

# APPLICATION OF A DRIVER MODEL IN COMPUTER SIMULATION OF A CAR MOTION

Andrzej Reński

Warsaw University of Technology, Institute of Vehicles

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## ABSTRACT

The paper presents a driver model, which can be used in a computer simulation of a curved ride of a car. A computer simulation of the curved ride and directional control of the car plays a significant role in a study of vehicle active safety, as the cheapest and safest investigation method. An analysis based on an advanced dynamic vehicle model only is not satisfactory in many cases, when an interaction between the driver and the vehicle is not to neglect. The double lane change manoeuvre (ISO/TR 3888 [4]) is an example of the typical test procedure in which the vehicle-driver-environment model should be taken into consideration.

In elaborated driver model it is assumed that the visual signal is most important for a directional control of the car. The driver model is described by three parameters: aim point distance, response delay and steering angle gain.

The driver model can be used in studies of vehicle handling and stability when closed loop procedures are needed. Examples of the model application in computer simulations of such test procedures as the double lane change manoeuvre and the wind gust manoeuvre are presented in the paper. It is shown that the use of the driver model in computer simulation of the car motion allows adapting better the car construction and its dynamic properties to the psychophysical characteristics of the driver and thus can contribute to improve the active safety of the car.

## INTRODUCTION

Road traffic is one of the most dangerous areas of human activities. From among the three components of the driver-vehicle-environment system, the driver is the most unsafe part of this system: over 70-80 % of accidents are caused by the driver's mistakes. In this case a better understanding of the driver-vehicle control system, which makes it possible to adapt the car construction to psychophysical characteristics of the driver, is a method to improve the active safety of the car.

The active safety problem is part of the study of vehicle dynamics. A computer simulation of the

curved ride and directional control of the car plays a significant role in this area as the cheapest and safest investigation method. An analysis based on an advanced dynamic vehicle model only is not satisfactory in many cases. A control response of the driver model, co-ordinated with visual stimuli and related to the dynamic vehicle control model can potentially make a correct simulation of the car motion possible. Traffic safety problems involving the interaction between the driver and the vehicle should also regard the highway environment. Therefore a system of these three elements and the vehicle-driver-environment model should be taken into consideration.

For the study of a steerability and a directional stability of cars different driver's activity schemes are used:

- A driver holds a steering wheel in a constant position (fixed control). It is applied in the study of a steady state turning of the car or an influence of disturbances (e.g. side wind) on the car's ride.
- A driver turns a steering wheel in a desired way (open loop control). It is applied in the study of transient responses of the car on a step, sinusoidal or random steering input.
- A driver controls a ride of the car using the steering wheel to keep the vehicle as precisely as possible on the desired path (closed loop control). It is applied in the study of the whole vehicle-driver system; e.g. tests of the double lane change manoeuvre (ISO-TR 3888 [4]) and the wind gust manoeuvre.

In the two first cases (fixed control and open loop) a car model is adequate for computer simulation and only car data are to be delivered. However, for computer simulation of the close loop manoeuvres the car model should be extended by a driver model, which samples the car position in relation to desired path and realises a control with a feedback of position error.

The method used for dynamic response analysis of the driver-vehicle model depends on a type of a model. For linear model, frequency domain procedures can be used to study dynamic modes,

stability conditions and transient response to various forcing functions like road disturbances, wind excitations, path profiles, obstacle avoidance. Time domain techniques are also useful and are necessary where nonlinearities (such as e.g. tire characteristics under high lateral acceleration) are significant.

### CONCEPTS OF THE VEHICLE-DRIVER-ENVIRONMENT SYSTEM

Various schemes for vehicle-driver systems have been considered and the driver-vehicle model structure has been developed and improved over the last years in several papers (cf. a more extensive list of publications in [3]). Many of these systems consist of three components: The first one represents the vehicle (road-vehicle kinematics and vehicle dynamics), the second one - the driver (his or her perception and response), and the third - the environment and the impact of different disturbances.

The driver-vehicle system applied here consists of the driver model and a vehicle model. The vehicle component generates dynamic output based on the drivers steering actions. A mathematical description of the vehicle is relatively easy. In this case for a description of the curved ride of the car a simple bicycle vehicle model can be used, although there is no restriction for using more complicated non-linear models, for example [5].

Much more complicated is the development of the driver model. His or her behaviour as a human controller can be changed in a very wide range. Psychological aspects should also be taken into account [9]. In order to describe the function of the driver mathematically, the driver model should be reduced to several conceptually simple parameters for closed loop compensatory vehicle control. One of the most important driver functions is directional control of the car. It was assumed that for the directional control most important is the visual signal (the driver obtains more than 80% of all information in this way). Taking into consideration problems with identification of driver parameters, it was assumed that the driver model should be described by a possibly small number of parameters.

### DRIVER MODEL

The driver's steering control law, used in the elaborated model [7] is limited to visual feed back loop and is defined as follows (see Fig. 1). A driver observes an aim point A, which is situated on the

desired path at a distance  $L_a$  down the road - aim point distance. The driver sees this point at an angle  $\epsilon$  to the longitudinal axle of the car. This angle is equal to

$$\epsilon(t) = \frac{y_d(x_{0S} + L_a) - y_{0S}(x_{0S})}{L_a} - \psi(x_{0S}) \quad (1)$$

where:

$x_{0S} = v t$  - longitudinal position, the way covered by the car down the road,

$v$  - constant speed of the car,

$y_{0S}$  - lateral position of the car,

$y_d$  - desired path deviation from  $x_0$ -axis,

$\psi$  - heading angle.

Steering angle  $\delta_1$  controlled by the driver is proportional to the  $\epsilon$ -angle (steering angle gain  $W$ ).

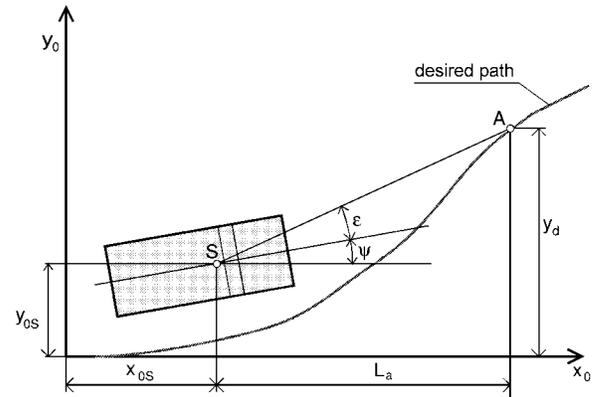


Figure 1. Driver's steering control law used in the driver model.

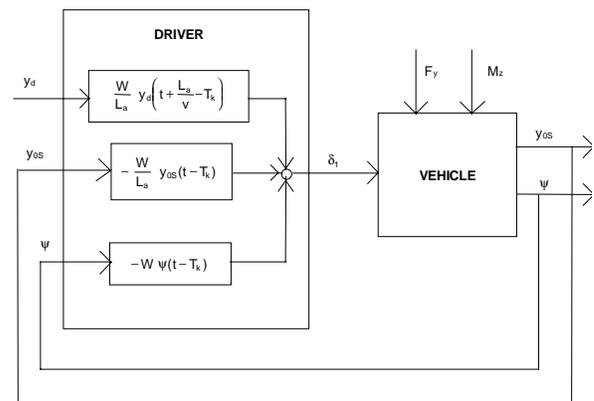


Figure 2. Block diagram of the vehicle-driver model.

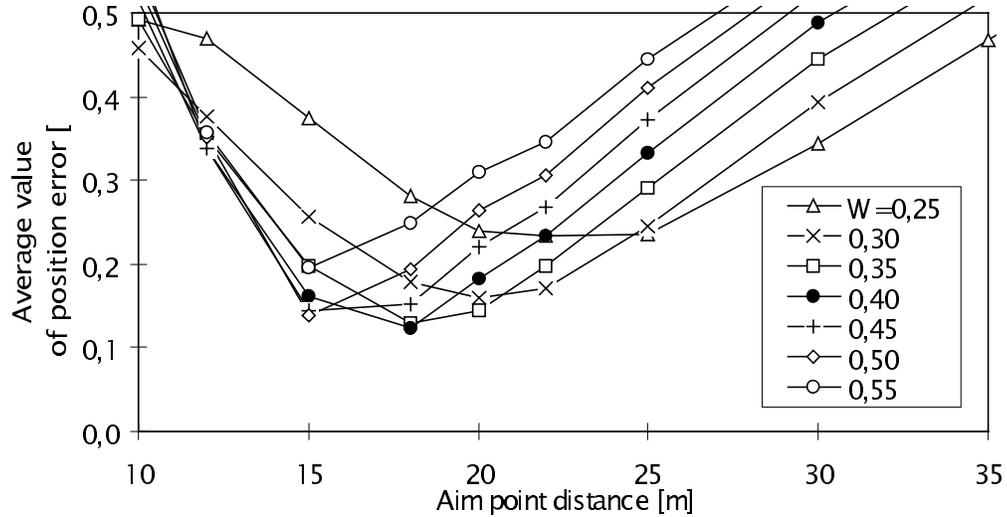
The driver response delay between position perception and steering response is  $T_k$ . Then

$$\delta_1(t) = W \varepsilon(t - T_k) \quad (2)$$

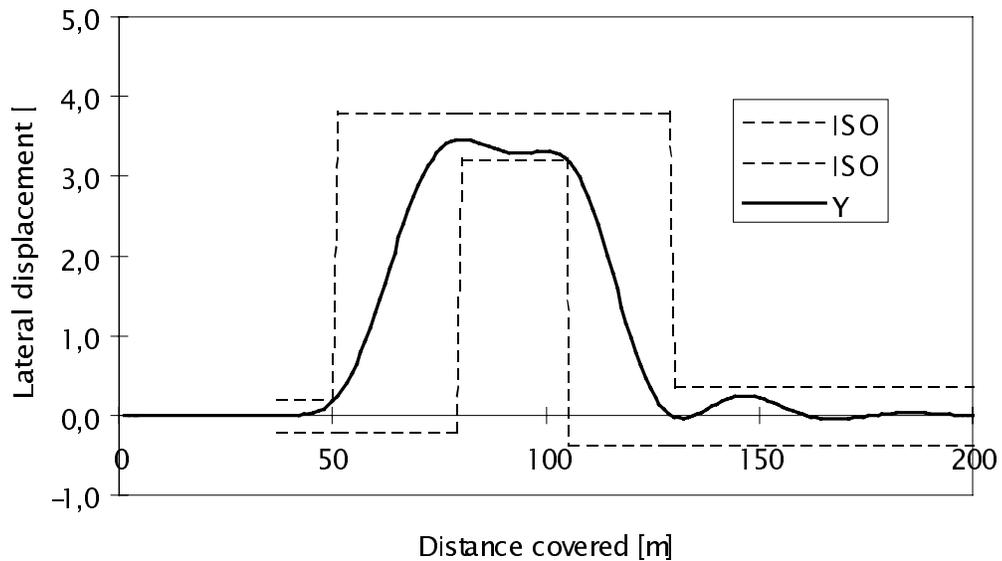
Finally

$$\delta_1(t) = \frac{W}{L_a} y_d \left( t + \frac{L_a}{v} - T_k \right) - \frac{W}{L_a} y_{OS}(t - T_k) - W \psi(t - T_k) \quad (3)$$

The block diagram of the model is shown in Figure 2. The desired path deviation from  $x_0$ -axis  $y_d$ , side force  $F_y$  (e.g. side wind) and torque  $M_z$  are external influences. The car lateral position  $y_{OS}$  and the heading angle  $\psi$  are feedback signals. Thus the driver model is characterised by three parameters: aim point distance  $L_a$ , response delay  $T_k$  and steering angle gain  $W$ .



**Figure 3. Optimisation procedure for the double lane change manoeuvre: The average values of the car lateral deviation from the desired path as a function of aim point distance  $L_a$  and steering angle gain  $W$  for response delay  $T_k = 0,4$  s.**



**Figure 4. Calculated car trajectory  $Y$  for driver parameters: response delay  $T_k = 0,4$  s, aim point distance  $L_a = 18$  m and steering angle gain  $W = 0,4$ .**

## IDENTIFICATION OF THE DRIVER MODEL PARAMETERS

The task of identification of the driver model parameters can be set on two ways:

- 1 - To find the driver parameters that enable car's lateral deviation from its desired path to be possible small;
- 2 - To find the driver parameters that enable the path realised by the driver-vehicle model to be possible similar to the path realised by the real driver.

### Driver Parameters that Minimise Lateral Deviation from the Desired Path

To identify the driver parameters computer simulations of the double line change manoeuvre are used. In this case the „best driver” is searched. The identification consists in a comparison of the trajectories calculated for the vehicle-driver model with the desired path (track of the double lane change manoeuvre). The optimisation method can be used here in order to find a combination of the driver model parameters for which the car deviation from the desired path is smallest. In the calculation data of a medium size car were use for the vehicle model. An example of the identification procedure is shown in Figure 3. A calculated trajectory obtained for the optimum driver parameters set (response delay

$T_k = 0,4$  s, aim point distance  $L_a = 18$  m, steering angle gain  $W = 0,4$ ) is shown in Figure 4.

### Driver Parameters that Reproduce the Path Realised by a Real Driver

The similar optimisation method can be used for identifying real driver parameters. Figure 5 shows trajectories obtained by three drivers in a double lane-change manoeuvre simulated on a test stand [8]. Instead of road tests the drum type ride simulator was used here to reduce a danger and a research cost.

An example of the optimisation procedure for one of the examined drivers (Driver 3 in Figure 5) is shown in Figure 6. As the result of this procedure the following optimum values of the driver model parameters were chosen: response delay  $T_k = 0,2$  s, aim point distance  $L_a = 18$  m, and steering angle gain  $W = 0,2$ . In Figure 7 the car trajectory resulting from computer simulation for the driver model characterised by the parameters obtained in the optimisation procedure from Figure 6 is compared with the trajectory realised by the real driver.

The parameters of models that can represent activity of all three drivers from Figure 5 are compared in Table 1.

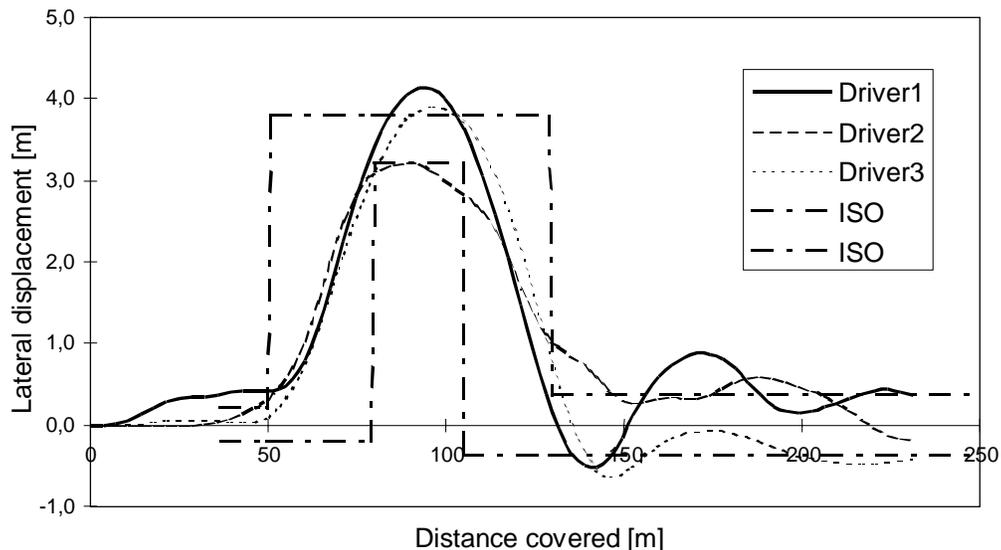


Figure 5. Diagram of the trajectories obtained on the test stand by 3 drivers.

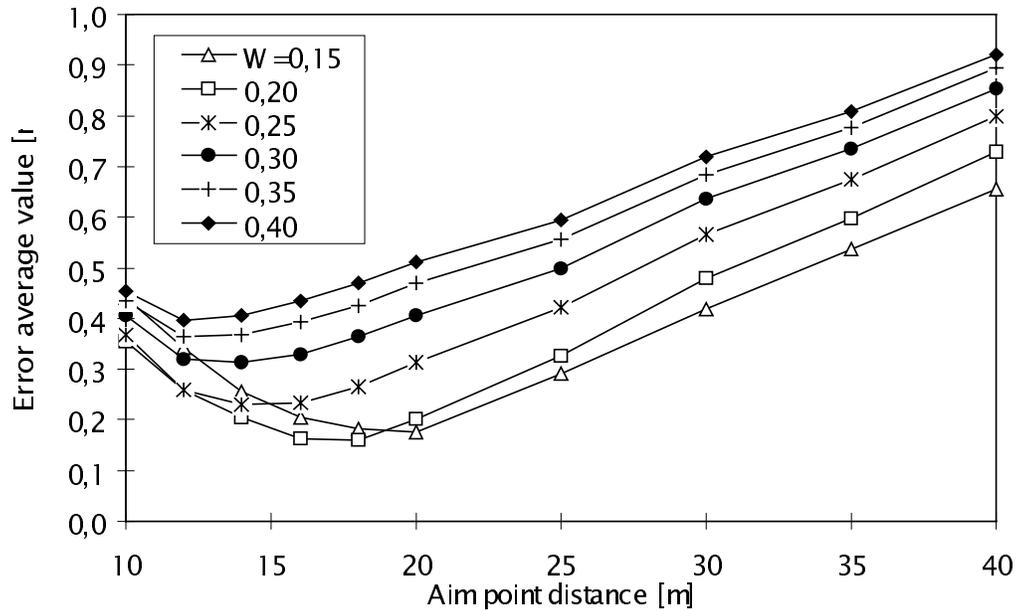


Figure 6. Optimisation procedure for the double lane change manoeuvre: Average values of difference between the trajectory calculated for time delay  $T_k = 0,2$  s and the trajectory realised by the real driver (Driver 3 in Figure 5), as a function of aim point distance  $L_a$  and steering angle gain  $W$ .

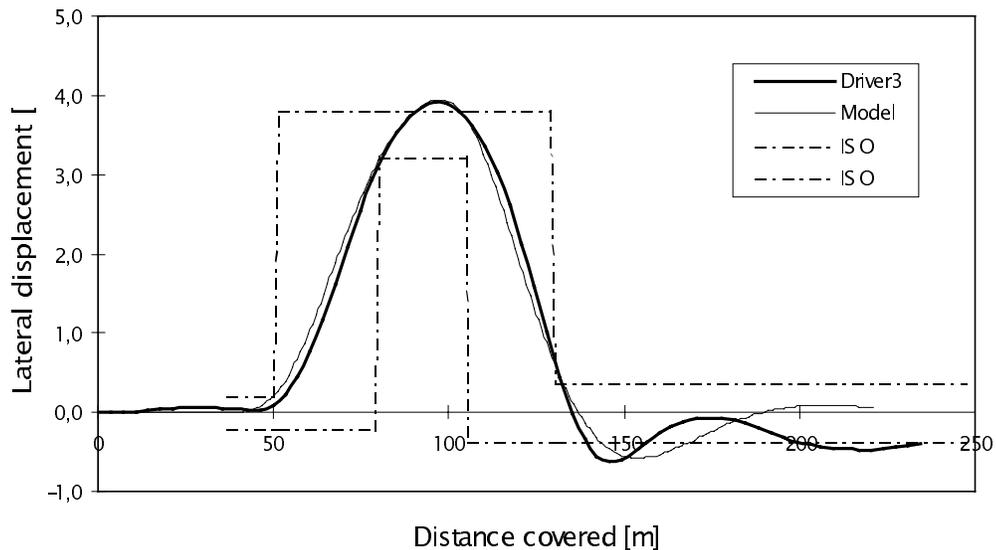


Figure 7. Comparison of the trajectory realised by the real driver on the stand (Driver 3 in Figure 5) and trajectory obtained as a result of computer simulation for the driver model (Model).

#### APPLICATION OF THE DRIVER MODEL

The elaborated driver model can be used in the studies of vehicle handling and stability when closed loop procedures are needed. Two examples of the driver model application are presented below.

##### Optimisation of Steering System

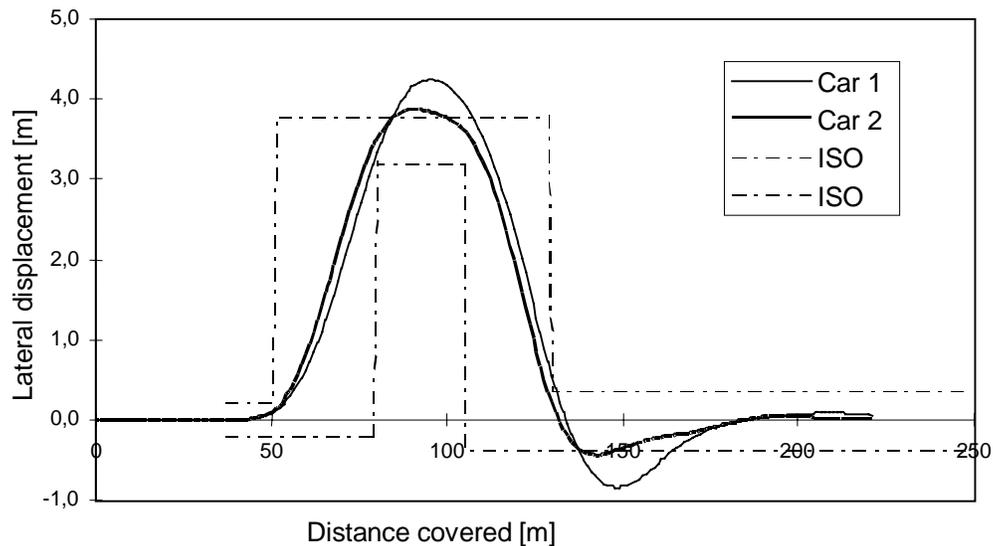
Driver models are widely used in studies of the car steerability [1, 2, 6]. Results of such investigation carried out by the author are presented in Figure 8. Computer simulation of the double lane change manoeuvre was carried out for 2 cars with different steering system. The first one (Car 1) has a

conventional steering system. The driver model parameters were chosen in order that in this case the driver-vehicle system could not pass the test correctly. Then the car was modified in this way that it was provided with a four wheels steering system and a rear suspension with an appropriate compliance steering characteristic (Car 2). As it is evident from Figure 8, the same driver in the modified car could realise the double lane change manoeuvre better than in the car with conventional steering system. The above example shows how the driver model can be

used for better matching of car dynamic properties to driver characteristics.

**Table 1. Driver Model Parameters for Real Drivers from Figure 5**

Driver	Aim point distance $L_a$ [m]	Response delay $T_k$ [s]	Steering angle gain $W$
Driver 1	17	0,5	0,25
Driver 2	30	0,3	0,15
Driver 3	18	0,2	0,20



**Figure 8. Comparison of 2 trajectories calculated for a car with conventional steering system (Car 1) and for a car with 4WS (Car 2). In both cases the same driver model was used. Speed of the car 80 km/h.**

### Reaction to Side Wind

Results of computer simulations of car reaction to side wind are shown in Figure 9. Calculations were carried out for 4 different sets of driver parameters (Table 2). A side wind gust force was assumed as equal to 1000 N and a speed of the car as equal to 120 km/h. The curves of lateral displacements versus time and steer angles realised by the drivers in order to keep the car on the desired path are shown on diagrams in Figure 9 as a result of calculation. A directional stability of the driver-vehicle system can be evaluated on a basis of a decrease rate of lateral displacement and steering angle oscillations.

A comparison of the curves makes it possible to study an influence of the driver model parameters on a stability of the driver-vehicle system. As it is evident

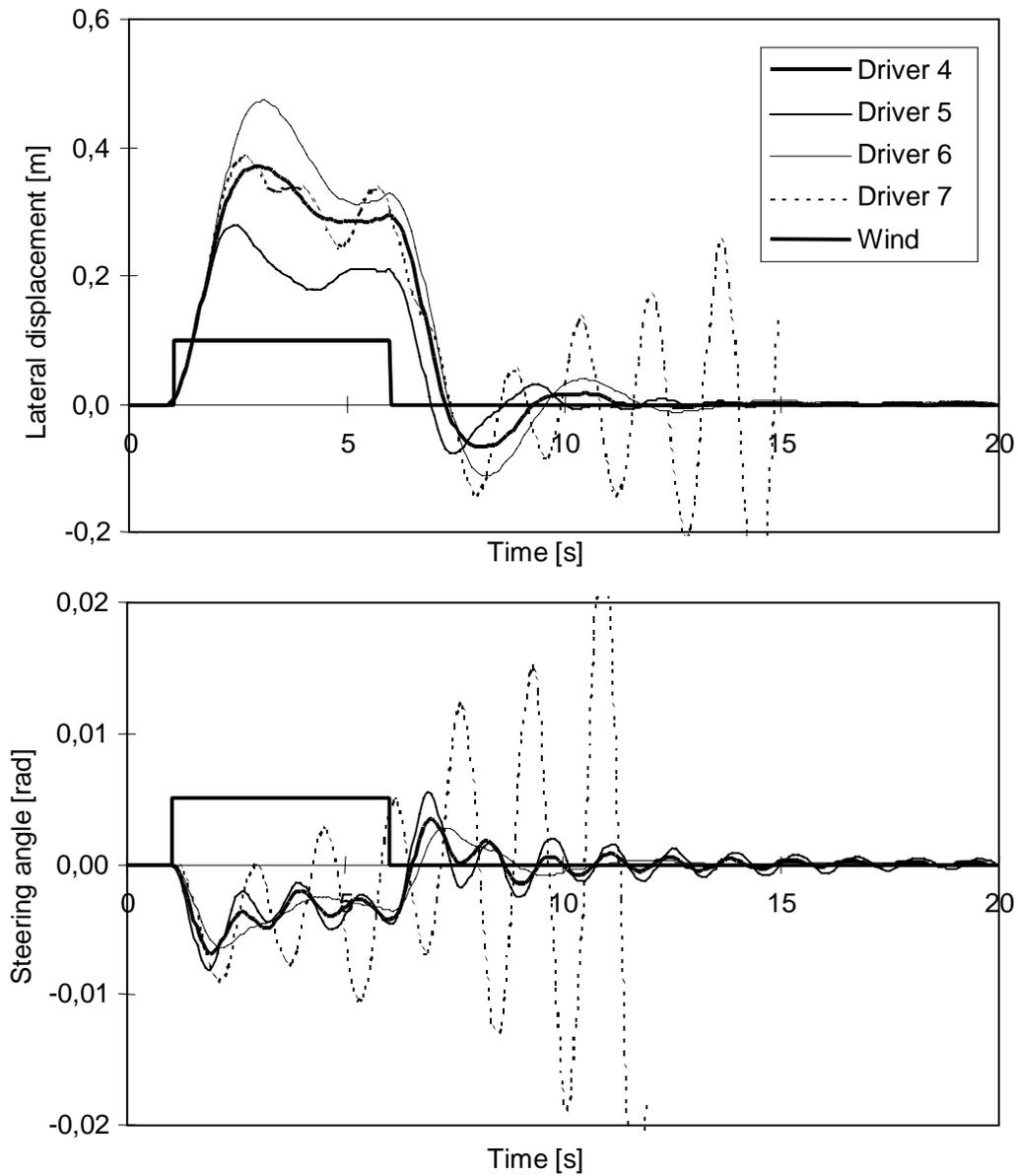
from Figure 9, in the case of the driver model indicated as "Driver 7", both the oscillations of lateral displacement and the oscillations of steer angle increase rapidly. The system is unstable and a reason of instability is an increase (in relation to Driver 4) of the time delay  $T_k$ .

A decrease of the aim point distance  $L_a$  (Driver 5) causes as a matter of fact a decrease of the lateral displacement involves however an increase of steering angle oscillations and longer time of its decline. This case corresponds well with an experience of driving in a poor visibility (fog or blizzard) when it is especially difficult to keep the car on its desired path.

**Table 2. Driver model parameters**

Driver model	Aim point distance $L_a$ [m]	Response delay $T_k$ [s]	Steering angle gain $W$
Driver 4	18	0.15	0.6
Driver 5	12	0.15	0.6
Driver 6	18	0.15	0.4
Driver 7	18	0.20	0.6

Furthermore a decrease of the steer angle gain  $W$  (Driver 6) causes smooth changes of the steer angle and a fast decline of its oscillation, involves however greater lateral displacement. In praxis, a driver, who corrects the car movement gentle with smaller steering angle changes, allows as a matter of fact greater lateral deviation but he can cause that the return of the car to the desired path is smooth with only few oscillation of the steering angle.



**Figure 9. Comparison of 4 driver models reaction to side wind. Lateral displacements and steer angles versus time. Speed of the car 120 km/h.**

## CONCLUSION

The elaborated driver model can be used in the studies of vehicle handling and stability when closed loop procedures are needed. The model can be used also for studies of influence of different car parameters on stability of driver-vehicle system and in this way for better matching of car dynamic properties to driver characteristics.

Presented optimisation method allows to automatize the identification of the driver model parameters. The optimisation procedure makes possible to find for each driver the model characterised by a set of parameters, which in computer simulation would be the best representation of his activity.

As it is evident from Figure 7, the shapes of trajectories obtained in the computer simulation and on the ride simulator are very similar, therefore presented driver model, though relatively simple reproduces well the driver activity.

On the basis of many calculations it can be concluded that for the simulation of different manoeuvres different driver parameters should be used. If the parameters are properly chosen the results of computer simulation of different car manoeuvres correspond well with experiences of real driving.

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