

## VALIDATION OF DRIVING SIMULATORS FOR TRAINING

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### **Abstract:**

This paper describes two kinds of method for the validation of driving simulators for training. The first one, named global method, which has already been used, aims at globally assess the transfer of the learning to the real world, the retention of what was learned and the long term effects of the training. The second method is more analytical and focuses on the requirements of the main components of a driving simulator taking into account the skills and knowledge which have to be trained. Introducing the use of a driving simulator in a whole training curriculum changes the organization and the pedagogy, new requirements appear, from the trainee's point of view and from the instructor's point of view.

### **BACKGROUND**

Driving simulators are nowadays used in different countries for driver training, testing and licensing, among others the often quoted interests are:

- control of the training environment, repeatability of specific situations,
- possibility to create, chain or combine scenarios,
- real time control, objective performance scoring,
- cost reduction,
- Safer training, no need of an instructor on the side of the trainee.

Driving simulators are not suitable to train all aspects of driver training, their use has to be embedded in a whole training curriculum composed of computer based training, e-learning and traditional driving in real world.

In the perspective of a broaden diffusion of these tools, it would be opportune checking their effectiveness and their ability to enhance the quality of training, this could be summarized by the two following questions:

- How driving simulators for training could be validated?
- How driving simulators should be rationally used?

A first method of validation of the simulators consists of globally comparing the results obtained by trainees using driving simulators in their training curriculum, and trainees using a traditional method without driving simulators. This kind of method only applies to specific cases and it integrates several and not easily distinguishable elements; simulator, training, organization and pedagogy.

The analytical method focuses on the simulator's components, for each scenario or set of scenarios the specifications of the main concerned components are described. Finally the use of simulator for training offers numerous new facilities for teaching, but to be efficient several conditions have to be satisfied to make the training acceptable by the trainee and to facilitate the instructor tasks.

### **GLOBAL METHOD FOR VALIDATION OF DRIVING SIMULATORS FOR TRAINING**

The goal of this kind of method is to globally assess:

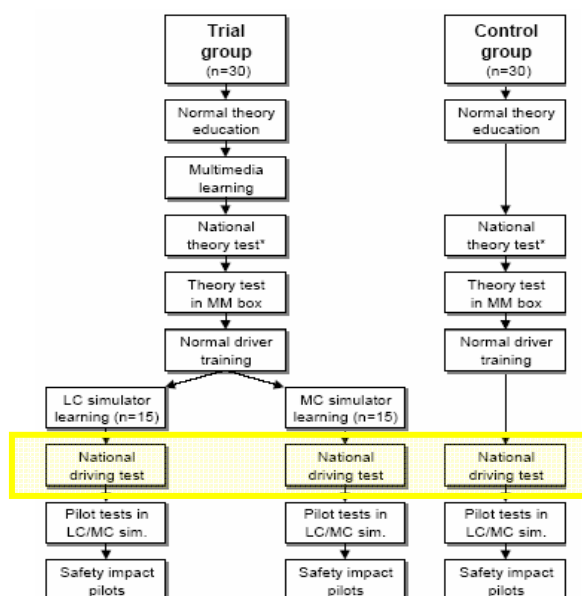
- the transfer of the learning to the real world,
- the retention of what was learned,
- The lack of negative effects.

Two main schemes or methods have been used; the first one aims at measuring the transfer of learning and the retention of what was learned, and is suitable for a homogeneous population in terms of knowledge before training, young and novice drivers for example. The second method is more complex to set up but is the only way to assess the retention of what was learned, and the long term effects of the training.

### First method: comparison between a “trial group” and a “reference group”

A method which has been used for the assessment of the transfer of learning and the retention of what was learned consists of globally comparing the results obtained at the end of a training session by a “trial group” for which training included driving simulator use and the results obtained by a “reference group” for which training does not include driving simulator use. The comparison could be done using a test (national driving test to obtain driving license) or by instructors evaluation on the road by means of a targeted questionnaire at specific subtasks.

*Example: Validation of the TRAINER training tool*



This study extract from TRAINER project report describes a method of validation which was conducted in Research Institute partners of four European countries to evaluate the training tool developed (a multimedia info-box and two versions of driving simulator -low-cost and a mean-cost). Tests will be conducted on each site with 30+30 learner drivers (candidate to the national driving test) in a trial group and a control group. The groups have been matched by age, sex and education level. The tests in 4 different countries will account for social and mentality differences between different EU regions.

**Figure 1: Design of the evaluation of the training tool (From TRAINER Project report).**

### Second method: cohort following

This method which aims at assessing the retention of what was learned and the long term effects of training consists in the following of a cohort of subjects, comparing the performances between two different periods before and after the training.

*Example: RESPECT PROJECT - Effectiveness of a 3 days training for truck drivers*

RESPECT – “Regulator Simulator based performance training for professional truck drivers” is also an EC funded project. This project consists of setting up a 3-day educational program for truck drivers with three main aspects: safety (reduction of accidents), economy (reduction of fuel consumption) and environment (reduction of maneuvering damages).

The 3-day training program consists of 3 elements:

- Theoretical component (classroom / computer based training - CBT)
- Practical component (driving with a real truck)
- Simulator component

Reference Information					Reference Information							
Entry test					Post test							
Training												
1	2	3	4	5	6	7	8	9	10	11	12	

**Figure 2: RESPECT Evaluation scheme (from RESPECT 1 Final report)**

The improvements of the driver due to the 3-day training program have been evaluated on a one year period; around 800 drivers from four countries take part in this evaluation. Two reference information periods of 6 months surround the training program. The effects of training are done in three ways:

- By means of collecting and analyzing practical data from transport companies (e.g. fuel consumption figures / information on number and costs of accidents).
- By means of a standardized test session on the simulator.
- (optional) Measurement on the training truck to be used for measurement of the effect of the practical component (real truck driving).

**Discussion**

These methods aim at validating the whole training curriculum efficiency, which encompasses the training on simulator itself but also other aspects of the training such as the distribution of knowledge acquisition between the different available means, the training organisation on simulator (duration of sessions, number of scenarios, ..) and the pedagogical aspect (instructor role, self training, etc..). For the first method, the trainees must have an identical level of knowledge and skills at the beginning of the training. For the cohort following, data acquisitions during reference periods are difficult to obtain, apart from professional context. This method is the only way to assess possible negative effects of driving simulator training such as overestimate confidence for the novice trainees or wrong risks awareness.

**ANALYTICAL METHOD FOR VALIDATION OF DRIVING SIMULATORS FOR TRAINING**

Driving simulators for training could be very different considering only the hardware aspect (body / architecture), and the cost could also vary on a wide scale. If we consider a complete curriculum, for novice trainees for example, the global amount of knowledge and skills that the trainees have to acquire is distribute into the available means; books, computer based training, e-learning and driving in real world with instructor. When a simulator is available it is preferably used to reduce the driving on the road component due to the fact that it is the most expensive one, but it can also be used for other purposes. Training on simulator is organised in scenarios, a scenario aims at teaching a specific knowledge or training one or several skills. Scenarios could cover a wide range of activities; from the basic vehicle control skills to strategic level decision making, in different contexts (urban, motorway, national road, etc.. ) both on practical and theoretical aspects. For this reason the requirements for simulators are very different depending on the scenarios. The principle of this method is to identify the required characteristics of the main simulator's components for the different scenarios, and to see if a validation method applies for the different components individually.

**Identification of the required characteristics of main simulator's components by scenario**

To illustrate this method we have chosen to start from the scenarios selected and described in the TRAINER project (D4.1, Driving simulator scenarios and requirements - 2001).

From a total of 96 scenarios suggested 31 were selected to be used on the TRAINER simulators, and are fully describe. These scenarios are structured in accordance with the four hierarchical levels of the GADGET-matrix.

Reference to GADGET-matrix					
Level	Knowledge and skill	Risk-increasing factors	Self-assessment	Title of scenarios	Number of scenarios
4				Influence of dangerous motives on driving	1
				<b>Goals for life Level 4</b>	<b>1</b>
3				Ecological/economical driving	1
3				Mental workload and use of stereo and mobile phone	1
				<b>Goals and context of driving Level 3</b>	<b>2</b>
2				Traffic rules	1
2				Gap acceptance	1
2				Light regulated intersections	2
2				Headway/tailgating, choice of following distance	3
2				Overtaking	4
2				Driving in darkness	3
2				Speed adaptation when turning	1
2				Parked car	2
2				Search strategy	1
2				Reaction time and stopping distance	2
				<b>Mastering of traffic situations Level 2</b>	<b>20</b>
1				Start and gear shift	1
1				ABS	2
1				Negotiating a curve	1
1				Low friction	4
				<b>Vehicle maneuvering Level 1</b>	<b>8</b>

**Figure 3: List of the 31 scenarios selected to be use on the TRAINER simulators.**

For each scenario a “Success criterion” is defined and a reference to which cell in the GADGET-matrix the scenario applies; level and column.

Levels : 1 Vehicle manoeuvring - 2 Mastering of traffic situations - 3 Goals and context of driving – 4 Goals for life.

Columns : Knowledge and skills - Risk increasing factors.- Self-assessment.

The content of the **knowledge and skills** column describes what a driver needs for driving under normal circumstances. In the second column about **risk increasing factors** the focus is on awareness of aspects of traffic and life that can be associated with higher risk. The column **Self-assessment** is about how the driver is assessing his/her own situation on the four levels.

In the table below we have highlighted for each scenario which among four major simulator's components are required and must be validated. The four main simulator components are:

- Visual system.
- Surrounding traffic.
- Vehicle model.
- Full driver cockpit commands.

Visual system	Surrounding traffic	Validated vehicle model	Full driver cockpit commands	Title of scenarios	Number of scenario/level
				Influence of dangerous motives on driving	1
				<b>Goals for life Level 4</b>	<b>1</b>
				Ecological/economical driving	1
				Mental workload and use of stereo / mobile phone	1
				<b>Goals and context of driving Level 3</b>	<b>2</b>
				Traffic rules	1
				Gap acceptance	1
				Light regulated intersections	2
				Headway/tailgating, choice of following distance	3
				Overtaking	4
				Driving in darkness	3
				Speed adaptation when turning	1
				Parked car	2
				Search strategy	1
				Reaction time and stopping distance	2
				<b>Mastering of traffic situations Level 2</b>	<b>20</b>
				Start and gear shift	
				ABS	2
				Negotiating a curve	1
				Low friction	4
				<b>Vehicle maneuvering Level 1</b>	<b>8</b>

**Figure 4 : Required simulator components by scenario.**

The main part of the scenarios suitable on simulator is in the level 2 (Mastering of traffic situations) - 64 %, and implies a realistic surrounding traffic.

Scenarios such as "Low friction" or "Driving in darkness" require special features for the vehicle model or the visual model which can not exist on all driving simulators.

For the scenario "traffic rules" it is specified that "this is best learned in the multimedia box, but the knowledge and the application of the rules could be emphasized in the simulator."

### Validation of the main components

#### *Visual system:*

Visual system as a major component is required for all scenarios, there is no specific validation for this system but three characteristics could be precised:

- Field of view – for all scenarios with surrounding traffic horizontal front field of view must be up than 150°, and there must be one to 3 rear views corresponding to the mirrors.
- Resolution – The current devices allow a resolution of rendering about 10 cpd (cycle per degree) while the visual performance is about 30 cpd. For example a panel of speed limit is read, by clear time, in 80m on simulator, while it is in approximately 200m in the reality.
- Realism of the scenes – The recent improvements in computer graphics and projectors have promoted the creation of databases more and more realistic (photo-realistic representation). However, from a training perspective it seems that this trend has to be moderate. Recent studies show that it could be better to simplify the scene and limit the detail to those relevant for the current scenario.

The modelling and the real-time rendering of scenes in low visibility such as darkness, rain, fog with a representation of the static and dynamic lightings is not completely resolved nowadays and needs further research.

***Surrounding traffic.***

The surrounding traffic behavior is a key feature for the validity of the simulator in training context, it appears in almost all the scenarios of level 2 and higher levels. All the vehicles of the surrounding traffic should have a realistic (human-like) behavior, this implies that each vehicle owns its perception, control and decision modules and its vehicle model.

Some research has been conducted on the validation of traffic model at the macroscopic level on motorway, in terms of traffic flow, platoon speed etc.

Other limited experiments (Ref 1) show a clear increase of the realism of driving simulators when autonomous vehicles are added. Nevertheless, there is a need for more complete validation methods of the behavior of the surrounding vehicles, perhaps benchmarks on data files of the state (position on the street, speed, acceleration, etc.;) of all the vehicles recorded during simulation could be created.

***Vehicle model.***

For training purposes there is no need for sophisticated vehicle model in common situations (good grip of the wheels, no loss of control situations). Numbers of vehicle models with 3 up to 6 dof (degree of freedom) are validated. Models for vehicle with specific behavior are also in use; low friction situations (snow for example), or vehicle with active component such as ABS.

***Full driver cockpit commands.***

Environment cockpit closer to an actual car – seat, gear lever, driving wheel and pedals – force feedback on driving wheel and pedals could ease the driving and improve the re-use of skills "on the road", mainly for scenarios of level 1 and higher levels (see Figure 3).

**Discussion**

The basic psychomotor aspects (vehicle control) could be trained on a driving simulator, but in any case, even with a sophisticated simulator the training in an actual car could not be replaced for these skills. A traffic model able to create and manage autonomous vehicle around the driven vehicle is a major component of the driving simulator dedicated to driver's training. Under control of scenarios, the traffic model could create and reproduce specific circumstances of traffic enabling the trainee to repeat and train certain tasks. In the same way, it is possible to train anticipating skills, or to enhance risk awareness by submitting the trainee to unexpected events.

**USING DRIVING SIMULATOR WITHIN A TRAINING CURRICULUM*****Trainee's point of view: what are the conditions for an efficient training?***

During training skills the trainee should be in good conditions in order to be concentrated on the learning tasks. The comfort and the easiness to drive are very subjective quality of a driving simulator and are depending on many parameters, it is known that when one parameter is badly tuned the simulator becomes rapidly un-drivable and may produce driver sickness.

The **transport delay**, "*the time elapsed between a driver's action and its result in the rendering of perceptual stimuli (visual, motion, haptic devices)*" could produce discomfort and difficulties to drive when too high; an acceptable delay is less than 100 ms. Other devices or functionalities on the contrary could enhance the perception of engine state (sound), road situation (surrounding vehicle noise) or vehicle accelerations (motion cueing system).

**Sound system:**

The sound system aims at reproducing all the sounds existing in a vehicle. The main sound sources are:

- Driven vehicle - engine noise, aerodynamic noise, tyre-ground generated noise,
- Surrounding vehicles noise – possibly spacialized,
- Special sound effects – wall reverberation (in tunnel) for example.

**Motion cueing system:**

Even on the high end driving simulator the motion cueing system is unable to reproduce actual vehicle accelerations and by the fact vestibular cues can not be correctly presented to the driver. Numerous architectures/configurations for driving simulator have been realized; platforms with 1 to 6 degrees of freedom (Dof), with/without rotation, with/without embedded visual system, with/without cockpit or seat vibration, etc.. , such systems are particularly useful for vehicle control scenarios (level 1). Limited and cheaper systems with one (longitudinal) or two (plus rotation) movements could be interesting for all the scenarios.

**Haptic feedback:**

Like motion and sound system haptic feedback on steering wheel (and eventually pedals) could enhance the feeling of the driver and the easiness to drive particularly for vehicle control scenarios.

***Instructor's point of view: what tools or functionalities of the simulator are or would be useful or effective to improve the teaching quality***

Unlike on the road training, surrounding traffic can be controlled on the simulator and it is possible to create specific situations. Each scenario should not necessarily be presented to the trainee as a separate lesson but as part of natural driving. This strategy aims at preventing trainees from preparing themselves by increasing and focusing their attention on the specific scenario task.

As on a driving simulator numerous driving parameters can be computed in real time and recorded, these facilities allow new ways of teaching:

- Recording facilities for all the vehicles and others actors around the driven car, this allow the possibly of replaying a situation, with the same or a different point of view.
- Computing in real time of indices such as TLC (Time to Line Crossing), TTC (Time To Collision), or more complex parameters allow the detection in real time of risky or erroneous situations.
- Automatic computation of a score or global assessment criteria at the end of each lesson.
- Possibility of self training, the trainee can repeat the same lesson while he/she feels not enough confident or if his/her score is to low.

The role of the instructor have also to be adapted, for example when a driving error is detected the instructor have the possibility to stop the current scenario, to review with the trainee the sequence where the error has occurred and to explain the cause or the way to avoid such a situation. The score obtained at the end of each lessons indicate the knowledge and skills progression of the trainee and help the instructor for the choice of the next lessons.

***Training organization:***

Training on driving simulator partly replaces other training methods as for the theory part as for the skills training, but it can not be a simple replacement. The general organization of the training should be redesigned taking account of this new possibility and the instructor role should also be redefined. The number, the duration of simulator training sessions and the way to manage the simulator or the simulators may vary depending on the type of training (basic, training session on a specific subject).

## CONCLUSION

Driving simulators are nowadays used in different countries for driver's training, testing and licensing, their efficiency seems to be established, as shown in the two following examples:

- At ANWB a Dutch driving school the instructors estimate a simulator lesson of 20 minutes to be equally effective as a 1 hour practical driving lesson.
- At AFT-IFTIM a French driving school for trucks drivers the estimate time profit is 24 hours on a total of 85 hours (duration of a complete training to obtain the driving license).

Nevertheless, the validation of driving simulators for training is nowadays little developed, some experiments have been done but several questions still remain open notably the assessment of retention of skills acquired through simulator training and the long terms effects of simulator's training

A key component of the driving simulator is the surrounding traffic which is required for training skills or scenarios of level 2 and higher levels of the GADGET matrix (2 Mastering of traffic situations - 3 Goals and context of driving – 4 Goals for life). There is a need for validation methods of the behavior of the surrounding vehicles, perhaps benchmarks on data files of the state (position on the street, speed, acceleration, etc. ;) of all the vehicles recorded during simulation could be created.

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