ADAMS: An Advanced Driving and Maneuvering Simulator For A Variety Of Training Needs

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ABSTRACT

The Advanced Driving and Maneuvering Simulator (ADAMS) is a new high-end truck driving simulator. It has been designed to meet the various customers' training needs at a reasonable price in order to substitute a considerable part of conventional on-the-road training by highly efficient simulator training. Furthermore, a simulator allows training appropriate reactions in situations that are impossible to arrange identically for all trainees in reality.

The requirements for a modern driver training system are first analyzed in depth. The main demands are that training be realistic and effective, unified and efficient, safe and non-polluting, and also economical. From these requirements, the design considerations for the driving simulator are deduced.

Due to modular construction, the driver's cabin is independent of the remaining simulator system. The cabin can therefore be adapted to any truck type. It is fully equipped with working controls and instruments. The collimated visual system consists of a panoramic front view display system plus rear view mirrors. The computer-generated images (CGI) are of high resolution and include all state-of-the-art features.

The trainee is given realistic feedback on the vehicle behavior through his view of the road and of traffic, appropriate vehicle noise, and a motion system. Instantaneous feedback on the driving performance is provided through spoken messages and through signs appearing in the sight. After a lesson, a training report is displayed on the control screen. Additionally, a detailed report generated by the automated assessment system can be printed and stored in the trainee database.

The lessons are carefully designed and contain training topics which have been thoughtfully selected in order to create a well-balanced training course. Life-like traffic simulations interacting with the trainee's ride support the reality of the road scenes.

Several simulator cabins can be integrated in a training site. They are connected to the instructor station for central data storage and trainee control. However, in each simulator cabin training progresses independently.

ABOUT THE AUTHORS

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After obtaining his master's degree in electrical engineering at the Swiss Federal Institute of Technology, Zurich (ETH Zurich) in 1986 he continued to work there for his dissertation on programming fast parallel real-time multicomputers. Subsequently, he joined a door automation company as a software engineer before changing to his current employer.

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INTRODUCTION

The demands on the quality of professional driver training have been increasing steadily over the years. Not only has the traffic density risen considerably, especially in urban areas, but the competition among freight carriers has also been increasing steadily and thus the pressure on the individual driver has risen. Another important stress factor for the drivers is that the vehicles for transporting goods have grown in size and weight. Due to the increased potential damage in case of a traffic accident or a manipulation error the error margin for the drivers has become very small. Additionally, an employer may want to evaluate driver performance periodically and give the employees continuing education.

For these reasons, it is indispensable to have a means to conduct training for truck, bus, and other professional drivers which is

- realistic and effective
- unified and efficient
- safe and non-polluting
- economical

Conventional classroom education, coupled with training rides in the vehicle, has reached the limits of its ability to provide drivers within a reasonable time with a level of proficiency which meets the demands of today's traffic. The limitations of the conventional, vehicle-based training method are:

- limited availability of training facilities
- environmental conditions cannot be influenced
- training critical situations is not feasible or too risky
- certain specific traffic and emergency situations occur rarely on the road
- trainee assessment is dependent on the individual instructor
- no potential to increase the training efficiency

The biggest disadvantage of vehicle-based training is that the situations for which training is most necessary cannot be generated at will.

Due to recent technical advances, it has now become feasible and economical to use technology previously reserved for expensive simulator systems (like flight simulators) also for driving simulators.

Especially computer-generated images (CGI) have been developed to a level which allows them to be used in driving simulators. For CGI systems, the requirements in scene density are even higher for driving simulators than for flight simulators.

The ADAMS (**A**dvanced **D**riving **A**nd **M**aneuvering **S**imulator) system has been designed for use by professional drivers such as truck drivers, bus drivers, and drivers of any other special large and/or heavy vehicles. For simplicity's sake, the text generally refers to truck driver training, all others being included.

REQUIREMENTS FOR AN EFFICIENT DRIVER TRAINING SYSTEM

The general training requirements for professional drivers have already been mentioned in the introduction. They constitute the basic requirements a driver training system has to fulfill. They are discussed in detail in the following sections.

It is not suggested that a training center only consists of driving simulators. Rather, the training on the road, with simulators, and the theoretical schooling of the trainees using classroom, computer-based training (CBT), and individual studies should complement each other.

Realistic and Effective Training

Training in an environment which contains elements that are clearly recognizable as unrealistic immediately loses its effectiveness.

Steering a simulated truck with a joystick is very well feasible, but this is obviously so far from reality that nobody would seriously consider it for training. Similarly, if the view in the projection system clearly shows the edges of a screen or the reflecting surface of a monitor, or if the images are blurred or show biased colors towards the edges, the sense of reality is very much diminished.

However, reality in a simulator must not be confounded with lack of abstraction. Quite the opposite is true, since it may be necessary to abstract certain features of the real world in order to emphasize the important items for didactic purposes.

Consider for example the sight of buildings in the CGI. Real buildings can be of quite complicated shapes. However, the visual data base does not have to be overloaded with their exact models since the buildings can be designed as cubes with roofs. Their faces are abstracted as flat rectangles painted with a realistic texture. This represents the surroundings and emphasizes the road, which is the main area of interest for driver training.

From the relevant elements of education and training, the following list of requirements can be compiled. A driver training system should contain:

- automated assessment tools
- specific vehicle characteristics
- optimized feedback (view, sound, motion)
- representations of all classes of roads to be driven on
- realistic interaction possibilities with traffic (volume and behavior)
- training opportunities for task-specific critical situations
- variable environmental conditions
- repeatable exercises
- intensive and demanding training

Feedback on the vehicle behavior is very important for generating the correct stimuli for the trainee. Especially for the view and the motion, a good compromise has to be found between the desired sense of reality and the technical feasibility of its simulation (cf. Wade et al. 1994).

Computer-generated images are composed of polygons. One of the limiting factors for CGI systems is the number of polygons in the view. Therefore, the shapes of the objects have to be simplified in order to lower the polygon load which in turn guarantees a sufficient image-refresh rate.

For the projection system, however, additional physiological factors have to be considered. The system has to be designed to minimize trainee fatigue and disturbing effects (cf. Frank et al. 1987). Therefore only collimating optics satisfy the needs for advanced systems (cf. Wynn et al. 1995).

Keeping the eyes constantly focused on a screen close by is one source of fatigue. In collimated view systems, the eyes focuses to infinity, thus gaining a relaxed view. Another source of fatigue are small and disturbing spots on the projection plane. In collimated view systems, they are not seen anymore, since the eye is focused to another distance. This eliminates the irritating effects known to all computer users (e.g., by fingerprints on the screen). Such effects very quickly destroy the realistic impression of the view.

Motion is impossible to emulate realistically at a reasonable cost. Therefore, a good abstraction is indispensable. The necessary information for the driver are the changes in lateral and longitudinal acceleration (jerk). The speed and partly the acceleration are communicated through the sound and the view (cf. Von Baumgarten 1987). The changes in acceleration can be transmitted through a seat motion system, possibly in combination with a simple cabin motion system.

Interaction with traffic must be bilateral, i.e., not only the trainee has to react to the other vehicles cruising in the streets, but the traffic surrounding the training vehicle has to adapt its behavior to the trainee as well. As a consequence, simply playing prerecorded video sequences is clearly insufficient. Instead, traffic has to be controlled in real-time according to the normal traffic rules.

One big advantage of training systems over training in the real vehicle is that control over the environment becomes possible. Time of day, weather, illumination, and road conditions can be set as desired for each exercise. Long and unproductive rides to distant sites with some special types of road or traffic situations can be avoided.

Another advantage is that trainees can repeat an exercise until they completely master it. All trainees are doing the identical exercises.

A last and yet important point is that intensive and demanding training prevents the trainees becoming bored.

Unified and Efficient Training

No transport organization can afford to waste its resources. Especially organizations with a constantly high demand on training are dependent on maximizing the efficient use of the training personnel and facilities.

Another important aspect is securing constantly high quality of the training and of periodical skill assessment. This is only possible with an unbiased and automated training system.

Therefore, a training facility must meet the following requirements for unified and efficient training:

- standardized lesson plan
- training to the desired level of skills
- individualized and self-paced training
- independence of weather, time of day, and season
- objective and unbiased trainee assessment
- optimization of instructor assignment

As a first step towards efficient training, a lesson plan must be developed which is based on a thorough analysis of the training needs for the specific institution. The resulting lessons have to be planned in detail and must offer a step-by-step path to the training goals. There must be a means to adapt the sequence and contents of the lessons to each trainee's individual foreknowledge and learning speed.

The lesson control allows an individualized and self-paced training which maximizes the training efficiency. The automated trainee assessment ensures that each trainee reaches the intended level of skills (see Korteling 1993).

With this system, the instructors can be assigned to the indispensable tasks, i.e., conducting a limited amount of live training with the trainees on the road, and assist trainees with special needs. Thus, they are relieved of boring routine tasks and can concentrate on areas where human engagement is essential.

Safe and Non-polluting Training

Safety issues and the prevention of environmental pollution are gaining importance. Therefore, a driver training must comply with these mandates as well:

- no exposure of man and material to dangers
- little noise and exhaust fumes

While the problem with noise and exhaust fumes can partly be solved by conducting most of the training in remote areas, the question of avoiding dangers during the training is more pressing.

With trainees inexperienced with a given vehicle or special task, the risk is high that the vehicle will be damaged. While for simple vehicles this is merely a question of repair and maintenance costs, the consequences with special vehicles or tasks can be severe. Just consider the case of tank trucks transporting dangerous chemicals, or a tractor towing a large commercial aircraft to a terminal. With such risks at stake, it would be irresponsible to let someone handle the real equipment before having reached proficiency in accomplishing the task with a simulator system.

Another point is that the trainee must not suffer any damage from the training system itself. While radiation emission of electronic equipment is known and strictly regulated, the sources of the so-called simulator sickness are less well known.

One reason for the simulator sickness cited in the literature is that the motion and visual cues do not match in time and therefore emulate poisoning (cf. Watt 1983). One reaction of the body to poison is nausea and vomiting. Through careful design of the cueing system, this source of simulator sickness can be minimized.

Economical Training

Large transport organizations will be able to fully utilize a training facility of their own. Smaller organizations could cooperatively maintain a training center serving the needs of all members and thus minimize the cost / benefit ratio.

Economy is a significant issue in any case, regardless of the financial possibilities of an institution. For driving simulators, the main economical issues are:

- reduction of actual driving hours with the instructor
- less wear and tear on the training vehicle
- less fuel consumption

If the driving time with the instructors is reduced, the instructors can be assigned more to indispensable tasks. Thus, the trainee throughput of the training institution can be increased. Similarly, the number of vehicles to be reserved and maintained for training purposes can be reduced.

As discussed above, the wear of equipment is higher in training than during normal use. If the trainees drive the real vehicles only after absolving the basic training in the simulator, the likelihood of an error in manipulation and of subsequent damage to the vehicle is much reduced.

Apart from the ecological aspect, reducing the fuel consumption for driver training is also an economical issue. While fuel costs are a small amount of the total operating costs, those savings still add up.

REQUIREMENTS FOR THE TRAINING DRIVING SIMULATOR

Given the analysis of the requirements for a driver training system, the functionality needed in a training driving simulator can be compiled.

The requirements for a training driving simulator are:

- interaction with the trainee and instructor
- true-to-life vehicle reproduction (cabin, dynamics)
- visual simulation with large field of view and non-fatiguing display system
- optimized feedback system (sound, motion)
- training environment with controllable scenarios (environment, vehicle setup, traffic situation)
- trainee performance assessment capability
- combination of several simulators at one site

The complexity of maneuvering a vehicle and driving in the traffic is due to the concurrent interaction of the driver with all other traffic participants and the environment. A driving simulator can only provide an adequate training environment if this interaction is realistic.

Additionally, the instructor must be able to influence the training. This starts with the definition of scenarios and exercises, and continues with interaction possibilities during the training (induction of vehicle failures, special traffic events) down to the possibility of monitoring the trainee on-line during the training.

The requirement that the vehicle reproduction has to be true-to-life is often neglected in existing systems. Both the cabin mock-up and the real-time software have to be specifically designed to give the trainee the "real" feeling.

In order to increase the sense of reality, the field of view has to be as large as possible, i.e., a wide angle for the front view and additional view channels for the rear-view mirrors. The display system has to meet high ergonomic standards in order to reduce the induction of simulator sickness.

As discussed above, the feedback system has to provide the trainee with all the information about the vehicle and the environment which is necessary to allow the trainee to assess the situation correctly and to react accordingly. This includes motion as well as the sound of the own and other vehicles.

Large six-degree-of-freedom motion platforms as in flight simulators are not necessarily needed, since they all have limitations in speed or acceleration. The much higher cost of such motion platforms is not justified by the limited increase of feedback intensity compared to simpler motion systems such as seat motion systems.

The scenarios used for the training have to be adaptable to the changing needs of the trainees. If the training possibilities are fixed in the beginning and cannot be changed, they are bound to sooner or later fall short of the real needs.

Conducting efficient training also means the integration of several simulators in one site, where one instructor can concurrently supervise several trainees.

KEY ADAMS CONCEPTS

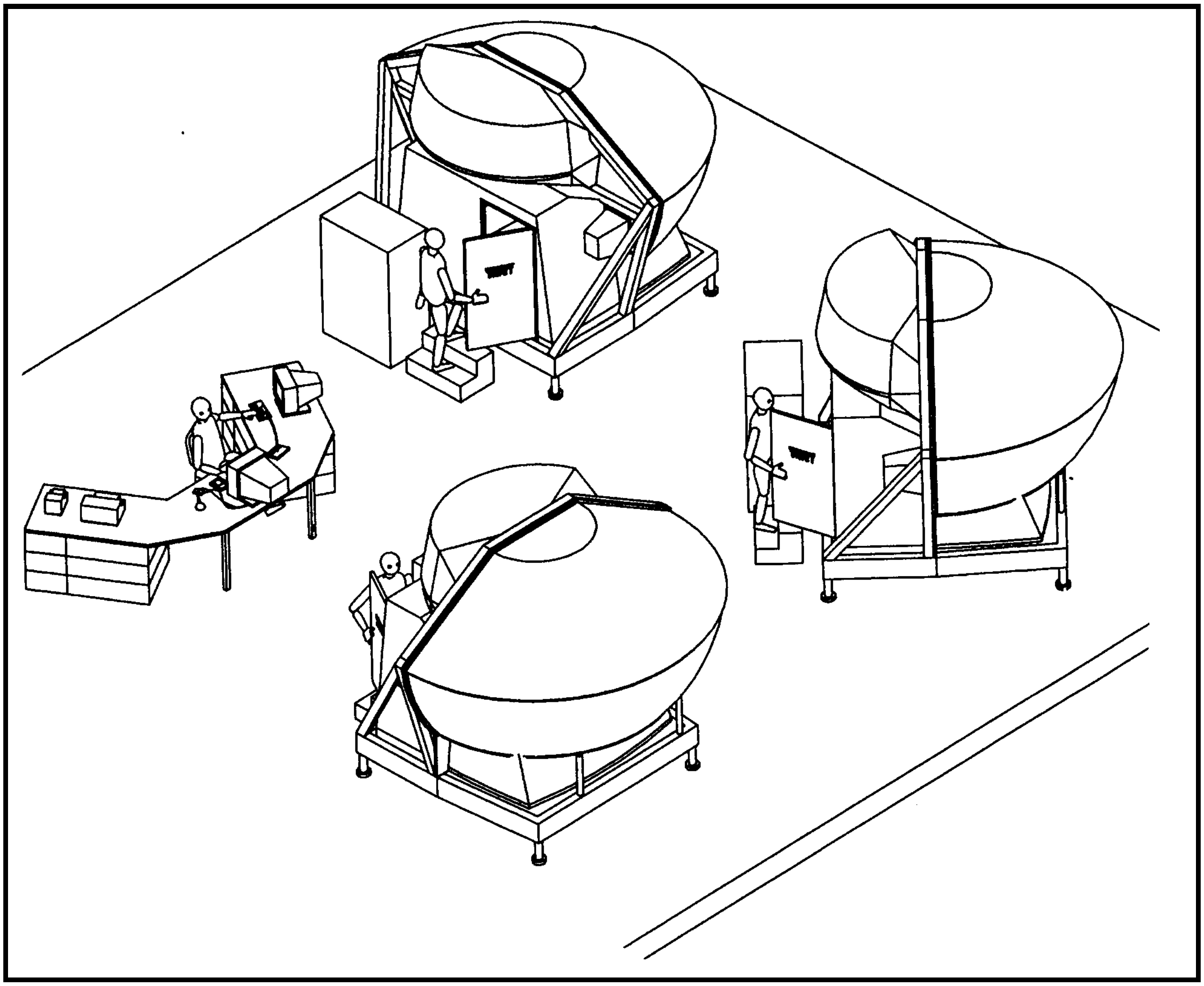
The requirements discussed above form the basis for the development of a driver training simulator system which should be

- highly training effective
- easily adaptable to different vehicles and training needs
- scaleable in the number of cabins
- cost effective

The relevant design features are discussed in the following sections.

A training facility consists of an instructor station and one to six simulators (training stations). The simulators are connected to the instructor station through a network. In each simulator, a trainee can complete his individual lesson. A facility with three training stations is shown in the figure below.

From the instructor station it is possible to monitor the trainees and to get in contact with them through a (bi-directional) intercom system.



Training Objectives

Depending on the training needs defined, the following training objectives are pursued with ADAMS:

- basic driver training
    - operating the vehicle
    - maneuvering
- training driving techniques
    - driving under various light and weather conditions
    - economical and defensive driving on various classes of roads
    - handling dangerous situations
- driving in traffic
- maneuvering with different vehicle configurations (with or without trailer, with different vehicle load)

A large variety of situations can be defined with the scenario control which allows the instructor to set up specific training environments. All scenarios are available from a list and are used to prepare the simulator for a trainee.

Subsystems of the Training Station

The training station (simulator) is structured in several subsystems (hard- and software) in order to keep it flexible for adaptations to needs of the training site. It consists of the following subsystems:

- vehicle cabin with operating controls and instruments
- visual system (CGI, front view display, rear-view mirrors)
- motions system
- sound system (vehicle and traffic noise)
- simulation computer with real-time software:

- vehicle simulation module
- scenario control module
- training supervision and control module
- exercise evaluation and trainee assessment module

The mechanical centerpiece of the training station is the vehicle cabin. It is a mock-up, constructed to look in the interior just like the original cabin. It contains all operating controls and instruments, most of which are those used in the original vehicle.

Through the windshield and the side windows, the panoramic front view and the original-sized rear-view mirrors are seen. This gives a realistic and sufficient impression of the environment. The front view system is a collimating projection system.

This projection system offers a viewing angle which is sufficient for the driver to watch the traffic around him. He is therefore able to collect all the information he needs to behave correctly in traffic.

The computerized image generator is an advanced model offering high resolution and state-of-the-art features like advanced texture mapping and weather simulation. It contains a data base which is designed according to the training needs and contains all the necessary types of roads and surroundings.

The motion system has been designed in two versions. The first version is a seat motion system which moves the driver's seat around two axes. With this, the static and dynamic orientation of the vehicle can be communicated to the driver. Additionally, the information about longitudinal and lateral acceleration and deceleration can be transmitted.

As an option, a motion system is available which moves the whole cabin. The cabin is located on a frame which can be tilted in two directions. It basically serves the same purpose as the seat motion system.

With the sound system, the noise of the own vehicle is generated according to the state of the vehicle. The noise of other vehicles close by is also reproduced. Through this, the trainee is able to detect the direction and speed of approaching vehicles.

The simulation computer performs all the real-time tasks which are needed for the simulation itself and for the exercise handling. All the modules mentioned in the list above cooperate in real-time and additionally communicate with the instructor station in order to exchange data when necessary.

Trainee Administration and Training Control

It is possible to set up a central trainee data base for a training site. For each trainee, an individual lesson plan is stored. As soon as a trainee identifies himself in a simulator cabin, his next lesson is loaded automatically and the simulator is prepared for the training.

After completion of the lesson, its result is stored in the data base and the next lesson can be loaded. The next lesson proposed is dependent on the trainee performance measured by the automatic assessment. If the performance was good, the regular lesson plan is followed. If the performance was poor, the repetition of the last lesson, or an alternate lesson with similar contents may be proposed.

The instructor always has the option to override the training schedule control.

From the trainee data base, reports and statistics about the performance level and the training status of individual trainees or of the whole group can be generated automatically.

Feedback and Assessment Tools

Feedback for the trainee is provided through the view, sound, and motion. Through optimized design, the feedback system can be kept small, but nonetheless effective (see Allen et al. 1994)

Feedback from the vehicle and the road is given through the view, the vehicle noise, the motion system, and through the dashboard instrumentation.

Feedback from the exercise control is provided by written messages on a touch screen. It is used to give an introduction to a lesson and to give instructions during the ride and for the handling of the simulator. Most instructions during the ride, e.g. for directing the driver, are reproduced as spoken messages. In this way, the trainee is less distracted from driving than if he had to read a message on a screen. Other ways to direct the trainee are through arrows in the view and written instructions on the control panel.

The automatic assessment tools continuously monitor the trainee's performance in the following categories according to the choices made by the instructor during the generation of the particular exercise:

- vehicle handling
- maneuvering
- obedience of traffic regulations
- behavior in traffic
- handling of special situations

During ordinary training, feedback to the trainee in the case of an error is given through spoken messages, written messages on the touch-screen for after-action review, and in appropriate situations through signs inserted in the view, especially during maneuvering exercises.

During tests, no feedback is given to the trainee.

A training or test report is generated and may subsequently be displayed and printed at the instructor station.

Modular and Flexible Training Station Structure

The training station is constructed in a modular and flexible way which makes it easy to adapt it to different vehicle types.

The self-supporting display system fits like a shell around the cabin mock-up. The cabin mock-up itself is a closed construction which is inserted in the display system almost like a drawer. Since only few contact points are mandatory, the cabin can be modeled as closely to the real truck cabin as necessary.

In the case that a cabin motion system is required, the cabin mock-up is fitted into the frame which supports the display system and is excited by the actuators.

The computers, CGI system, and the other electronics are situated in a separate housing on the rear of the training station.

Key Technologies

The combination of several key technologies is crucial for inclusion in an effective and multi-functional driver training simulator system. The technologies are:

- high performance real-time computer systems
- optimized man-machine interface (MMI)
- AI / expert system applications
- computer-generated images (CGI) and advanced display systems
- matched motion systems
- automated trainee performance assessment

All these technologies are combined in a driver training system which meets the requirements identified in this paper.

CONCLUSIONS

Training professional drivers requires the combination of various teaching methods and equipment. The requirements for training facilities in general and for driving simulators in particular have been analyzed in this paper. For realistic, efficient, safe and economical training, simulators are well suited.

In a simulator, the trainee finds himself in the usual surroundings, i.e., in the truck cabin, where his work in the "real world" also takes place after the training. This is a prerequisite for realistic and efficient training. Another requirement for modern driver training is safety. This includes protection of the vehicle and other traffic participants from damage due to erroneous manipulations by the trainee, but also protection of the trainee from injury. Especially in the first phases of training, simulators offer significant advantages in this area.

Another aspect of realistic and economical training is that the scenario is controllable with simulators.

With the ADAMS (Advanced Driving and Maneuvering Simulator) system, the requirements of modern driver training can be met. Due to the use of advanced technology, the trainee is presented a realistic view in an ergonomic way. Feedback is optimized in order to support the training aims. This feedback is provided through the view, motion, sound, as well as audible and written messages. Both the environmental and traffic conditions can be set up as desired. Scenarios can be created and stored for later use. For each exercise a lesson report is generated. It is used by the instructor to identify the individual training needs.

The ADAMS training facility consists of one instructor station and up to six training stations connected with a network. Each training station consists of a mock-up modeled after the real cabin, a motion system, an image generation and projection system, and the real-time computer. In each training station, individual training takes place which can be monitored by the instructor.

As a whole, the ADAMS system represents a flexible driving simulator adaptable to a wide variety of training needs.

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