A Simple Simulation Predicting Driver Behavior, Attitudes and Errors

Aladino Amantini and Pietro Carlo Cacciabue

KITE Solutions, SNC
Via Labiena 93, 21014 Laveno Mombello (Va), Italy
aladino.amantini@kitesolutions.it

Abstract. This paper presents the simulation tool called SSDRIVE (Simple Simulation of Driver performance). Following a brief description of the theoretical background and basic algorithms that describe the performance of drivers, the paper presents two case studies of DVE interactions, predicting dynamic situations according to different driver attitudes, in similar traffic conditions. In this way the potential ability of the simulation tool to consider behaviors and errors at different levels of complexity is demonstrated.

1 Introduction

The difficulty of developing sound theoretical architectures able to capture the complex Human-Machine-System (HMS) and Human-Machine Interactions is well known and has been widely discussed in the literature. On the other side, an issue that is not always accurately considered is the assessment of the strength and versatility of the adopted numerical solutions and computerized algorithms that enable the implementation of the theories into predictive simulations [8].

Moreover, the overall theoretical model has to cope with the challenges derived from the inclusion, at human level, of cognitive variables such as intentions, motivation, or attitudes, and, from the machine side, of automatic and partially adaptive assistance systems to enable expanded and improved performances.

From the software development perspective, the basic architecture of the simulation has to be designed from the early stages so as to accommodate the inclusion of more and more variables and complexity, in order to enable the representation of decision making processes and actions. This paper presents the simulation implementation, called SSDRIVE (Simple Simulation of Driver performance), of a model that describes at theoretical level the interaction between Driver-Vehicle-Environment (DVE) [4].

In the following sections, the SSDRIVE is initially briefly described with the objective to recall its essential algorithms and correlations. Then, the predictive ability of the tool is documented, showing the type of analysis and evaluation that can be performed when attitudes and personal characteristics of different drivers are modified by input data. Two case studies are analyzed of different driver behaviors in similar traffic conditions. Finally, the conclusions focus on possible further development of the simulation and its potential exploitation for safety assessments.

V.G. Duffy (Ed.): Digital Human Modeling, HCII 2009, LNCS 5620, pp. 345–354, 2009.

2 The Model of Driver Behavior

The overall model of the Driver, Vehicle and Environment (DVE Model) is based on the concept of the "joint" cognitive system, where the dynamic interactions between driver, vehicle and environment are represented in a harmonized and integrated manner. The model focuses on the driver cognitive and behavioral performances, whereas the other two components of the joint DVE system, i.e., Environment and Vehicle, are dealt with relatively simple correlations [4]. At present, the modeling architecture is based on:

1. *Parameters*, which enable the consideration of dynamic behavior and interaction between the three components of the DVE system; and
2. *Task analysis*, which enables to formalize and structure the performance of a driver in a sequence of goals and actions carried out during the DVE interaction.

2.1 Parameters and Modeling Architecture

It has been assumed that five parameters govern the driver behavior, namely: *Experience*/competence (*EXP*), i.e., the accumulation of knowledge or skills that result from direct participation in the driving activity; *Attitudes*/personality (*ATT*), i.e., a complex mental state involving beliefs and feelings and values and dispositions to act in certain ways; *Task Demand* (*TD*), i.e., the demands of the process of achieving a specific and measurable goal using a prescribed method; *Driver State* (*DS*), i.e., Driver physical and mental ability to drive (fatigue, sleepiness…); and *Situation Awareness*/Alertness (*SA*), i.e., perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near futures.

They interact within a "classical" human Information Processing System (IPS) architecture, which assumes that behavior can be described in as similar way of a "system" that "processes" the information and signals to which it is exposed. The most known examples of the IPS related models are the SRK (Skill-Rule-Knowledge) approach of Rasmussen [7] and the Michon's [5] scheme, where the primary driving task is described at different levels of abstraction, namely strategic, tactical and operational. A very simple way to implement the principles of the IPS paradigm is to describe the four basic functions of cognition, namely Perception, Interpretation, Planning and Execution (PIPE). In this approach: Perception considers the sensorial inputs (signals) generated by the vehicle and the environment; Interpretation is the elaboration of the perceived information; Planning implies the formulation of goals and intentions and/or selection of tasks to be carried out; and finally, Execution is the actual performance of actions.

The five parameters affect mainly the first three functions of the PIPE architecture. In other words, the environmental and vehicle variables are perceived and interpreted by the driver and generate typical decision making quantities, such as *intended speed*, *overtaking a leading vehicle* or *stop own vehicle*, to *attain higher speed,* or *lower speed,* or to *maintain speed*, etc. The cognitive function "Execution" describes the actual actions performed by the driver. The model makes the assumption that certain actions are performed in an automatic way, with no cognitive effort. These are typical "skill-based" activities, such as the control of the lateral and longitudinal safety margins, as well as the acceleration (or deceleration) to attain higher (or lower) speed.

2.2 Task Analysis

The most suitable model for representing driver behavior during the performance of activities is to apply a simple "Task Analysis" approach.

In order to represent the set of Tasks that are carried during driving, a certain differentiation has been defined according to the complexity associated with a task:

- *Elementary Functions*, represent basic activities;
- *Elementary Task***,** are task made of elementary functions; and
- *Complex Task***,** are tasks made of a combination of elementary tasks.

In addition to "regular" tasks, the model accounts for *permanent* or *automatic tasks,* which are identified by the fact that they are permanently carried out during a DVE interaction and do not require specific pre-conditions to be launched. These are the stereotypes of what are called "skill-based" activities described above.

3 The Simulation of Driver Behavior

The overall SSDRIVE simulation architecture and process are described in Fig. 1. In particular, at each time interval, the *driver model* receives the vehicle and environment variables which have been calculated at previous time steps. These variables affect the evaluation of the five *parameters* and consequently the selection the new task and associated actions that are carried out, essentially: settings of indicators and basic vehicle control actions, such as steering and accelerating/braking in order to obtain to the desired vehicle position and speed.

The Driver Model calculates the implementation of tasks and generates profiles of steering angle and actions on the break or the accelerator, in order to accommodate for the desired lane position and speed. The *Simulation Manager* is the governing module of the simulation, which receives input from all three main DVE components and evaluates the overall error generation mechanism by means of the Driver Impairment Level and keeps account of the synchronization of the simulation. The effect of ADAS and IVIS, if contained by the vehicle simulation, is also fed to the simulation manager.

In particular, the behavioral part of the simulation implements a number of algorithms for the control of steering and the attainment of intended speed:

- The control of the speed and acceleration has been developed on the basis of empirical correlations [6], which account also for road geometry, principally curves. It considers also the driver attitude and cognitive performance, according to the parameters, primarily EXP, ATT and TD.
- The steering performance has been based on the dynamic interaction of the driver with the vehicle and road and by means of an algorithm that predicts vehicle performance, based on the perceived road characteristics and vehicle speed and position. This algorithm calculates the lateral distance between the middle of the lane (lane centre-line) and the vehicle position according to forecasts generated by the human visual, proprioceptive and vestibular systems (Ayres, 1979). These systems enable human beings to predict their motions processes according to visual as well as feelings processes. A graphical representation of the way in which this algorithm works is shown in Fig. 2.

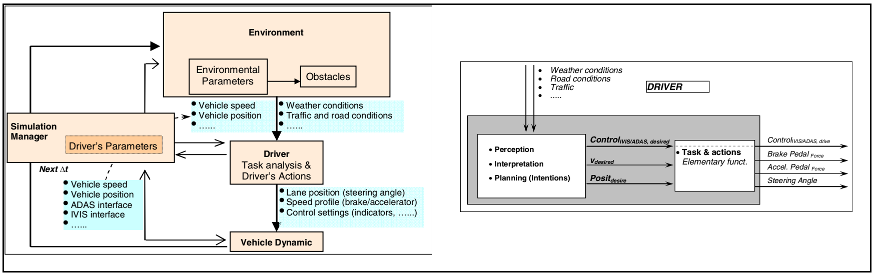


Fig. 1. Overall dynamic DVE interaction process

- The error generation model enables to account for errors made at different levels of cognition, which is then manifested in inadequate actions.

3.1 Error Generation

The last open issue concerns the correlation of the five basic *parameters* with driver behavior and performance with respect to error generation. The mechanism that has been devised to describe Driver error and behavior in relation to the basic parameters has been called Model of Basic Indicators of Driver Operational Navigation (BIDON). A short description of the error model follows, whereas a more extended description may be found elsewhere [2].

It is assumed that the variables affecting the driver behavior, i.e., the dynamic parameters *DS* and *SA* and *TD*, as well as the quasi-static parameters *EXP* and *ATT* are represented by "containers" with thresholds/levels, that change from a driver to another and enable to define the overall state/performance-ability of the driver, as the DVE interaction evolves.

At simulation level, the parameters are associated with initial values (SA_0, DS_0, etc.) and will change every time certain events occur, according to the correlations that associate dynamic vehicle and environment variables and parameters, as described above. The values of the parameters affect the driver performance and error making. In other words, this mechanism contributes to the dynamic process of progressive "filling" or "draining" of the "containers" of the BIDON model (Fig. 3).

The error generation mechanism that is implemented in the SSDRIVE is essentially associated to a single parameter called, Driver Error Propensity (DEP) which represents the tendency towards error making (including violations) that may be generated by impairment, as well as by other possible conditions, e.g., distractions, lack of knowledge, intentional actions etc., which are not related to impairment. The following correlation applies:

$$DEP_t = f(SA_t, DS_t, TD_t, EXP, ATT) \qquad 0 \le DEP \le 1$$

The logics and fuzzy formulations that are implemented in the simulation depend on the user availability of specific algorithms and correlations. A dynamic evolution of sequences of possible error generation is depicted in Fig. 3.

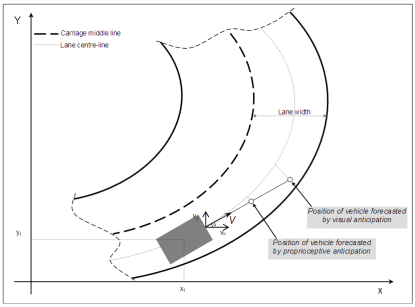


Fig. 2. Schematic representation of proprioceptive and visual anticipation

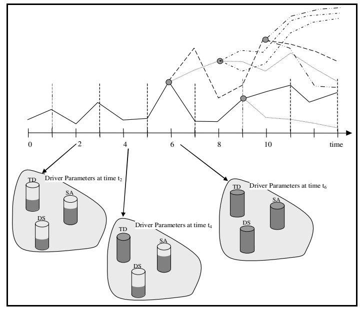


Fig. 3. Error mechanism and dynamic sequences generation

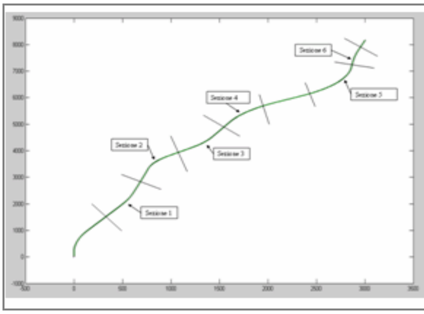
4 Sample Cases of Predictive Simulations of Driver Behavior

In order to demonstrate the predictive power of the SSDRIVE tool a number of case studies have been performed. The track of a Virtual Reality (VR) full scale simulator was utilized in terms of carriageway characteristics, mainly curves and straight lanes. The track was subdivided in six sections (Fig. 4).

The traffic has been simulated in terms of the SSDRIVE input data. This allows the user to consider any number of leading and incoming vehicles, as well as different types of complications that may be found along the road, such as stationary vehicles, pedestrians and other objects.

Various driver behaviors can be simulated simply by changing the input data associated to the so called main-car and main-driver. The main driver is traveling the road, having to deal with other cars, both in the same and in the opposite lane. These other vehicles are simulated as “obstacles”, that is they are handled as entities with a certain mass and volume traveling at a constant speed. As opposed to the main-car, which is simulated by means of a simple but sufficiently realistic model, so as to respond to the control actions of the main-driver, obstacles do not have a behavior-choice process, and cannot change speed or direction.

The objective of these case studies was to show the potentialities of the simulation tool. In the following, the DVE interactions will be described and discussed for a specific part of the track, namely the first two sections and limited to the first two overtaking maneuvers. The correlations that have been utilized to describe the main-driver behavior are very simple and coincide with those implemented as default in the SSDRIVE. Moreover, the main-vehicle is simulated without any particular advanced on board system. For a safety assessment and/or the evaluation of various driver behaviors in the presence of diverse safety and control systems, a different type of analysis would be required, covering more extensive timing of simulation, as well as numerous DVE interactions and a variety of traffic situations. However, this type of study goes beyond the scope of the present paper and would require the use of more detailed and validated correlations for the parameters characterizing driver behavior and in-vehicle support and information systems.



	Start (m)	End (m)
Section 1	1800	2500
Section 2	2500	4100
Section 3	4100	5000
Section 4	5000	6600
Section 5	6600	8000
Section 6	8000	9000

Fig. 4. Simulator subdivision in sections for SSDRIVE simulation purposes

In the cases under discussion in the following, in the first two sections of the track, the simulation scenario includes a couple of cars, traveling at low speed in the same lane of the main-car. The driver (main-driver) aims is to overtake them and proceed with higher speed. However, in order to achieve this objective, the presence of other four cars coming in the opposite direction must be taken into consideration. Depending on the driver characteristics, different actions will be performed. The presence of vehicles in both lanes is kept the same for both simulations.

4.1 Case Studies Input Data

For the two case studies, the following parameters are associated to the main-driver and kept constant throughout the DVE interactions.

Case study 1:

- Attitude: ATT = Prudent
- Experience: EXP = High
- Task Demand: TD = Medium

Case study 2:

- Attitude: ATT = Sensation Seeker
- Experience: EXP = High
- Task Demand: TD = Low

In Case study 2 the attitude of the driver is modified, passing from “prudent” to “sensation seeker”. The TD is also changed decreasing from medium to low. No other changes are made. This implies that, in the second case, a more aggressive type of driving is expected, with higher speeds and more abrupt changes of lanes, acceleration and braking maneuvers. As discussed above, the desired speeds are defined by the simulation at high cognitive level (perception, interpretation and planning), while the more behavioral activity (executions of actions, e.g., braking, accelerating, lane change, etc.) are handled by the part of the simulation based on the SRK Model.

In particular, even if TD is a typical dynamic parameter, for these two sample cases, TD as well as ATT and EXP are kept constant throughout the simulation.

4.2 Running of Test Cases and Review of Results

The output of the SSDRIVE is based on a pictorial outcome of the dynamic vehicle control operations which has the objective of showing the DVE interactions in "real simulation time". In addition to the road and vehicles dynamic, these pictorial outputs show the dynamic evolution of several relevant variables, such as the intentions of the driver (follow, overtake, change lane, cruise, etc.), the intended and current speed, the acceleration, or braking actions, etc.

In addition to this, all variables calculated during the simulations are collected and stored in data logs for more detailed and specific analyses.

The amount data collected during the simulation offers the possibility of a much more accurate and complete analysis of the DVE interactions. As an example, the log files obtained from the two case studies allow the comparison of the values for desired speed, actual speed and distance vs. time. These data cover the first two overtaking maneuvers of leading vehicles.

The outcomes of the data logs with the output of the simulation runs are shown in **Fig. 5** to Fig. 8. The analysis of these data logs allows a much more accurate assessment of the simulated behaviors of these two different types of drivers.

Prudent driver behavior

More in detail, focusing on the prudent driver, **Fig. 5** shows the actual and desired speed, and the distance covered by the main-car vs. time during the first 60 seconds of simulation. **Fig. 7** presents the driving "modes" and lane position main-car vs. time. The prudent driver starts by choosing a desired speed of about 95 km/h (**Fig. 5**). When the first leading vehicle is reached, at about 13 s. of the simulation (**Fig. 7**), the driver decides to overtake, and, as no obstacles are found on the opposite lane, the manoeuvre starts. The driver changes lane ("change lane" driving mode), and continues the overtaking until the leading vehicle is passed, before returning on the rightmost lane. This operation is completed in about 20 seconds. The driver then continues until reaching a second leading vehicle proceeding at a slower speed at approximately 45 seconds of simulation. The driver decides to overtake the leading vehicle and starts by increasing the desired and actual speeds (**Fig. 5**). However, in the meanwhile, an incoming vehicle in the opposite lane is approaching, and as this vehicle is too close, the overtaking maneuver has to be interrupted by braking, reducing speed and assuming the driving "mode follow" (**Fig. 5** and **Fig. 7**). Once the incoming vehicle has passed, the overtaxing can take place and the operation is performed and concluded at about 60 seconds.

A final comment may be made on the performance of the prudent driver shown in **Fig. 7**. During the second overtaking process, when the desired speed of ~ 27 m/s (97 km/h) is reached (at ~ 55 sec.), the speed shows a sudden reduction before returning to its desired value. This is due to the fact that the driver releases the accelerator, and actually touches the brakes, as consequence of the attitude of prudence, before gradually regaining and maintaining the desired level of speed.

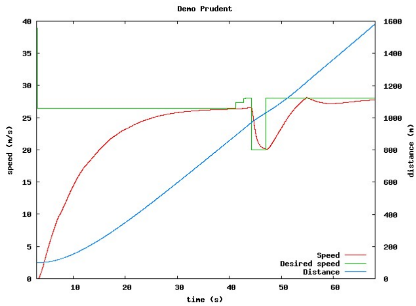


Fig. 5. Speed (actual and desired) and distance vs. time - Driver *ATT = Prudent*

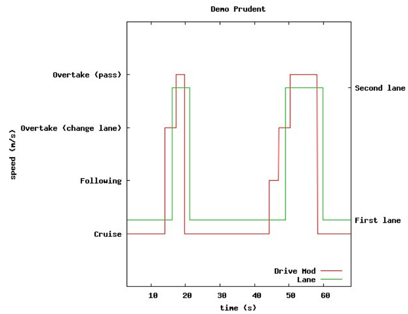


Fig. 6. Driving "modes" and lane position *main-car* vs. time - Driver *ATT = Prudent*

Sensation Seeker Behavior

The analysis of the behavior of a sensation seeker type of driver (**Fig.7** and Fig. 8) shows a substantial difference in comparison with the previous simulation. In particular, the desired speeds are in general considerably higher; already the first desired speed is of 120 km/h, as apposed to 95 km/h. As a consequence, the actual speed is also higher and the first leading vehicle is reached in a shorter time with respect to the previous case study. However, in this case, the overtaking can not take place immediately, as an incoming vehicle from the opposite lane is too close. The driver has to brake, reduce speed and enters a "following mode" to avoid collision with the leading vehicle, until the overtaking lane is free and the maneuver can take place (**Fig.7**). It is noticeable that, because of the traffic conditions, the sensation seeker, in order to complete this first overtaking maneuver, has actually taken the same time (if not a little longer) than the prudent diver, although the intended speed was almost 30% higher.

After the first overtaking has been performed, the vehicle reaches the second car on its lane at about 37 seconds. The intended and actual speeds of the main-vehicle are much higher than before. This time, considering its own speed, the speed of an incoming vehicle and the distance from it, the driver decides that it is possible to overtake immediately. Therefore, the driver does not wait that the incoming car has passed and accelerates to an even higher speed in order to carry out the overtaking of the leading vehicle, completing the maneuver at about 40 seconds.

In comparison with the previous case, the consequence of the more aggressive attitude and higher speeds of the sensation seeker is that the second overtaking is performed at higher speed and much earlier than the case of the prudent driver. Moreover, no particular effects are present of speed control and reduction, as it occurred in the previous case, when the final cruising speed is reached.

Finally, it can be observer that, although the first overtaking manoeuvre requires almost the same time by the two drivers, the overall sequence, i.e., both overtaking and setting of last cruising speed, is completed much earlier by the sensation seeker than the prudent driver (40 sec. vs. 55 sec.). Moreover, the final cruising speed of the sensation seeker is much higher than the one of the prudent driver (~ 137 km/h vs. ~ 100 km/h), and also well above speed limits!

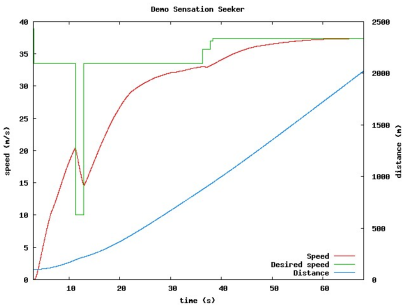


Fig. 7. Speed (actual and desired) and distance vs. time - Driver *ATT= Sen. Seek*

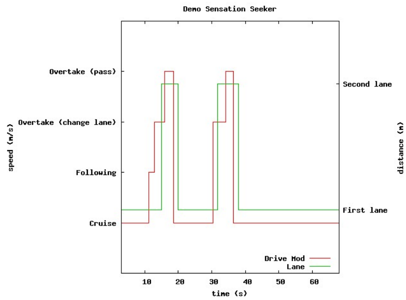


Fig. 8. Driving "modes" and lane position *main-car* vs. time - Driver *ATT= Sen. Seeker*

5 Conclusions

This paper has presented and discussed the simulation tool SSDRIVE that aims at offering designers and safety analysts an instrument for performing rapid and fast running predictions of Driver behavior and DVE interactions in different dynamic conditions. The tool is a classical computer simulation program that imbeds a set of algorithms and correlations derived from a well defined modeling architecture. It exploits the power of modern information technology that enables the fast running and solution of complex algorithms and generates large data structures and detailed graphical outputs.

In order to show the potentiality of the tool, a number of case studies have been performed simulating specific personality attitudes of drivers by means of specific input to the DVE module ”Driver”. It has been shown that the SSDRIVE enables to predict traffic evolution and generation of potentially risky situations.

At present only a limited set of validation experiments of the simulation algorithms has been performed. Therefore, the use of the results of simulation has to be very carefully considered, especially when its predictive power is exploited for safety critical types of applications.

At the same time, it is known that many correlations exist and have been tested that are able to describe different attitudes and behavior. However, these are usually confidential and not open to general application. For these reasons, the software structure of SSDRIVE has been developed in such a way to enable users to implement different correlations and formulations according to own and propriety data sets.

These types of problems exist in all types of numerical solutions adopted in modern technology and represent an important question that is not always sufficiently recognized vis-à-vis of other more flashy issues, such as "software bugs" or "configuration issues" that affect modern computer technology

Finally, even if the major steps of implementation of the dynamic DVE interaction have been resolved, a substantial amount of work remains to be done for completing the tool and enabling a more accurate and extensive simulation. Examples of such improvements are:

- The implementation of the driver error generation mechanisms, based on the generation of multiple logical scenarios derived from different error modes.
- The development of further sets of tasks and goals, so as to complete the implementation of the overall driver activity, including the crucial effects derived and associated with adaptation aspects [3].
- The development of other driver-modules so as to consider multiple interaction of populations of drivers in a shared traffic context.
- The implementation of more complex models of vehicles in consideration of multiple Advanced Driver Assistance Systems and In-Vehicle Information Systems; etc.

All these improvements are included in a plan of development of the SSDRIVE tool that will progressively be developed and implemented as further research will be performed with the aim of developing a tool that will be eventually useful and supportive for design and implementation of new instruments dedicated to accident prevention and safety improvement in the domain of automotive systems.

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