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Advantages and Disadvantages of Driving Simulators: A Discussion

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Introduction

For half a century at least, each new generation of computer chip, appearing every two years or so, has provided twice as many transistors per unit cost (as predicted by Moore's law [1]). Extrapolating the accelerating pace of technological potential, logic dictates that computational devices will be tiny and powerful by the early 2020s, giving rise to virtual-reality applications such as displays built into our eyeglasses [2]. By the 2030s, going to a website could mean entering a totally realistic and compelling virtual environment facilitated by miniature computers that interact with brain cells, and people will probably spend most of their time in virtual reality [3]. Although these prospects may sound farfetched, we can already see that virtual-reality-based applications are increasingly used in such common tasks as driving. We use driving simulators for assessment, rehabilitation, learner driver training, race-car driver training, research into safety, and for at-home entertainment and in amusement halls.

Advantages of driving simulators

Driving simulators offer various advantages compared to real vehicles, including:

1. *Controllability, reproducibility, and standardization.* Behavior of virtual traffic, weather conditions, and the road layout can be manipulated (offline or in real-time) as a function of the training needs or research aims. Purpose-developed scenarios enable trainees to practice a large number of dedicated maneuvers per time unit. Wassink et al. [4] describe software architecture for generating dynamic scenarios in a driving simulator. With the aim of maximizing the effectiveness of the training, the authors apply a metaphor from the 1998 movie The Truman Show: everything surrounding the learner driver responds to the driver's behavior. Using simulators, participants in different physical locations can drive under the exact same conditions. This is beneficial for creating standardized driving tests and reproducible research results. In contrast, the real traffic environment is largely random.

2. *Ease of data collection.* A driving simulator can measure performance accurately and efficiently. With a real vehicle, it is far more cumbersome to obtain complete, synchronized, and accurate measurement data. It is a fundamental challenge to get an accurate recording of where a real vehicle actually is in the world. For example, in one study using an instrumented vehicle and a driving simulator, it was impossible to determine the distance between the vehicle and a stop line on the road, while in the simulator this information was readily available [5]. Measurement of lateral position is challenging as well, as this requires visible lane markers while weather conditions, reflection, and shades may affect the quality of the measurement [6]. Santos et al. [7] found that lateral position measurements of the instrumented vehicle were of marginal quality while this information was accurate in the simulator, leading the authors to conclude that "problems with field studies in an instrumented vehicle have been confirmed" (p. 145). Because of the measurement capabilities of simulators, new types of behavior analyses come within reach, such as trigonometric analysis of time-to-line crossing [8] or object detection and hazard perception research using eye-tracking [9].

3. *Possibility of encountering dangerous driving conditions without being physically at risk.* Simulators can be used to prepare trainees to handle unpredictable or safety-critical tasks that may be inappropriate to practice on the road, such as collision avoidance or risky driving [10]. In addition, simulators make it possible to study hazard anticipation and perception by exposing drivers to dangerous driving tasks, which is an ethically challenging endeavor in real vehicles [9]. Flach et al. [11] stated that simulators

"offer an opportunity to learn from mistakes in a forgiving environment" (p. 134). Allen et al. [12] made a similar case: "Motor vehicle crashes are significantly higher among young drivers during the first year of licensure, and crash risks decline with increased experience. […] This produces an interesting dilemma about how to provide young drivers with driving experience without significantly increasing their crash risk. Driving simulation may be the solution to this dilemma."

4. *Novel opportunity for feedback and instruction.* Simulators offer the opportunity for feedback and instruction that is not easily achieved in real vehicles. For example, it is possible to freeze, reset, or replay a scenario [13]. Feedback and instructions can also be delivered in other modalities besides speech, such as visual overlays to highlight critical features in the environment.

Disadvantages of driving simulators

However, simulators have several known disadvantages and challenges, including:

1. *Limited physical, perceptual, and behavioral fidelity.* Low-fidelity simulators may evoke unrealistic driving behavior and therefore produce invalid research outcomes. Simulator fidelity is known to affect user opinion. Participants may become demotivated by a limited-fidelity simulator and prefer a real vehicle instead (or a more costly high-fidelity simulator for that matter). Interestingly, while safety is often cited as an advantage of driving simulation (see above), sometimes this same feature is interpreted as a disadvantage. For example, Käppler [14] pointed out that real danger and the real consequences of actions do not occur in a driving simulator, giving rise to a false sense of safety, responsibility, or competence. Simply investing resources to increase fidelity is not necessarily a desirable solution, as it adds to the complexity of the device and might hamper experimental control. In some cases, deliberate deviations from reality yield valid results [15][16]. Evans [17] provided an interesting thought experiment, arguing against a blind focus on high-fidelity driving simulation: "Consider a make-believe simulator consisting of an actual car, but with the remarkable property that after it crashes a reset button instantly cancels all damage to people and equipment. What experiments could be performed on such make-believe equipment that would increase our basic knowledge about driving? The answers provide an upper limit on what might be done using improved simulators" (p. 190).

2. *Shortage of research demonstrating validity of simulation.* A growing body of evidence indicates that driving-simulator measures are predictive for on-the-road driving performance [18]-[23]. However, only a few studies have investigated whether skills learned in a driving simulator transfer to the road (see [24]-[26] for a few exceptions). Note that in the field of aviation, studies on the transfer of training are far more common [27], but even in aviation critical questions remain unanswered, for example whether a motion base provides added value for the effectiveness of flight training [28].

3. *Simulator discomfort, especially in older people or under demanding driving conditions.* Simulator sickness symptoms may undermine training effectiveness and negatively affect the usability of simulators. This is a serious concern, but fortunately, useful technological and procedural guidelines are available to alleviate it [29]. Research shows that simulator sickness is less of a problem for young drivers [30]. Experience shows that limiting the horizontal field of view, avoiding sharp curves or stops during driving, and using short sessions (≤10 min) with sufficient rest breaks improves or even eliminates simulator sickness.

Conclusion

Because of the increasing potential of computer technology, we foresee increasing use of driving simulation in areas such as driver assessment, driver training, research, and entertainment. Low-cost virtual-reality applications will come within the reach of many organizations. However, several research questions may need to be answered before ubiquitous driving simulation becomes feasible, particularly questions related to simulator fidelity, predictive validity of driving simulators, simulator-to-reality transfer of learning, and simulator discomfort.

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