

Effectiveness of simulator-based training for heavy vehicle operators: What do we know and what do we still need to know?

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Abstract

The use of simulation to train heavy vehicle operators has much potential. However, realising the potential efficiencies associated with simulation-based training can be a challenge for training providers. While some guidance exists on simulator selection, information is lacking about how best to incorporate simulation into a broader training program, including which skills to target and how much simulation to provide relative to other forms of practical training (i.e., range-based, and on-road). This paper presents the key outcomes of a literature review, which sought broadly to explore the effectiveness of simulation in training heavy vehicle operators. The review focussed on the research evidence pointing to a role for simulation-based training in critical technical (i.e., vehicle control) and non-technical (e.g., hazard perception) skill areas at the entry level, and in the principles of eco-driving at the post-licensing level. Regarding technical and non-technical skills, it was found that evidence of effectiveness has typically come from evaluations drawing on global performance measures (e.g., licence test scores) rather than on specific measures. Also, despite evidence of learning, there appears to be scant evidence on transfer of training to the real-world and on long-term skill retention. In the case of eco-driving, the review showed that there exists evidence of learning in the simulated environment, positive transfer of training to the real-world, and skill retention. However, any flow-on benefits of reduced fuel consumption to safety have yet to be explored objectively. The implications of these outcomes are discussed in terms of opportunities for the future.

Introduction

Driving simulation has much to offer as a training tool. In particular, relative to training in an actual vehicle, simulation provides trainees with the opportunity to practice a range of driving manoeuvres in a safe, risk-free environment. Simulation also allows for greater quality of formal training in a given period of time. Exact situations needed to learn given skills are readily available, and more trials can be presented in a given time frame providing increased opportunity for skills practice (Morgan, Tidwell, Medina & Blanco, 2011; Thompson, Carroll & Deaton, 2009; Triggs, 1994).

Realising the potential benefits associated with simulation-based training is not a trivial undertaking. While there are many types of simulator available, a system with a high level of physical realism is not necessarily better when it comes to training (e.g., Triggs, Lenné & Mitsopoulos-Rubens, 2008). The level of realism that is appropriate, and indeed whether simulation itself is appropriate and likely to be effective, will depend on several considerations, including the overall purpose of the training, the specific task to be trained, cost, the trainees, and the capability and motivation of the trainer. Moreover, for best effect, simulators need to be integrated into the total training program, which involves several training methods, strategies and tools, for addressing the overall training requirements (Salas, Wilson, Priest & Guthrie, 2006; Triggs et al., 2008).

This paper presents the outcomes of a literature review, which sought broadly to explore the effectiveness of simulation in training heavy vehicle operators. The review focussed on the research evidence pointing to a role for simulation-based training in critical technical and non-technical skill areas at the entry level, and in the principles of eco-driving at the post-licensing level. We present first a brief overview of training, including discussion of the conceptualisation of training quality.

This provides the framework for the discussion to follow on the effectiveness of simulator-based training at the entry-level and in turn, eco-driving at the post-licensing level. In general, our intent in preparing this review was to provide a high-level snapshot on the status of simulator-based training for heavy vehicle operators, to highlight some of the questions which still need to be addressed, and to generate discussion among readers about whatever other issues (beyond the scope of the current review) still need to be considered.

Simulation-based training – An overview

Barnard, Veldhuis and van Rooij (2001) note that “the main goal of training is to prepare trainees for the tasks they are going to perform on their jobs” (p. 269). Applied to heavy vehicle operations, training aims to impart in heavy vehicle operators the necessary knowledge, skills and attitudes, which will allow them to drive their vehicle safely and efficiently for their work in a way that is compliant with the road rules and organisational requirements.

Training typically comprises both theoretical and practical components. The theoretical component is traditionally classroom-based, while the practical component involves opportunity for supervised driving on-the-range and on-the-road (Brock, McFann, Inderbitzen & Bergoffen, 2007; Staplin, Lococo, Decina & Bergoffen, 2004). Simulators provide an additional environment in which trainee operators can gain supervised practice.

While proponents of simulator-based training acknowledge that simulation should not be used as a substitute for real-world supervised practice, the use of simulation as part of a training program is based on the foundation that it is possible to trade-off time spent training using an actual vehicle with time spent training in the simulator. This raises the often pragmatic issue of how much or what proportion of a training program should be allocated to simulator-based instruction, without unduly sacrificing other training components. While by no means trivial to execute, the solution is to match, given the purpose of the training and the experience level of the trainees, the knowledge and skills to be trained with the appropriate medium. The ultimate goal is to maximize overall training quality through the use of multiple, yet complementary, media, without compromising safety and without adding unnecessarily to training costs and to time requirements. Nonetheless, how simulators should be used within a wider curriculum constitutes one of the main challenges facing trainers and training organisations (Parkes, 2005).

Classification of skills for training

Safe and efficient operation of real-world systems rests on the premise that operators have acquired, or at least have reached the necessary level of competence in their development of, the pre-requisite skills. It follows that the aim of training programs should be to impart these skills. What are the critical skills? In their review on driver and vehicle crew training, Goode, Lenné and Salmon (2013) discuss two broad categories of skills to be trained: “technical skills” and “non-technical skills”. Technical skills refer in general to skills of a procedural or psycho-motor nature. These are skills which involve the execution of action sequences and that become highly automatised through practice. In the context of vehicle operation, the critical technical skills to acquire relate to one’s ability to control and manoeuvre a vehicle (Goode et al., 2013).

Non-technical skills generally refer to “road craft” skills and include higher-order skills. These skills draw on cognitive processes which are used by the vehicle operator for a range of operational tasks outside of routine manipulative, highly automatised tasks. These processes typically involve memory and the control of attention, where attention refers to the allocation of mental resources. This allocation of resources may be deliberate, that is, open to conscious awareness, or not (Triggs et al., 2008). The higher-order skill to have received the most attention in the context of vehicle

operation is that of hazard perception, which broadly defined is the ability to detect and perceive both actual and potential traffic hazards, and to respond to them appropriately.

While there is increasing emphasis on training non-technical skills, the focus of conventional vehicle operator training, at least at the entry-level, has been on imparting technical skills – and, in particular, the technical skills needed to satisfy the requirements of the licensing test. While intuitively this might seem appropriate, it is important to recognise that little evidence exists demonstrating a link between good performance on the licensing test and low crash involvement post-licensing (Triggs et al., 2008). This stems from an increasing acknowledgement that, while necessary, adequate skill in vehicle control is insufficient for safe driving – competence in non-technical skill areas is also needed (Triggs et al., 2008).

Conceptualising the assessment of training quality

As discussed by Triggs et al. (2008) there are three main criteria that ought to be considered when examining whether a given training medium or technology represents an effective option for training competencies in the target area. These are training time, skill retention, and transfer of training.

Training time refers to the amount of training (how long and how many repetitions of events) that is required in order to reach a given pre-defined level of performance. *Skill retention* relates to the extent to which skills are retained post-training. *Transfer of training* is concerned with how well what was learned in training transfers to the real-world operational setting (Barnard et al., 2001; Liu, Blickensderfer, Macchiarella & Vincenzi, 2009). In assessing the quality of simulation for training purposes, the focus of attention has been on transfer of training. This is perhaps not surprising given that, as stated by Triggs et al. (2008), “transfer of training provides an important aspect of training validation for the simulator” (p. 7).

Factors influencing simulator training quality

Discussions on simulator effectiveness in the training context typically centre on the issue of fidelity, and the importance of matching fidelity to training requirements (e.g., Blanco, Hickman, Hanowski & Morgan, 2011, Brock, Jacobs, Van Cott, McCauley & Norstrom, 2001; Staplin et al., 2004; Triggs et al., 2008). At the core of the issue is the distinction between physical (or task) fidelity and functional (or instructional) fidelity.

Physical fidelity is concerned with the degree to which the simulator looks and feels like the real-world operational system. The two main factors considered to influence physical fidelity are the levels of visual detail and motion (Thompson et al., 2009). At one extreme, lower fidelity simulators typically comprise a single PC monitor, simplified vehicle controls (e.g., mouse, keyboard, steering wheel and pedals built for gaming) and a fixed base. Key characteristics of simulators with very high physical fidelity include a large projection screen, giving a wider field of view and thus more immersive experience, actual vehicle controls, and a full motion base.

Functional fidelity relates to the extent to which the simulator acts like the real-world operational system. The consensus is that if there is good functional fidelity then there is likely to be high positive transfer of learned skills to the operational environment (Triggs et al., 2008). Thus, in selecting a simulator for use in operator training, at least functional fidelity should be high. However, while high functional fidelity is necessary, a low level of physical fidelity may be sufficient. This will depend on the purpose of the training and on the nature of the tasks to be trained. For acquisition of some higher-level skills, there is some evidence that higher physical realism may be advantageous. Further, high physical fidelity may be very important for operator periodic re-training, operator assessment or endorsement, and some training tasks where the skills

to be trained are highly dependent on interaction with the equipment layout and involve elements of task execution (Triggs et al., 2008).

In essence, beyond issues of simulator fidelity, the ultimate effectiveness of training can be attributed to several interrelated factors including instructional technique, training content, timing of training delivery, duration of training, training assessment, and the trainers. Instructional technique refers here to the types of exercises and activities that trainees are asked to undertake as part of the training. Content concerns the range of scenarios and events that are covered as part of the training. Timing is closely related to the stage of skill development: the premature delivery of practical training for more advanced skills before more rudimentary or precursor skills have had the chance to develop to a sufficient degree may be futile as the trainee may not be ready developmentally. Duration refers to the quantity of training. How much training is required? How many sessions and for how long should training sessions be in order for sufficient skill acquisition and transfer to occur? Sessions that are too long may be counterproductive. Concerning assessment, the critical question to ask is what performance criteria and what level of performance should be used to ascertain whether a trainee has satisfied the requirements of one training module before being permitted access to the next? Premature acceleration through training modules as performance thresholds are set too low may not lead to skill retention and effective training transfer. Further, trainers must be suitably qualified and motivated to deliver the training (Staplin et al., 2004). Indeed, trainer level of commitment is paramount to training effectiveness as is a genuine belief on the part of the trainer that simulation is an effective and useful means through which to impart training.

The factors just listed relate primarily to training design, and while these are arguably the most obvious when it comes to discussing simulation, it is still useful to consider training effectiveness in the broader context. While several models of training effectiveness have been proposed (e.g., Salas et al., 2006; Liu et al., 2009), we present here for its clarity the model described by Liu et al. (2009). Briefly, the model views training effectiveness as the interplay between input factors, the amount learned in training, and the conditions surrounding the generalisation and maintenance of what has been learned in training to the real-world operational setting. According to the model, input factors, in addition to training design factors, are factors related to the individual trainee and to the organisational environment. Salas et al. (2006) identify several individual characteristics as critical contributors to learning, including cognitive ability, self-efficacy, goal orientation, and motivation. Important organisational influences include a strong safety culture and overall commitment of an organisation to training as this will, in turn, influence the amount of resources allocated to training (Liu et al., 2009; Salas et al., 2006; Staplin et al., 2004).

Effectiveness of simulator-based training of heavy vehicle operators at the entry-level

Much of the early discussions concerned with the role of simulation in the training of new operators of heavy vehicles were based mostly on data which were collected through subjective methods, including self-report (e.g., Brock et al., 2001; Staplin et al., 2004). More recently, sponsored by the US Federal Motor Carrier Safety Administration, the “SimVal” study constitutes one of a growing body of research programs to have collected objective data on the effectiveness of truck training simulators (Morgan et al., 2011).

The overarching objective of the SimVal research was to examine the effectiveness of simulation-based training for truck operators at the entry-level through a comparison of three different options for training drivers to operate an articulated truck with non-synchromesh manual transmission. These options were as follows.

- *Conventional training.* Drivers in this group (n=33; Mean age=34 years; 31 males) completed an eight-week training course, certified by the US-based Professional Truck Driver Institute

(PTDI), involving classroom (147 hours) and practical (50 hours) components, with all supervised practice carried out behind-the-wheel in a real truck (on-road and on-range). Participants were recruited in to the study on the first day of their eight-week course.

- *Simulator training.* Like the conventional training group, except that, for drivers in this group (n=32; Mean age=35 years; 31 males), 58% of the practical component occurred in a truck simulator. Again, participants were recruited to take part in the study on the first day of their eight-week course.
- *Commercial Driver Licence (CDL)-focused training.* Drivers in this group (n=33; Mean age=35 years; 30 males) completed a short two- to four-week course comprising both classroom and practical (on-road and on-range) components, but designed to train only those skills needed to pass the licence test issued by the US Department of Motor Vehicles (DMV). Participants in this group were recruited in to the study on the day of their CDL test at the DMV.

The course undertaken by those in the CDL group was not PTDI-certified, implying that the CDL course does not train the full range of skills and knowledge that the PTDI consider to be needed for entry-level drivers to operate a heavy vehicle safely. The PTDI standards cover a range of technical and non-technical skill areas, including basic vehicle operation (e.g., vehicle inspections, basic control, shifting, reversing, coupling); safe operating procedures (e.g., visual search, space and speed management); advanced operating procedures (e.g., night operation, hazard perception); and vehicle systems and reporting malfunctions (e.g., identification, diagnosis and reporting malfunctions) (see www.ptdi.org).

On-road and on-range training and testing was carried out on articulated trucks with a 9 or 10 speed non-synchromesh manual transmission. Simulator-based training and testing was carried out on a FAAC TT-2000-V7 driving simulator, providing a field-of-view of 225 degrees and simulating three degrees-of-freedom of motion through the seat. Force-feedback steering was also used, and the cab had original equipment manufacturer working gauges, indicator and warning lights, pedals and gear shifter with range selector. To match the actual vehicle, the simulator was programmed with a 9 or 10 speed non-synchromesh manual transmission. Simulator scenarios for the simulator group were created to mimic the lesson plans of the conventional training group.

At the conclusion of their respective training periods, participants in each group performed the DMV on-range and on-road tests, along with custom-developed and validated on-road and on-range tests for the actual and simulated settings. These latter tests included the same manoeuvres as the DMV tests, were developed to enable direct comparisons to be made across the simulated and actual vehicle settings and were assessed against the same criteria as the DMV tests. Critically, an independent assessment of video recordings of the tests by an examiner external to the research team revealed no systematic biases in participant scores either across training groups or across simulator and actual vehicle modes. The on-road test assessed such aspects as turning, dealing with intersections, dealing with different roadway conditions (urban, rural, freeway), lane changes, dealing with curves, roadside exits and entries, dealing with railway crossings, traffic control device compliance, and general driving (e.g., gear shifting). The focus of the on-range test was backing/reversing performance.

Statistical analyses were undertaken to examine the effect of training method on on-road test scores and on-range test scores. The results are summarised in Table 1. All differences listed Table 1 represent statistically significant differences. Particularly noteworthy in the current context is that, on the DMV and actual on-road and on-range tests, performance of the simulator group did not differ significantly from that of the conventional group and, in most cases, exceeded that of the CDL group. These findings provide some support for simulator-based training of heavy vehicle operators at the entry-level. Specifically, the findings suggest that simulator-based training offers an

appropriate surrogate for training in an actual vehicle. Nonetheless, some questions remain, such as what constitutes the appropriate amount and make-up (in terms of specific technical and non-technical skill areas) of simulator-based training as part of a comprehensive entry-level program. A further goal of the evaluation was to assess skill retention several months post-training. A visual inspection of the data suggested that the pattern of observed effects on the actual on-road test persisted for at least four-months after training, with the conventional and simulator groups still outperforming the CDL group at this time. Unfortunately, due to a lack of suitable data from an adequate number of participants, it was not possible to explore this aim in depth or to make any definitive conclusions on the issue (Morgan, et al., 2011).

Table 1. Summary of SimVal findings regarding effect of training method on test performance

	On-road test	On-range test
DMV	No significant difference between Conventional, Simulator, and CDL groups	Conventional group > CDL group Simulator group did not differ significantly from either Conventional or CDL groups
Actual	Conventional & Simulator groups > CDL group	Conventional & Simulator groups > CDL group
Simulator	Conventional & Simulator groups > CDL group	Simulator group > Conventional & CDL groups

Eco-driving

Drawing on both technical and non-technical skills is the ability to apply principles of eco-driving. The main goal of eco-driving is the reduction of fuel consumption and emissions (Young, Birrell & Stanton, 2011). There is now good acceptance that driving behaviour can influence fuel consumption (e.g., van der Voort, Dougherty & van Maarseveen, 2001). While technical solutions for reducing emissions from vehicles exist, optimising fuel efficiency through strategies designed to make appropriate changes to driver behaviour, in order to realise the full potential of technical solutions, provide an attractive option to trucking organisations.

While a number of behaviours have been identified as leading to more economical driving, the core set of behaviours can be distilled into the following as summarised by Young et al. (2011): (1) planning ahead to avoid unnecessary braking and stopping; (2) using moderate engine speeds and a uniform throttle for steady speeds; (3) changing gear up as soon as is possible using positive, but not heavy, acceleration; (4) avoiding sharp braking; and (5) where possible, using engine/auxiliary brakes for smooth deceleration.

Simulation has emerged as a tool through which to train experienced truck operators in the principles of eco-driving. The effectiveness of candidate programs to have adopted such a role for simulation is considered next.

Effectiveness of simulator-based training of heavy vehicle operators in eco-driving

Strayer and Drews (2003) were among the first to conduct systematic research into the extent to which simulator-based training in eco-driving principles leads to demonstrable improvements in fuel efficiency among existing operators of heavy vehicles. Participants in their study (n=40; Mean age=46 years) were all licensed heavy vehicle operators, and had been working for their current organisation, a local (Utah, USA) trucking company, for an average of 5 years.

The simulator used for training was a TranSim VSTM simulator. Simulator scenarios and courseware were those developed and delivered by the simulator manufacturer. The course took two hours to complete and included classroom-based and simulator-based training. The focus of the course was on imparting strategies intended to optimise shifting to maximise fuel efficiency. These

included progressive shifting, double declutching, timing, and appropriate gear selection. To assess the effect of the training, fuel consumption data, expressed as miles per gallon, were collected for each driver pre-training and again, on a monthly basis over a period of six months post-training.

The results, overall, were positive. Specifically, they were indicative of positive transfer of training to the real-world. Training increased fuel efficiency by an average of 2.8%. This was based on a comparison of the amount of fuel consumed pre-training and that consumed, on average, over the six month post-training period. While there was a modest decline in transfer over that period, critically, the beneficial effects of training were still evident in the sixth month of the post-training period, suggesting good skill retention. Fuel efficiency in the first two months post-training had increased by approximately 4%. The value at six months was still positive, albeit lower, at about 2.5%.

Noteworthy is that Strayer and Drews (2003) also found that it was the participants with the poorest rates of fuel efficiency pre-training who benefitted most from the training. The best performers pre-training derived little benefit, but this may be, at least in part, because they were already performing at a high level. It was further found that training efficiency was unaffected by participants' age, their years of employment at the current organisation, and whether they drove the same vehicle or switched vehicles post-training. These findings suggest good generalisability of the results on at least some variables.

Two more recent studies have also demonstrated improvements in fuel efficiency among experienced heavy vehicle operators as a result of eco-driving training in a simulator (Parkes & Reed, 2006; Reed, Parkes, Peacock, Lang & Rehm, 2007). Each study is described briefly in turn.

Participants in the "SCOTSIM" project (Reed et al., 2007), completed a half-day training program, which comprised an initial period of familiarisation with the simulator, followed by an initial assessment drive in the simulator, a period of instruction, and then a second assessment drive. Participants (n=641; Mean age=41.7 years; 635 males) were drawn from a number of companies across Scotland, and had an average of 13.9 years as a professional truck driver.

Two types of high fidelity, full-mission simulator were developed for use in the research: a fixed system and a mobile system. Both simulators allow for six degrees-of-freedom of motion; however, while the cab and visual system are installed on the motion platform in the fixed system, the screens of the visual system are mounted on the floor, independent of the motion platform, in the mobile system. The simulator cab is a real truck cab converted for use in the simulator. All instruments, gauges and controls work as they do in the real vehicle, and force feedback is provided through the steering wheel, pedals and gear shift. The visual system provides 180 degree field-of-view to the front, and allows for the normal use of mirrors. The audio system simulates a range of vehicle and road traffic noises. The training scenarios and exercises were custom-developed for use in the simulators and were designed to impart the principles of safe and efficient driving as guided by the Safe And Efficient Driving (SAFED) standard. SAFED criteria include clutch control, gear selection and use, and making progress and planning.

Objective performance data (time taken to complete the drive, number of gear changes, fuel consumption) were collected in each of the two assessment drives in the simulator. Results were positive. Overall, there was a 20.8% reduction in the number of gear changes and 11.4% reduction in fuel consumption post-training compared with pre-training. There was also a 10.6% reduction in the time taken to complete the drives, indicating that the savings in fuel did not come at the cost of reduced efficiency. Despite these positive outcomes, the study did not include an assessment of the effects of the training on real-world performance. Thus, whether there was any positive transfer of training to the real-world is not known. The "TruckSim" program, however, did incorporate such an assessment.

TruckSim (Parkes & Reed, 2006; Reed et al., 2010) is a high fidelity, full-mission simulator located at the Transport Research Laboratory in the UK that was developed to provide training for heavy vehicle operators. It consists of a Mercedes Actros cabin mounted within a pod and surrounded by a curved screen giving a 270 degree field-of-view. The pod is mounted on a motion platform to give six degrees-of-freedom of motion. There is an 8-speed manual transmission gear box in the cab. There is also an audio system to provide realistic vehicle and traffic noises.

In addition to providing insight into drivers' acceptance of the technology, the initial evaluation phase of the TruckSim project identified fuel efficiency as a suitable target for simulator-based training. Thus, subsequent work sought to develop appropriate scenarios and courseware for fuel efficiency training in the simulator. As was the case for SCOTSIM, these were based on the SAFED criteria. The final phase of the research was conducted with the aim of exploring the effects of the training over repeated sessions, and whether any benefits to performance observed in the simulated environment transfer to the real-world.

Participants (n=36; Mean age=44.4 years; all males) in this final phase were drawn from eleven different companies, and were all experienced heavy vehicle operators. Across participants, the average number of years as a truck driver was 16 years. Participants' training session in the simulator proceeded as follows. Following a period of familiarisation with the simulator controls, participants completed a simulator drive of approximately 20 minutes duration while being observed by a qualified driver trainer. The drive comprised rural, urban, and motorway sections. In turn, participants received instruction on the sorts of driving strategies they could adopt to improve their fuel efficiency. Strategies included selecting an appropriate gear, block changing gears when appropriate, avoiding harsh braking and accelerating, and forward planning to keep the vehicle moving efficiently as far as possible. Participants then attempted the simulator drive a second time, giving participants the opportunity to implement and practice the strategies that they had been taught. For each participant, the simulator was configured to operate as an articulated vehicle with 100% load.

In addition, participants were also provided with immediate feedback on their performance following each drive. The performance assessment was provided automatically through a custom-developed analysis tool, which compared various aspects of the participant's performance with reference values established as part of an earlier project phase. For each aspect, participants' were given a grade: green for good, yellow for fair, and red for poor fuel efficient driving behaviour. This information could then be used by the trainer to provide tailored and targeted feedback to the participant on which aspects of the participant's driving he/she needs to focus in order to improve fuel efficiency.

Participants completed the simulator training on three separate occasions. The interval between the first and second visits was about eight weeks, and the interval between the second and third visits was four-to-six weeks. At each visit and for each drive, data were collected on several measures including fuel consumption, number of gear changes, and time taken. Results were positive overall. Participants improved their fuel efficiency by 11% over their three visits to the simulator. While the improvement was largest at the first visit, fuel efficiency did not deteriorate between the visits, suggesting good skill retention at least over the study period. The gains in fuel efficiency were likely the result of improved vehicle handling and adoption of eco-driving principles, more generally. For example, there were 29% fewer gear changes over the course of the study, and a 22% decrease in average RPM during periods of acceleration resulting in the engine operating in a more efficient region. Moreover, these changes were not at the expense of efficiency, with no observed increases in the time taken to complete the drives.

To enable assessment of any transfer of training to the real-world, participants recorded for the five working days before, and the five working days after, each of their three simulator visits, the total

fuel used and the total distance travelled. Equivalent data were also provided for a matched control group. Thus, for each of the “simulator” and “control” groups, the amount of fuel consumed, in terms of miles per gallon, could be calculated for each of the six data collection periods (i.e., before and after each of the three simulator visits). Critically, results overall demonstrated a positive transfer of training to the real-world setting. Relative to the matched control group, participants in the simulator group showed an increase in their fuel efficiency over the course of the study, with a 15.7% improvement in fuel consumption observed after the third simulator visit.

Table 2 presents a summary of the key features and findings of the studies reviewed in this section on simulator-based training in eco-driving. Particularly noteworthy is that all three studies reported a positive effect of the training on fuel efficiency overall. In every case, improvements in fuel efficiency occurred in parallel with reductions in the number of gear changes and without compromises in travel time. These companion effects are suggestive that the effects of training on fuel efficiency are likely the result of implementation of eco-driving principles. Similar approaches to fuel efficiency training were adopted across the studies and, in every case, the simulator exercises were of a full-task nature.

Table 2. Summary of studies evaluating effectiveness of simulator-based training in eco-driving

Study	Simulator platform & task type	Data sources	Effect on fuel efficiency	So what?
Strayer & Drews (2003)	TranSim VS TM ; Full-task	Real-world pre-training and every month over 6 months post-training	+ 2.5%	Positive training transfer to real-world; Good skill retention
SCOTSIM (Reed et al., 2007)	High fidelity (6 degrees- of-freedom motion, 180 degree field-of-view); Full-task	Simulator pre- & post-training	+11.4%	Evidence of learning in simulator
TruckSim (Parkes, Reed & colleagues)	High fidelity (6 degrees-of-freedom motion, 270 degree field-of-view); Full-task	Simulator pre- & post-training on 3 separate occasions (4 to 8 weeks apart); Real-world pre- & post-training for each of the 3 visits (relative to matched control group)	Simulator: +11%; Real-world: +15.7%	Evidence of learning in simulator; Positive training transfer to real-world; Good skill retention

The studies by Strayer and Drews (2003) and Parkes, Reed and colleagues (i.e., TruckSim) both showed good skill retention and positive training transfer to the real-world environment. However, the magnitude of the transfer effect on fuel efficiency in the TruckSim study was much greater than that observed in the Strayer and Drews (2003) study. We can only speculate as to the reason for this discrepancy. One possibility is the assumed difference in simulator. Although a full-task approach was used in both studies, the assumption is that the TruckSim simulator is of higher fidelity than the TranSim VSTM simulator, enabling participants to immerse themselves more fully in the task. A further potential difference is the provision of targeted, tailored feedback to participants in the TruckSim evaluation as opposed to generic instruction in fuel efficiency in the Strayer and Drews (2003) study. In any case, the critical point to note is that real-world improvements in fuel efficiency associated with simulator-based training were observed in both studies.

Conclusions

Simulation has many advantages to offer over training in an actual vehicle. While guidance exists on how best to match simulator capabilities and task type with training needs, there is still a gap in knowledge regarding how much simulation (i.e., what proportion of a broader training program

should be simulation-based) is both necessary and sufficient to maximise the overall effectiveness of a training program. In the absence of such knowledge, the issue is typically addressed on pragmatic grounds. This then leads to the question of where should the focus of the simulator-based training component lie given a simulator platform of given characteristics, the length of time that can reasonably be allocated to simulator-based training, and the purpose of the training and the target trainee audience.

While studies reporting beneficial effects of simulator-based training of heavy vehicle operators at the entry-level exist, those that draw on objectively-derived data are few in number. Clearly, there is a need for well-designed studies which aim to provide a comprehensive and objective assessment of the quality of simulator-based training for heavy vehicle operators at the entry-level, and that provides adequate coverage and assessment of both technical and non-technical skill areas. An area gaining in momentum is the use of simulation to train existing heavy vehicle operators in the principles of eco-driving. Encouragingly, studies showing real-world improvements in fuel efficiency and that draw on objectively-derived data already exist. These studies constitute good, growing support for the continued development and implementation of simulation-based fuel efficiency training for existing operators of heavy vehicles. Further research efforts in this area can help to identify with greater certainty the precise mechanisms underlying the observed positive effects, and to explore in depth any potential flow on effects to safety.

The key findings of the review are summarised in the following list.

- For new heavy vehicle operators, there is research evidence pointing to the effective use of simulation in technical skill training at the entry/licensing level:
 - But, evidence of effectiveness to date has typically come from evaluations drawing on global performance measures (e.g., licence test scores) as opposed to more specific performance measures (e.g., speed selection, gear choice, lane positioning);
 - Also, despite evidence of learning, there appears to be scant evidence on transfer of training to the real-world and on long-term skill retention.
- For new heavy vehicle operators, there is some research evidence pointing to the effective use of simulation in non-technical skill training at the entry/licensing level:
 - But, evidence of effectiveness to date has typically come from evaluations drawing on global performance measures (e.g., licence test scores) as opposed to more specific performance measures (e.g., time take to detect hazard, response to hazard);
 - In heavy vehicle operator training, there appears to have been a tendency to focus on the training of technical skills, however, it is in the training of non-technical skills where we might expect to see the greatest gains in safety in the long-term.
- For existing/current heavy vehicle operators, there is research evidence pointing to the effective use of simulation in eco-driving training at the post-licensing level:
 - There exists good evidence of learning in the simulated environment, positive transfer of training to the real-world, and skill retention;
 - While the evaluations to date have typically drawn on global performance measures (i.e., fuel consumption), some have also reported on the effects of training on more specific measures (e.g., number of gear changes, RPM during acceleration/deceleration periods);

- But, any flow-on benefits of reduced fuel consumption to safety have yet to be explored objectively.
- In general, more research is needed to establish how simulator-based training compares with more conventional training methods. This includes the calculation of costs and benefits.

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