ASSESSING DRIVING SIMULATOR TECHNOLOGY BASED ON TRAINING REQUIREMENTS ANALYSIS

Urban A. Thoeni, Oerlikon Contraves AG, Training Systems and Simulator Department
Birchstrasse 155, 8050 Zurich, Switzerland, e-mail: cztu@ocag.ch

ABSTRACT:

The hardware and software design of a simulator must be carefully matched to the intended training aims in order to achieve maximum training efficiency and economical use of the training facilities.
In this paper, the training requirements for land vehicle simulators (car, truck, tank, tram) are analyzed and categorized. Various categories of the available simulator component technologies (e.g., motion systems, display systems, vehicle simulation models, etc.) are defined.
The combination of these didactic and technological dimensions are used to define a matrix of the possible solutions for training simulations.
When each of the fields is additionally rated under the economical aspect (cost of the component relative to total system cost) a three-dimensional profile of the simulator technology results. Such a profile is valid only for a period of time if the changes in training needs and technology are taken into account.
For each type of system to be simulated and the intended training aims, an upper feasible cost limit for the simulation system can be defined which is related to the cost of the original equipment and very much also to the cost of creating identical training situations in reality. If the simulator technology profile is compared to this training-specific measure, an excellent tool results to take the appropriate design decisions, or to assess the feasibility of a proposed simulator system.
This analysis may serve to indicate the direction the technical progress should take and development efforts have to be invested in order to allow for more cost-efficient and training-effective systems.
Examples of driving simulators (tank, truck, tram) in use or proposed in Switzerland are viewed under these aspects, and key technologies are identified which are expected to make significant progress in order to make simulators more feasible as an alternative to purely “on-the-road” training.
This method of analysis is also very well applicable to other kinds of training simulators.

AUTHOR’S BIOGRAPHY

Dr. Urban A. Thoeni is a senior systems engineer with the Simulation and Training Systems Department at Oerlikon Contraves AG. His work includes system design and specification for training simulators developed for the civilian and military market.
After obtaining his master’s degree in electrical engineering at the Swiss Federal Institute for Technology, Zurich (ETH Zurich) he continued to work at the same institution on his dissertation on fast parallel real-time multicomputers. Since then he has been working for several years in the simulation industry.
He has published a book and numerous papers on real-time systems and simulator technology. He is a member of national and international engineering societies, such as IEEE and ACM, among other.

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INTRODUCTION

The decisions for the introduction of a technology-based training (TBT) system in any civilian or military organization become more and more difficult and are challenging in almost any point of view. On the one hand there is the ever-increasing pressure to introduce more sophisticated training means, based on the growing awareness of the possibilities and the progress in technology, on the other hand, there is an increasing need to utilize cost-efficient equipment and training methods due to shrinking budgets and increased competition.

Recently a number of investigations have been published by training organizations which deal with this pressure to find the most cost-efficient training equipment ([BeSvTh 97], [CooHam 98], [Roy 98], [TalHut 98)]. These reports describe the procedures with which the coherence of the training aims with the training system envisioned is to be ensured.

Today the once separate worlds of highest-tech training equipment where costs were irrelevant and low-fidelity training systems which were affordable but of limited training use are starting to converge. Nevertheless, it is still difficult to decide for a particular training system what technology is appropriate and most cost-efficient for the intended use.

In this paper, driving training simulators are categorized with respect to two main aspects: training requirements and component technology. By combining the two views the cost-driving requirements and components can be identified. Thus a valuable aid to deciding on the final design of a training system is provided.

Even though it has been developed for driving simulators the methodology presented is applicable to any technology-based training system.

TRAINING REQUIREMENTS FOR DRIVING SIMULATORS

Driver training, in general, can roughly be divided into the following categories:

- Basic vehicle handling (R1)
- Maneuvering (R2)
- Traffic regulations (R3)
- Basic behavior in traffic (R4)
- Complex traffic situation handling (R5)
- Handling of special situations (e.g., vehicle breakdown) (R6)

Depending on the type of vehicle involved certain categories are more important than others. When training car and truck drivers, the primary goal is to enable them to handle all traffic situations safely at the speed they select to be appropriate. They basically need to be able to drive defensively. For tram (streetcar), and train drivers, passenger security is of utmost importance (besides handling many security procedures and systems), together with keeping on schedule. Drivers of tanks, on the other hand, encounter a somewhat different situation since they must be able to control their vehicle even under heavy pressure and conduct quick maneuvers which may stress the vehicle and its crew to their limits.

Therefore for basic driver training just vehicle handling and simple traffic situations may suffice while for advanced training a sophisticated simulation of the environment and real or simulated crew members are required, possibly with integration of additional simulators.

SIMULATOR TECHNOLOGIES

Driving simulators are composed of several components which can have various levels of technical sophistication. Key components of such simulators are:

- Cabin mock-up (T1)
- Vehicle simulation (T2)
- Display system (T3)
- Image generator (T4)
- Motion system (T5)
- Trainee monitoring equipment (T6)
- Exercise evaluation system (T7)
- Exercise generation tools (T8)
- Interconnection among simulators (T9)

For the cabin mock-up and the vehicle simulation the decision needs to be made between a generic model and the emulation of a specific vehicle. Technically, there is little. The capabilities of the display system , on the other hand, very much depend on the type of vehicle to be emulated. Driving a tank with closed hatch requires a very small field of view (FOV) whereas driving a bus which consists almost exclusively of windows in the front part asks for a very large FOV. Additionally a choice must be made between collimated displays and flat screens with different ways of projection.

The image generation system is basically determined by three factors: the FOV, the resolution, and the frame rate (i.e., frequency with which the image has to be recomputed). As mentioned, the field of view is determined by the type of vehicle, the resolution is dependent on the tasks the driver has to fulfill (distinction of objects necessary at a given distance), whereas the frame rate depends on physiological facts as well as on the vehicle dynamics. (Slow vehicles require a lower frame rate than vehicles with highly dynamic behavior.)

The same applies to the motion system. Its capabilities clearly are determined by the vehicle dynamics, but also by the type of training conducted and the environment (terrain) in which the vehicle moves.

The system's capabilities for trainee monitoring and automatic trainee assessment not only are dependent on the vehicle instrumentation, but also on the method of evaluation which is to be applied. If the trainee has to be monitored and assessed on-line by instructors, specific monitoring equipment is required. If the trainee is assessed automatically the monitoring equipment can be reduced, but additional assessment systems and software are required.

The facilities for after-action reviews depend on the intended training and – in the military – debriefing procedures.

The same rationale applies to the exercise generation capabilities. If a given set of exercises remains constant throughout the life of the TBT system, exercises can be generated during system development, whereas changing training aims and trainee categories require more flexible exercise generation capabilities.

Depending on the type of training (partial task training, crew training, mission training, etc.) the need for interconnecting simulators with other, possibly dissimilar systems may arise.

THE TBT SYSTEM REQUIREMENTS/COMPONENTS MATRIX

Systematically speaking, the training requirements and the simulator components span a two-dimensional space in which any simulator covers a certain area, depending on the training aims the system covers and the technology it uses. This space can also be displayed as a matrix, the so-called Requirements/Components Matrix (RCM). In this matrix each field is filled with a mark if the given training objective is dependent on the given technology and vice versa. By itself the RCM only illustrates the way the simulator is realized.

THE SIMULATOR TECHNOLOGY PROFILE

Enhancing the RCM by replacing the marks in the fields by figures which represent the relative cost of each component compared to the total cost of the TBT system creates a unique tool to assess the system and to identify the cost-driving components and training goals. Obviously this requires a close cooperation between the designers of the technical system and the designers of the didactic concepts. However, a careful analysis of costs and training aims may lead to astonishing revelations and to the design of more cost- and training-effective systems.

During system design the relative costs of the components relative to the training aims encompassed for the training system have to be estimated. However, with the experiences gained in the realization of other systems, it is relatively easy to come reasonably close to the actual costs.

Once the relative system costs of the components have been estimated in dependence of the training aims, the simulator technology profile has been defined and the specific design can be assessed for feasibility. When analyzing the components with high relative cost, it must be decided for each of the components whether the gain in training efficiency and flexibility justifies the costs. If not either the training aims have to be revised or the component must be re-engineered in order to reduce its costs.

Therefore the simulator technology profile represents a very useful tool to asses simulator design and technology. When displayed graphically in a 3D-plot the critical components can easily be identified.

FEASIBLE COST LIMITS FOR DRIVING SIMULATORS

Training simulators are typically procured in connection with the introduction of new types of vehicles. Seen as a whole procurement process, the costs of the real equipment also determines the cost limits for the simulators.
When the costs of the simulators and the actual vehicle are compared, a commercial airplane simulator is cheap while a sophisticated car simulator is prohibitively expensive even though the absolute budgets for the simulators alone are the very opposite.
This view is understandable when considering the total budget but it nevertheless distorts the relevant issues for determining the feasible cost limits of a simulator.
Additional cost factors which should be taken into account, but frequently are not, for determining the feasible costs for a driving simulator are:

- savings compared to conventional training by avoiding unnecessary drives to remote sites where specific training situations are available
- estimated costs of recreating specific training situations, especially particular traffic situations. Even then, many special traffic situations cannot be reproduced in reality without endangering man or material. Therefore, cost estimates are impossible. Put differently, regardless of the costs, a simulator is always cheaper than live training.
- savings in instruction personnel due to automated training.

However, the experience with quite a few driving simulator projects shows that procurement agencies tend to grossly neglect the immaterial aspects of the real value of a TBT system.
Generally speaking, even expensive simulators for relatively inexpensive vehicles like cars and trucks can be cost-effective if high training aims are met. Otherwise, if only basic tasks can be trained, the only way to achieve cost effectiveness is to resort to inexpensive COTS (conventional off-the-shelf) components.

CASE STUDIES

The following case studies are based on systems in which the author has been involved personally or has detailed knowledge of.

Case Study 1: Low-Fidelity Car Driving Simulator

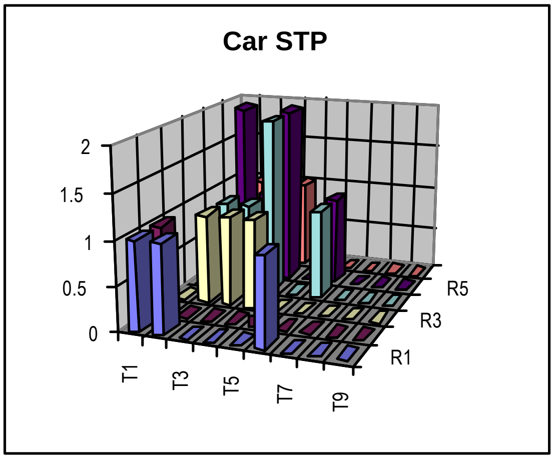
The training aims followed by this type of simulator are mainly vehicle handling, mastering a set of the traffic regulations by the trainee and correct behavior in a few traffic situations combined with some emergency training.
A typical low-fidelity car driving simulator is characterized by the following features:

- a simplified and generic cabin mock-up with controls (T1)
- vehicle and traffic simulations limited to a simplified modeling of driving (T2)
- a small field of view, possibly a monitor-based display system (T3)
- the image generation is either based on recordings or low-resolution computer-generated images (CGI) (T4)
- no motion system (T5)
- very simple trainee monitoring equipment, e.g., separate vehicle displays and controls (T6)
- no automatic exercise evaluation (T7)
- predefined, non-modifiable exercises (T8)
- no interconnection to other systems (T9)

The following simulator technology profile (STP) results. The training requirements R1 .. R6 are the ones listed in section Training Requirements For Driving Simulators at the beginning of the paper. They will be used for all the other case studies in this paper as well

	R1	R2	R3	R4	R5	R6
T1	1	1	0	0	0	0
T2	1	0	1	1	2	1
T3	0	0	1	1	1	1
T4	0	0	1	2	2	1
T5	0	0	0	0	0	0
T6	1	0	0	1	1	0
T7	0	0	0	0	0	0
T8	0	0	0	0	0	0
T9	0	0	0	0	0	0

Displayed graphically, the simulator technology profile (STP) looks as follows:



The costs related to the vehicle handling and traffic interaction are clearly visible (R1, R4, R5). The high relative costs of the image generation are reflected by the fact that the row T4 relatively high populated. The limited training aims and flexibility in training clearly show up in the missing components for exercise evaluation and generation (T7, T8).

Case Study 2: High-Fidelity Truck Driving Simulator

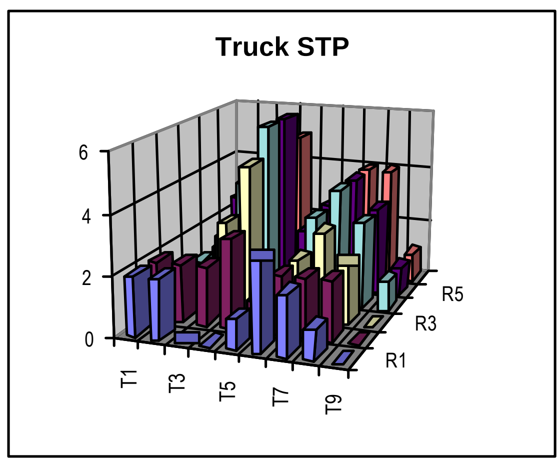
A high-fidelity truck driving simulator like the one described in [ThoDür 95] is designed to provide a broad range of training capabilities for all possible classes of users from beginners to experts. It covers all training aims in the Requirements/Components Matrix (RCM) for driving on the road.
The training aims cover vehicle handling, maneuvering, and traffic regulations. Behavior in traffic, advanced traffic situations and special situations include different specific situations for particular kinds of users, e.g., emergency braking for drivers of tanker trucks.
Due to the broad range of training aims, the hardware is sophisticated and includes

- fully functional cabin mock-up (T1)
- paramterized and sophisticated vehicle simulation, “intelligent” and controllable traffic (T2)
- wide-angle display system, possibly collimated (T3)
- high-resolution image generation with a high update rate (min. 60 Hz) (T4)
- motion system, but not necessarily a full motion platform (T5)
- possibilities of trainee monitoring, including detailed vehicle and traffic information, video surveillance (T6)
- automatic exercise evaluation to free the instructor from routine monitoring tasks, combined with replay and after-action review facilities, training documentation (T7)
- full possibilities of exercise generation (T8)
- possibly interconnection to other simulators (T9)

The following simulator technology profile (STP) results:

	R1	R2	R3	R4	R5	R6
T1	2	2	1	1	1	1
T2	2	2	1	2	3	3
T3	0	2	3	4	4	3
T4	0	3	5	6	6	5
T5	1	1	0	0	2	2
T6	3	2	2	3	3	3
T7	2	2	3	4	4	4
T8	1	2	2	3	3	4
T9	0	0	0	1	1	1

Displayed graphically, the profile looks as follows:



For the truck driving simulator the most challenging training requirements are located in the area of traffic interaction. For this area the most cost-driving technologies lie in exercise evaluation and image generation.

Case Study 3: Tank Driving Simulator

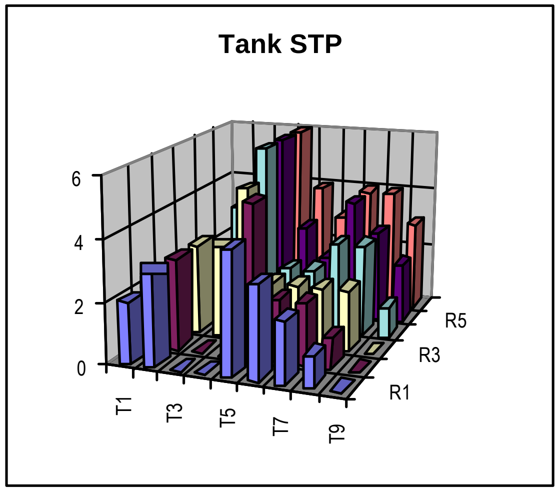
Tank driving simulators are employed for a broad range of training types. They may start with pure driver training and extend to tactical and combat training for the whole crew. In this case study an example system will be considered where a driver trains controlling the vehicle in different environments under the control of the tank commander.
The emphasis in the training aims therefore lies on vehicle handling and maneuvering, including off-road driving, coupled with the basic traffic regulations and driving in traffic. Few advanced traffic situations and special situations have to be trained.
The simulator components can be described as follows:

- for pure driving the tank cabin does not need to be very sophisticated; only the driver compartment must be emulated (T1)
- vehicle simulation needs a good model for on- and off-road driving; normal traffic simulation (T2)
- the display system needs a wide angle plus mirror driving display capabilities (T3)
- image generation with a high resolution and high update rate (T4)
- good motion system including motion platform is mandatory (T5)
- trainee monitoring is required for instructor interaction, including detailed vehicle information, video surveillance (T6)
- automatic exercise evaluation for supporting the instructor, combined with replay and after-action review facilities, training documentation (T7)
- full possibilities of exercise generation (T8)
- possibly interconnection to other simulators (T9)

The following simulator technology profile (STP) results:

	R1	R2	R3	R4	R5	R6
T1	2	2	1	1	1	1
T2	3	3	3	2	1	2
T3	0	0	3	4	4	3
T4	0	0	5	6	6	6
T5	4	5	2	2	3	4
T6	3	2	2	2	2	3
T7	2	2	2	3	4	4
T8	1	1	2	3	3	4
T9	0	0	0	1	2	3

Displayed graphically, the profile looks as follows:



For the tank driving simulator, the emphasis lies on the interaction with traffic and handling special situations. Clearly visible are the costs of image generation and of the motion system.

Case Study 4: Tram Driving Simulator

Training tram drivers consists in teaching the drivers vehicle handling and the special traffic regulations which apply to trams. Due to the limitation of trams to their tracks behavior in traffic must be trained at all levels. Additionally, special situations related to boarding passengers and crossing pedestrians must be trained.
Therefore the system configuration of a tram situation consists of

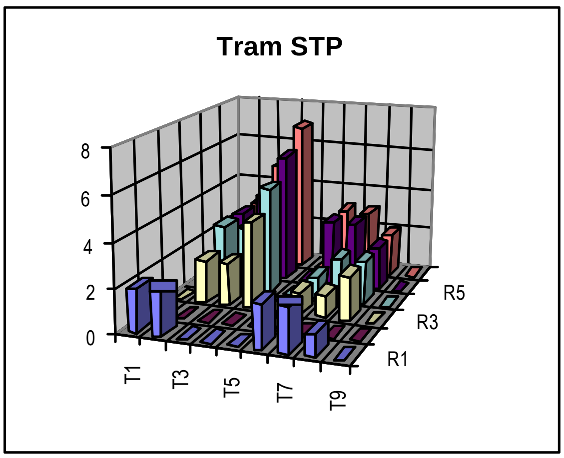
- cabin mock-up (original or generic) (T1)
- vehicle simulation with simplified dynamics for driving with moderate speed, simplified traffic simulation including some special traffic situations (T2)
- wide-angle display system (T3)
- medium- to high-resolution image generator (T4)
- no motion system or, at most, a very limited one (T5)
- trainee monitoring with emphasis on checking the driver's interaction with the environment (T6)
- exercise evaluation with emphasis on behavior in traffic and dealing with passengers (T7)

- once the set of exercises has been defined, no exercise generation is needed (T8)
- no interconnections to other simulators are needed (T9)

The following simulator technology profile (STP) results:

	R1	R2	R3	R4	R5	R6
T1	2	0	0	0	0	0
T2	2	0	2	3	3	3
T3	0	0	2	3	4	5
T4	0	0	4	5	6	7
T5	0	0	0	0	0	0
T6	2	0	1	1	3	3
T7	2	0	1	2	3	3
T8	1	0	2	2	2	2
T9	0	0	0	0	0	0

Displayed graphically, the profile looks as follows:



One of the most important areas for tram driving simulators is training of the driver's interaction with the environment with a strong emphasis on the handling of special situations. The image generation is clearly the most cost-intensive technology.

Feasibility discussion of the types of driving simulators

Even without giving detailed figures of the costs of each system, it is possible to rate their feasibility.
The low-fidelity car driving simulator obviously is a low-cost system. The technology involved can offer only limited functionality, and therefore the possible training goals have their limitations. So while such a system is affordable, it is in many cases not feasible.
The high-fidelity truck driving simulator contains expensive technology, but offers a very broad range of training. Since the real vehicle is comparatively cheap, such a simulator is only feasible if it is also used for training special situation which cannot be emulated safely in reality.
Tanks are expensive to operate, so even an expensive simulator pays off soon. If training of special situations is conducted as well, the benefits multiply.
Tram simulators are not overly expensive if compared to the real vehicle. If it is taken into account that they can improve passenger safety, their use is justified very much.

SUMMARY AND TECHNOLOGY ROADMAP TO THE FUTURE

When comparing the Simulator Technology Profiles of the case studies it is obvious that a broader range of training requirements immediately calls for the combination of many and advanced component technologies. Regardless of the vehicle to be simulated the high relative cost of the image generation and the display system are clearly visible. The motion system is a relatively expensive component as well and is used only if justified by clear training requirements.
Therefore a careful definition and justification of the training aims of a planned simulator system is necessary since the technology necessary to satisfy the training needs very quickly leads to high costs.
Considering the general technological progress of computers, the cost of image generation must be lowered drastically to satisfy the user expectations at feasible costs. As more simulators are installed it is to be expected that some standardized types of display systems will be introduced which will then be available at a reduced cost.
Once other components are standardized as well, the simulator system costs can be lowered such that these training facilities become more feasible for broader applications and cheaper vehicles.
The effect of more cost efficient driver training facilities being available is increased security on the road – a goal we can all support.

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