated through the use of driving simulators. Because of the ease with which a simulated driving scenario can be 'frozen' at any time point within a test drive, simulation is an especially apt platform through which to study SA. Although it can also be studied in on-road or test track studies by using retrospective recollection techniques or by an accompanying experimenter asking the driver probe questions while driving, the precise control over conditions and subjects makes driving simulation the ideal methodology for SA. Using a query method in which experimenters stopped the simulator at given time points and asked participants relevant questions about the current driving scene and a direction-following task, Kass et al. [26] found that engagement in mobile phone conversations while driving decreased participants' scores on both SA measures. The authors concluded that, when participants talked on the mobile phone, they were unable to maintain the same level of SA as other drivers. Interestingly, novices using mobile phones were involved in more simulated collisions, drove through more stop signs, and crossed the centreline more often than more experienced drivers using mobile phones, a finding that mirrors on-road crash statistics [28].

A simple method to assess SA in both simulator and on-road research is to measure participants' reaction time on the PDT. This method is advantageous over the query method, in that it does not interrupt the ongoing driving task, and infers the degree of SA from a driver's performance on the PDT through measurement of stimulus detection, the accuracy of the detection, and the latency to respond [29].

Hazard perception. A driver skill that has been found to reliably correlate with crash risk is hazard perception ability [30]. In fact, the relationship is so well established that many driver licensing systems require license applicants to successfully complete a hazard perception test, or HPT, before they can be awarded licensure [31].

Hazard perception ability can be successfully evaluated using driving simulation, for example, using the PDT or by evaluating brake reaction time (BRT). BRT can be measured extremely precisely within a simulated environment. This makes it an ideal dependent measure for most studies designed to evaluate the effects of environmental or secondary task manipulations on driver behaviour and response to threatening or potentially hazardous stimuli. For example, in a simulator study looking at drivers' use of in-vehicle MP3 players (iPods), BRT was found to increase significantly by 26 percent, or by 0.42 s, when drivers were performing a 'difficult' iPod task compared to when performing an 'easy' task [32]. The authors interpreted this finding as indicating that iPod interactions impaired drivers' ability to respond to hazards on the roadway and to maintain safe vehicle control, as prolonged glances away from the road have been argued by many to pose an increased crash risk [33, 34]. Other driver conditions that have been found to affect hazard perception ability in driving simulation studies include sleepiness or drowsiness [30, 35], and driver experience [36-38].

Other than benefits in terms of safety, simulation offers advantages over on-road methods in evaluating hazard perception. For example, the level of control over critical event presentation available to the experimenter is much greater in simulator studies than on-road, and allows for greater control over data collection. Further, precise hazard perception measurements such as drivers' 'useful field of view' can be measured more easily in driving simulators than in actual vehicles [35]. Previously validated hazard perception tasks, including the evaluation of brake reaction time, can be easily implemented in the driving simulator to test the effects of various road design, engineering and infrastructure-based interventions on road safety.

4. The use of driving simulation to inform speed-setting guidelines

In the real world, relative crash risk associated with a segment of road is determined by comparing the observed crash rate to crash rates from other, similar segments of road, with key variables (e.g., time of day, traffic volume, etc.) being controlled [3], generating a numerical relative risk ratio. Using this method, it is possible to calculate the relative contribution of road design factors to the crash risk associated with roads with the same speed limit [39, 40]. Results from driving simulation research on surrogate measures of crash risk can similarly potentially be used to estimate the direction and general extent of any changes in real world crash risk through the application of numerical relative risk factors. This is the subject of the on-going research program.

As a first step in predicting how road design factors influence travel speed and real world crash risk, driver workload, situation awareness and hazard perception are currently being used in a medium-fidelity driving simulator experiment to evaluate the effects of an environmental road design factor, on-street parking, on driving performance, travel speed, and inferred crash risk. The aim of the simulator study is to demonstrate the validity of using simulation to investigate the behavioural constructs that underlie environmental factors' effect on speed and crash risk. Choice of the environmental factor of interest (on-street parking) was informed by previous analyses of observed crash statistics that identified the presence of on-street parking as a contributory factor to observed crash risk in urban road environments [41-43].

Twenty-four adult participants will drive the MUARC portable simulator through an urban, 60 km/h road environment consisting of segments representing three possible conditions: no on-street parking, on-street parking with unoccupied parking bays, and on-street parking with 90% occupied parking bays. Dependent measures include reaction time to a safety-relevant PDT, driving performance variables (vehicle speed, standard deviation of vehicle speed, lane position and lane position variability), driver workload ratings following each road segment, and reaction time to an unexpected pedestrian event. Results will demonstrate whether these dependent variables and surrogate measures of crash risk are affected by the various levels of on-street parking, and will allow for the development of speed-related and other countermeasures to moderate the effects of on-street parking on crash risk and to improve overall road safety. For example, if full parking bays are found to be associated with decreases in driver performance on surrogate measures of crash risk (increased workload, decreased performance on HPT, increase in reaction time to pedestrian event) compared to empty parking bays, it may be possible to devise a formula to calculate the speed limit required to improve these measures to an acceptable level. Another possibility would be to evaluate previously untested, novel configurations of parking bay distribution on surrogate measures of crash risk as a means to limit inferred crash risk.

5. Conclusions and Future Directions

Driving simulation offers a safe, low cost method to identify and investigate environmental factors affecting speed and crash risk that are not, currently, included in speed setting guidelines. Speed has been demonstrated to be a valid dependent measure for simulator experiments designed to investigate road-based speeding countermeasures that shows corresponding changes to on-road speed behaviour as measured using an instrumented vehicle [7]. Psychological constructs that are commonly used as "surrogate" measures of real world crash risk in driving simulator research include driver workload, situation awareness, and hazard perception.

Although a simulator's physical validity, or fidelity, is important insofar as ensuring that the simulator provides a driving environment that is reasonably representative of the real demands of driving, results from behavioural and other research that have considered validity issues of simulators demonstrate that it is a simulator's behavioural, and especially its relative, validity that is of greatest import with respect to the validity of results and their application to the real world. Simulation represents an important, and essential, first step in evaluating speed interventions that are previously untested. In this regard, it can and should play an important role in road authorities' understanding of the relationship between the road environment, speed and crash risk by validating those factors that are suspected, or are identified through statistical modelling methods, of contributing to real world crash risk.

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References

1. VicRoads, Traffic Engineering Manual, Volume 1, Chapter 7. 2009, VicRoads: Melbourne.
2. Donald, D., VLIMITS: An expert system speed zone adviser. The first three years, Research Report No. 236, Australian Road Research Board Ltd.
3. MUARC, Review of Speed Zone Guidelines Stage 1 and Stage 2, Unpublished consultancy report to VicRoads, 2004, 62.
4. Moroney, W.F. and M.G. Lilienthal, Human factors in simulation and training: An overview, in Human Factors in Simulation and Training, P. Hancock, et al., Editors. 2009, Taylor & Francis Group, LLC: Boca Raton. p. 3-38.
5. Allen, R.W. and H.R. Jex, Driving simulation - Requirements, mechanization and application. SAE Technical Paper Series, 1980. Paper number 800448: p. 1-12.
6. Kaptein, N.A., J. Theeuwes, and R. van der Horst, Driving simulator validity: Some considerations. Transportation Research Record, 1996. 1550: p. 30-36.
7. Godley, S.T., T.J. Triggs, and B.N. Fildes, Driving simulation validation for speed research. Accident Analysis and Prevention, 2002. 34: p. 589-600.
8. Bella, F., Driving simulator for speed research on two-lane rural roads. Accident Analysis and Prevention, 2008. 40: p. 1078-1087.
9. Nilsson, L. Behavioural research in an advanced driving simulator - experiences of the VTI system. in Human Factors and Ergonomics Society 37th Annual Meeting. 1993. Seattle, Washington: Human Factors and Ergonomics Society.
10. Graziano, A.M. and M.L. Raulin, Research Methods: A Process of Inquiry. 1989, New York: Harper & Row.
11. Liu, D., N.D. Macchiarella, and D.A. Vincenzi, Simulation fidelity, in Human Factors in Simulation and Training, P.A. Hancock, et al., Editors. 2009, Taylor & Francis, LLC: Boca Raton. p. 61-73.
12. Blaauw, G.J., Driving experience and task demands in simulator and instrumented car: a validation study. Human Factors, 1982. 24(4): p. 473-486.
13. Törnros, J., Driving behaviour in a real and a simulated road tunnel--a validation study. Accident Analysis and Prevention, 1998. 30(4): p. 497-503.
14. Shinar, D., Traffic Safety and Human Behavior. 2007, Amsterdam: Elsevier.
15. Yan, X., et al., Validating a driving simulator using surrogate safety measures. Accident Analysis and Prevention, 2008. 40: p. 274-288.
16. Gartner, W.B. and M.R. Murphy, Concepts of workload, in Survey of methods to assess workload, B.O. Hartman and R.E. McKenzie, Editors. 1979, AGARD-AG-246.
17. Gawron, V.J., Human workload, in Human Perfromance, Workload, and Situational Awareness Measures Handbook, V.J. Gawron, Editor. 2008, Taylor & Francis: Boca Raton. p. 87-230.
18. Strayer, D.L., F.A. Drews, and D.J. Crouch. Fatal distraction? A comparison of the cell-phone driver and the drunk driver. in Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. 2004: University of Iowa.
19. Nilsson, L., J. Tornros, and R. Ceci. Using the mobile phone while driving: How much load does it impose on the driver? in Road Safety on Four Continents: 13th International Conference. 2005: VTI.
20. Patten, C.J.D., et al., Using mobile telephones: cognitive workload and attention resource allocation. Accident Analysis and Prevention, 2004. 36: p. 341-350.
21. Engstrom, J., E. Johansson, and J. Ostlund, Effects of visual and cognitive load in real and simulated motorway driving. 2005. Transportation Research Part F: p. 97-120.
22. Jamson, A.H. and N. Merat, Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. Transportation Research Part F, 2005. 8: p. 79-96.

23. Fuller, R., Towards a general theory of driver behaviour. Accident Analysis and Prevention, 2005. 37: p. 461-472.
24. Hart, S.G. and L.E. Staveland, Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research, in Human mental workload, P.A. Hancock and N. Meshkati, Editors. 1987, Elsevier: Amsterdam, North Holland.
25. Endsley, M.R., B. Bolté, and D.G. Jones, What is situation awareness?, in Designing for Situation Awareness, M.R. Endsley, B. Bolté, and D.G. Jones, Editors. 2003, Taylor & Francis: New York. p. 13-30.
26. Kass, S.J., K.S. Cole, and C.J. Stanny, Effects of distraction and experience on situation awareness and simulated driving. Transportation Research Part F, 2007. 10: p. 321-329.
27. Stanley, L.M., M.J. Kelly, and S. Lassacher. Driver perfromance while interacting with the 511 travel information system in urban and rural traffic. in Third International Driving Symposium on Human Factors in Driving Assessment, Training and Vehicle Design. 2005.
28. TAC. Young driver statistics. 2009 [cited 2009; Available from: www.tacsafety.com.au.
29. HASTE, HASTE Deliverable 1: Development of experimental protocol. , Institute for Transport Studies, 112.
30. Smith, S.S., et al., Hazard perception in novice and experienced drivers: The effects of sleepiness. Accident Analysis & Prevention, 2009. 41: p. 729-733.
31. VicRoads. Hazard perception test. 2009 [cited 2009; Available from: www.vicroads.vic.gov.au/Home/Licensing/GettingYourPs/HazardPerceptionTest.htm.
32. Chisholm, S.L., J.K. Caird, and J. Lockhart, The effects of practice with MP3 players on driving performance. Accident Analysis and Prevention, 2008. 40: p. 704-713.
33. Klauer, S.G., et al., The impact of driver inattention on near-crash/crash risk: an analysis using the 100-car naturalistic study data, National Highway Traffic Safety Administration.
34. Green, P., Where do drivers look while driving (and for how long)?, in Human Factors in Traffic Safety, 2nd ed., R.E. Dewar and R. Olson, Editors. 2007, Lawyers & Judges Publishing: Tucson, AZ. p. 57-82.
35. Rogé, J., et al., Alteration of the useful field as a function of state of vigilance in simulated car driving. Transportation Research Part F, 2002. 5: p. 189-200.
36. Liu, C.C., S.G. Hosking, and M.G. Lenné, Hazard perception abilities of experienced and novice motorcyclists: An interactive simulator experiement. Transportation Research Part F 2009. 12: p. 325-334.
37. Lee, S.E., et al., Detection of road hazards by novice teen and experienced adult drivers. Transportation Research Record, 2008. 2078: p. 26-32.
38. Leung, S. and G. Starmer, Gap acceptance and risk-taking by young and mature drivers, both sober and alcohol-intoxicated, in a simulated driving task. Accident Analysis & Prevention, 2005. 37: p. 1056-1065.
39. Taylor, M.C., A. Baruya, and J.V. Kennedy, The relationship between speed and accidents on rural single-carriageway roads, TRL511, Transportation Research Library.
40. Taylor, M.C., D.A. Lynam, and A. Baruya, The effects of drivers' speed on the frequency of road accidents, TRL Report 421, Transport Research Laboratory.
41. Greibe, P., Accident prediction models for urban roads. Accident Analysis & Prevention, 2003. 35: p. 273-285.
42. Pande, A. and M. Abdel-Aty, A novel approach for anlyzing severe crash patterns on multilane highways. Accident Analysis & Prevention, 2009. 41(985-994).
43. Roberts, I., et al., Effect of environmental factors on risk of injury of child pedestrians by motor vehicles: A case control study. British Medical Journal, 1995. 310: p. 91-94.