These minimal physical features can be enhanced in numerous ways—for example, with multichannel projection, partial or complete vehicle cabins, working auxiliary controls (e.g., indicators), a vibration table, and a motion system to provide a facsimile of the acceleration forces felt in real-world driving.

Currently, simulator images are generated by real-time animation. But even before real-time graphics became feasible, a driving simulator could be built around miniature vehicles driving on rolling road, usually with a motorway layout. The windscreen view was typically generated with a small camera positioned above the rolling road. The accelerator and brake controlled the speed at which the roadway was rolled, and driving was restricted to a single roadway, with the only permitted lateral movement being a lane change. A simulator of this type was used by Mortimer (1963) to study the effect of alcohol impairment and headlight glare, and a rolling road simulator was in operation at the Transport and Road Research Laboratory in the United Kingdom until the 1990s (Irving & Jones, 1992). Other early driving simulators used images from filmed scenes, whereas the use of computer-generated graphics displays became feasible in the 1970s (Wierwille & Fung, 1975).

The standard approach for road scene display in modern simulators is to apply real-time graphic image generation. This gives almost total flexibility in terms of the scenes and situations that can be displayed, within the limits of the projection system that is used. It has to be recognized that projectors and monitors have some natural limitations, such as resolution and limited luminous intensity. This latter limitation means that it is not possible to directly create the true optical effect of glare with a projector or a monitor or display, although the halo effect of nighttime glare can be mimicked by means of animation. However, image generation alone does not define what constitutes a driving simulator.

Simulators are commonly classified into the categories of high-level, mid-level, and low-level (Kaptein, Theeuwes, & van der Horst, 1996; Slob, 2008; Weir & Clarke, 1995). In this classification, simulators incorporating motion systems and full vehicle cabs are in the high-level category, static simulators based around projection systems and full cars are in the mid-level, and those built around simple components such as game controllers and computer monitors are in the low-level category. Of course, this classification is quite arbitrary. It is possible to think about simulators that combine some low-cost and relatively low-fidelity components with other high-end features. A laboratory simulator with games-based controls can have an elaborate projection system and even (in theory) a motion platform. Similarly, there are systems with extremely sophisticated motion that have quite limited visualization capabilities. It therefore makes sense to consider simulator cost on a single scale, but not simulator capability. A simulator may be highly capable in terms of one subsystem but only moderately capable in terms of another. Also, not surprisingly in view of the major effort required, no studies have been run in which every aspect of a simulator—from field of view to graphics resolution, motion system design and tuning, sound system performance, and software and mechanical delay—was systematically varied in order to assess the effect on participant performance.

3. WHY USE A DRIVING SIMULATOR?

There are a large number of motivations for using simulators. Perhaps the greatest incentive is the ability to control the experience of the participants and to create repeatable situations, scenes, and scenarios. This control creates a degree of efficiency in experiments that cannot be matched by conducting observations in the real world. In tens of minutes on a simulator, it is possible to accomplish a study that might take months of real-world driving. The full control—over participant selection, instructions to the participants, ordering of conditions, and event triggering—is virtually impossible to equal in real-world studies. Also, because of this efficiency and effectiveness, the cost of conducting a simulator study tends to be far lower than that of a counterpart study in real-world conditions. The control element reduces random extraneous effects in the data so that for a given number of participants, experimental power is greater.

Studies that would be very difficult or impossible to conduct in the real world are feasible in simulators. New vehicle technologies—driver assistance systems, vehicle handling systems, and even novel vehicle controls such as joystick control replacing pedals and steering wheel—can be created through software and electronic interfaces. Simulators have played a major role in system development and system design: The usability, acceptance, and effectiveness of alternative system specifications and human-machine interfaces can be systematically evaluated (Jamson, Lai, & Carsten, 2008).

Impaired driving can be investigated without serious risk to participants. Studies of the impact on driving performance of distraction such as from mobile phones, of the effects of fatigue, of alcohol, of over-the-counter and prescription drugs, and even of illicit drugs such as marijuana have all been conducted on simulators. Thus, the meta-analysis of the impact of alcohol on driving carried out for the European DRUID project found a large number of studies that had carried out the investigation using a driving simulator (Schnabel, Hargutt, & Krüger, 2010). The investigation of the impact of cannabis on driving is much more difficult to carry out for legal reasons, but even