Understanding of Drivers Speed Decisions to Improve Traffic Management on Highways of the Future

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Abstract. Driver behaviour is a crucial factor not only with respect to traffic safety but also when considering traffic management systems. Modern Intelligent Transport Systems (ITS), such as Variable Speed Limit (VSL) system, enable real time dynamic traffic management using actual traffic data. However, in order to achieve an effective system, it is crucial to provide its speed limitation decision algorithm that is based on actual driver behaviour and not on theoretical expectations. Proper understanding of the driver decision making process and driving psychology is a key to effective and resultful traffic management systems of the future. In this paper authors describe their study aiming to create a driver behaviour model with respect to VSL system based on data from driving simulator experiment. The resulting model is to be further applied to data of Czech drivers' population in order to create background for future microsimulations of traffic and wide range of objectives connected to calibration, analysis and deployment of future VSL systems in country.

Keywords: Driver behaviour · Driving simulator
Experiment design · VMS

1 Introduction

The need for deployment of Intelligent Transport Systems in modern transport network is a widely accepted fact nowadays [1]. A simple idea behind it is, that there is no more space for further construction of wider road structures, but instead focus is put on an effective way of using existing structures. This effective way is meant as optimum usage of the road space, thus increasing the throughput and capacity of particular road network elements being streets, intersections, tunnels, highways bridges etc. One of the ways how to achieve that are electronic information and traffic control systems capable of reacting on traffic situation in real time. Any control system, in order to be efficient, needs to incorporate in its control decisions assumptions of its effects on the controlled object [2]. In case of the traffic control systems their goal is to produce repeatable and expected

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outcomes when applied on the traffic under given conditions. This implies that relation and influence of the traffic stream and the systems is mutually related. In order to achieve that, an obvious criterion is that the algorithm of the system has to comprehend and affect well on the traffic described as set of traffic parameters such as density, intensity and speed. Moreover this relation needs to be bilateral which means for given traffic parameters, given reaction of the system is expected and as well specific action of the system leads to anticipated change of traffic parameters. Variable Speed Limit systems are an example of such systems which is very sensitive and dependent on the drivers compliance and tolerance for the limits indicated by the system. Furthermore, mentioned quality of the algorithm is dependent and inseparable from our comprehension of the drivers behaviour [3] and decision making patterns, as well as reliance level that they assign for given system. This implies the need of better understanding this behaviour which can be understood as a set of driver decision making processes, preferences and choices made during driving [4].

1.1 Variable Speed Limit System

The VSL system takes advantages of nowadays technology, our knowledge about traffic flow parameters and their relations from fundamental diagram developed by Greenshield in early 1930s [5]. This basic relation depicted on Fig. 1 clearly states that rising traffic density results in decreased speed of traveling vehicles. When density is close to 0 any vehicle that occurs on the highway can travel with speed limited only by the traffic law regulations, and in ideal situation could travel at maximum preferred speed. Figure 1 suggests that in order to prevent traffic to fall into unstable state at very high density (high traffic demand) we need to artificially decrease the speed of traveling vehicles. This will artificially prolong the stable state of the traffic over expected critical density point and also will improve driving conditions (Level of Service, LoS) and safety by prohibiting occurrence of the shock-waves (stop-and-go) on the road. The shift from the stable to unstable traffic state through metastable stage is called hysteresis effect. It occurs only in one direction, and is irreversible - traffic stream can not immediately return to fluent flow state after traffic density passed critical value. The purpose of VSL system is intelligent and On-line reacting on changes in traffic stream parameters (traffic flow, speed and density) in such manner, as to prevent the hysteresis described above. Such goal can be achieved by monitoring of traffic and reacting by implementing speed limitations on traffic aiming to artificially increase of road capacity. This is a result of traffic speed and road capacity inverse proportionality described among others in [6].

1.2 Driving Simulator

The project described in this paper is performed on the driving simulator constructed by Ing. Petr Bouchner Ph.D. and his team at the Faculty of Transportation Sciences in the Czech Technical University. Architecture of described simulator is well described in [7]. The functional structure of the simulator is

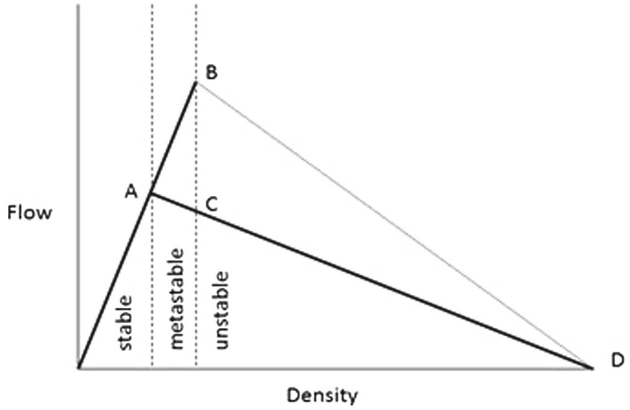

Fig. 1. Basic scheme of traffic flow parameters as presented by Greenshield [5].

presented in Fig. 2. Overall, system of CTU simulator can be described as model with four connected layers, which are separated in Fig. 2 by green lines. The first layer represents the simulator device itself as an external interface to the driver. It consists of both software and hardware parts. Cockpit that is composed from parts of a real vehicle and PCs connected to a network, are considered as the hardware of the simulator. I/O cards (like CAN bus to PC interface) are also included in this layer. Software of the simulator consists of Virtual Reality engine (generation of 3D graphics and spatial sound) and mathematical model of the car and environments. The physical engine is always a compromise between a very accurate physical behaviour and a very fast (real-time) response [8].

The next layer represents a database of testing tracks (also referred as scenarios) and cars. Each experiment requires a individually and carefully designed scenario. To get objective results it is necessary to precisely define difficulty and plot of each scenario. Sometimes we need a curved road to study drivers ability to keep the car on the road while he/she is forced to fulfill an additional task. On the other hand, a scenario for investigation of drivers drowsiness and fatigue is recommended to have a very boring (almost straight) highway road which cannot divert him/her, but it brings the driver into relaxation state. Another may need implementation of some case-specific objects in the road surroundings. It is necessary to treat the database of cars similarly. Strong engine with automatic gearbox is suitable for measurement of drowsiness while a car with manual gearbox and weaker engine with worthier grip serves better for classification of ones driving style [9].

The last layer represents tools for creation of assets that construct scenarios. Those are mainly modelling of 3D objects and tools for automation of such process and databases (storages) of modelled objects. Each object in virtual reality is accompanied by a texture or a set of textures. The texture is a picture, which simplifies the 3D object creation in following manner: the geometry of any real object is very complex, on the other hand it is possible to replace

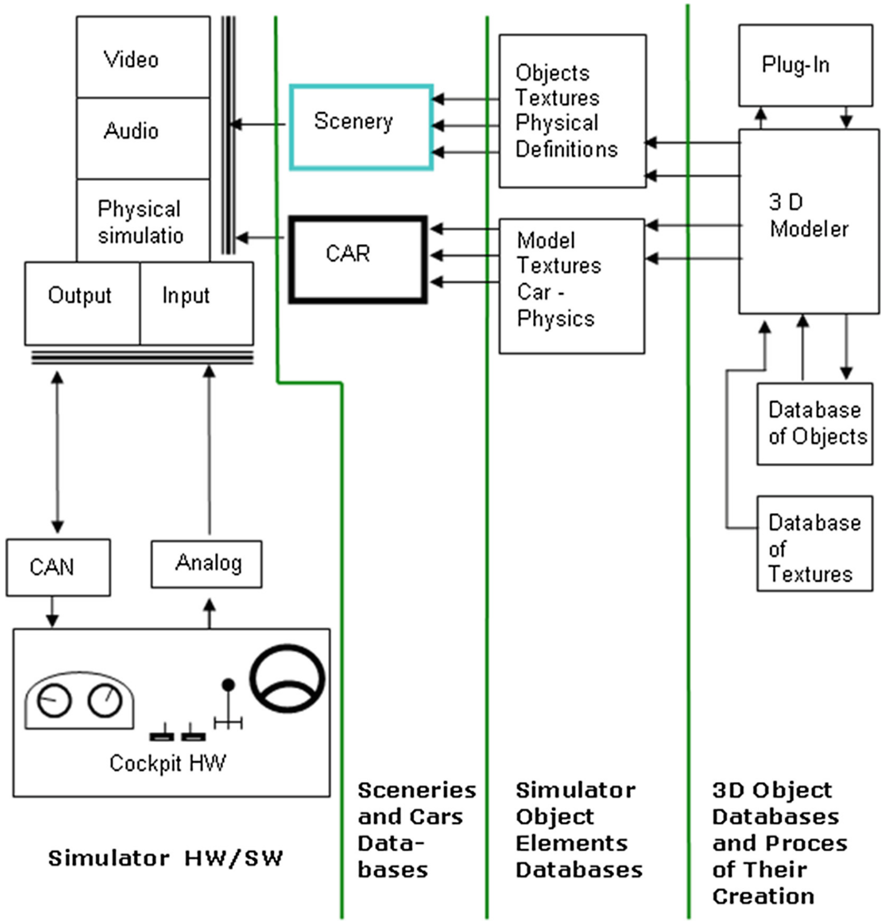

Fig. 2. Block scheme of CVUT driving simulator architecture [7].

it with a very simple geometry covered by a worked out digital photography (texture). The textures can be of different types; general, which are tillable (i.e. repeatable, such as grass or road surface) and the unique ones (such as houses or traffic signs). The amount of textures over one scenario could be very high but lots of them could be reused on several different pieces of geometry. For that reason, it is also very practical to have separate database of 3D models (objects) as well as a database of textures [7].

When considering behaviour analysis of drivers, that includes highway traffic and thus overtaking of vehicles, essential role play also another equipment of simulator that is often neglected and skipped. This objects are vehicle mirrors. Since surrounding world in driving simulator is presented with use of projection screens, implementation of vehicle mirrors can be troublesome. Interesting solution for this task was proposed by Novotny, Bouchner et al. [8], by implementation of physical vehicle mirrors pointing at reversed LCD monitors. In their study authors proved validity of such solution and thus it was adapted for this project. Overall validity of the driving simulator results as basis for scientific research have been confirmed numerous times for both, traffic controls systems and in vehicle advanced systems [10], and thus was accepted without further analysis.

2 Experiment Description

The goal of described project is to collect statistically representative amount of data about the drivers behaviour with respect to the speed limit presented on VSL system and perform analysis of collected data to conclude their reaction on VSL system. Complex experiment scenario was designed, including the simulated highway with predefined traffic conditions and VMS setup along the road. Data about driver performance and position in the simulated world were collected in a synchronized manner. On the other hand, each experiment participant fulfilled the survey after his completed experiment, which aimed to collect their sociodemographic information and beliefs about VSL system. This information was later utilized in driver reaction model as described in Chap. 3. Table 1 depicts all sociodemographical data collected during the experiment.

Table 1. Sociodemographic information collected in the experiment.

Variable	Description
X_1	Information about sex of the observed experiment participant
X_2	Information about age of the observed experiment participant
X_3	Information about education level of the observed experiment participant
X_4	Information about driving experience of the observed experiment participant
X_5	Information about received speeding tickets in the past
X_6	Information about driver understanding of VSL principles
X_6	Information about wealth status of the observed experiment participant

Such data will be processed and analysed to improve our understanding of the VSL effect on the traffic stream and therefore will help to ease the process of designing new algorithms for those systems. Through collection of the information on driver reactions on the VSL indications or lack of it, it is presumed to understand conditions that are necessary to fulfill in new designed systems, to improve their effectiveness. This can be achieved by delivering indications about the most effective spacing of signs, traffic parameters thresholds (for activating different VSL stages), adjust speed limits and improve their positive influence on the traffic stream. In addition to these variables a set of socio demographical information about experiment participants is collected in order to create database of describing variables in future model of driver behaviour. Simplified scheme of the parameters and relations influencing driver behaviour (causality) is depicted in Fig. 3. Automatically collected data from driving simulator are consisted of but not limited to:

- *Which sociodemographic driver features have influence on the driver speed decision, and how big this influence is?*
- *What is the distance from VMS that drivers read its message?*
- *Do drivers comply with VSL indications, and to what extend?*
- *What is the distance from VMS that drivers control their speed at?*
- *What is the distance from VMS that drivers react on VSL at?*

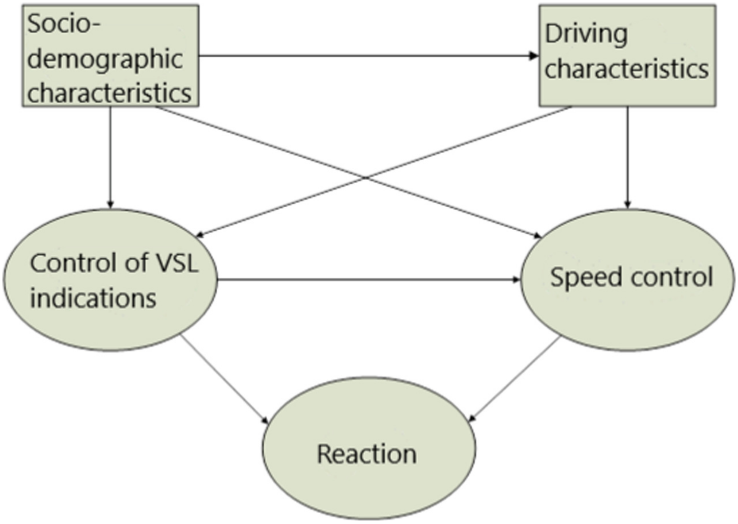

Fig. 3. Diagram of factors and their causality influencing driver reaction on VSL. (own source)

Simulator scenario was set as 84 Km circuit of 2 lane rural highway with Variable Message Signs (VMS) spaced every 1,1 to 1,8 km. On each gate VMS there is speed limit displayed in such a manner to imitate behaviour of real world VSL system according to traffic parameters. Both indications of VSL and surrounding traffic (vehicles simulated during experiment) are predefined and modeled in microsimulation software Vissim to create environment that will imitate real driving conditions on Czech highways. Behaviour of simulated surrounded traffic was calibrated based on pre-processed data from Prague City Ring with VSL system in operation. Each experiment participant drove full simulated track under the same conditions, and after that had to fulfill a questionnaire about their socio-demographic data. These 2 sources of information were collected for each driver and concatenated in one joined database. Whole process is depicted in Fig. 4.

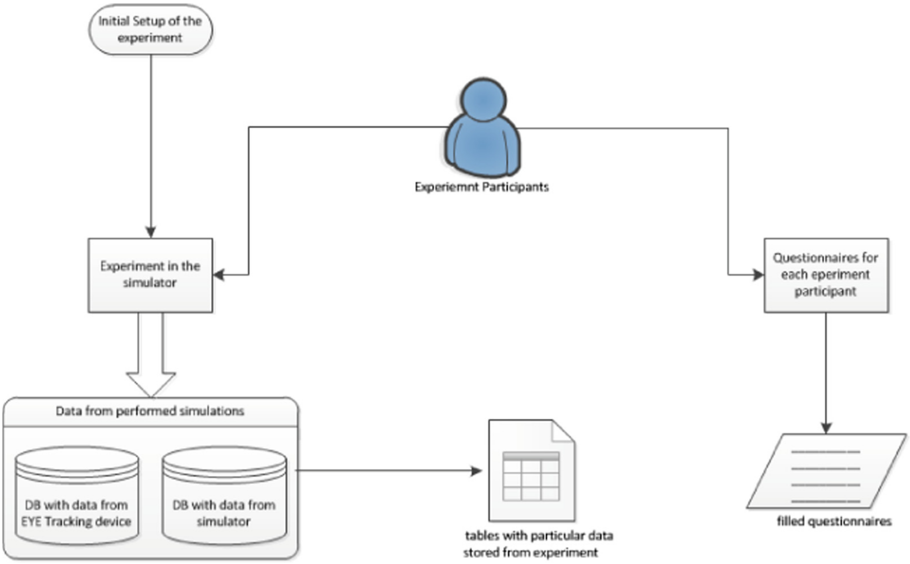

Fig. 4. Data collection and preprocessing scheme. (own source)

After collection, all data are preprocessed to extract each VMS passing from each participant drive. Matching data from questionnaires are added to those from driving simulator (Fig. 5).

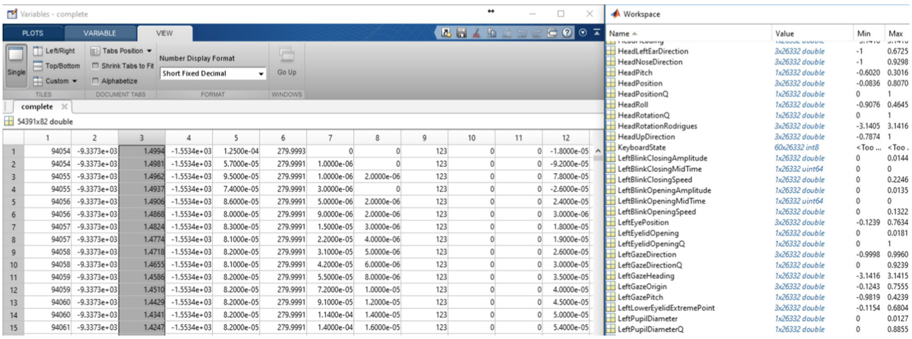

Fig. 5. Example of simulation results stored in MatLab parsed file. (own sources)

3 Behaviour Model Establishing

In the last phase all collected and used data are divided into dependent and independent variables, as to create base for computation of driving behaviour (decision making as described in Chap. 2) model of Czech drivers by use of logistic regression model as proposed in [11]. Socio-demographic data are collected and used in model as independent variables describing characteristics of each driver participating in experiment. On the other hand driver reaction data such as speed adjustments, reaction distance and speed compliance are treated as dependent(described) variables, occurrence of which we predict in our model. Mathematically, logistic regression estimates a multiple linear regression function for Y_n defined as [12]:

$$Y_n = log\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k, \tag{1}$$

where Y_n is a dependent variable, X_k denotes the k^{th} independent variable in the model, β_k denotes the k^{th} factor describing magnitude of each independent variable's influence on the dependent variable and P denotes the probability of occurrence of the variable Y.

Results of the above model established in that manner are to be further utilized in connection with data about driver population in Czech Republic. Such procedure allow us to create behaviour map of Czech drivers wit respect to statistical data about synthetic driver population in country. In our experiment measured reactions of the drivers are considered as dependent variables, and sociodemographic data along with driving conditions such as traffic density are considered as independent variables. In such way we hope we will be able to correlate specific behaviours and reactions associated with VSL system to specific sociodemographic groups. As proven in numerous studies, proper assumption bout drivers speed compliance and way of reacting on VSL system can be source of great benefit for effectiveness of future designed systems [13].

4 Preliminary Results

As said before, the effectiveness of the Variable speed limit system is heavily dependent on the drivers' compliance level and resulting proper calibration of the system activating thresholds. Such results are confirmed and described among others in [1]. Based on initially collected data from described experiment in driving simulator, simulations in Aimsun were performed in order to verify influence of newly gathered data of drivers behaviour on effectiveness of VSL systems. Traffic microsimulation software interfaced with MatLab software were used to simulate influence of various driver compliance factors on effectiveness of four different control algorithms in simulated VSL system. Figures 6 and 7 present exemplary results in form of space-time (LT) diagrams with traffic stream speed depicted in different colours. It was proved in simulation that speed compliance factor is very important parameter and it can significantly influence sensitivity of the algorithm especially when considering smoothening effect. These results clearly prove that speed compliance level assumed in simulation, has significant influence on proper evaluation of the most suitable VSL control algorithm and

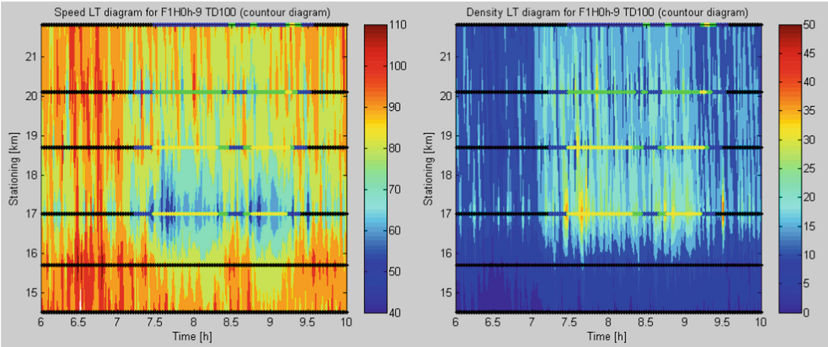

Fig. 6. LT diagram for VSL algorithm and drivers with very high compliance (1.0).

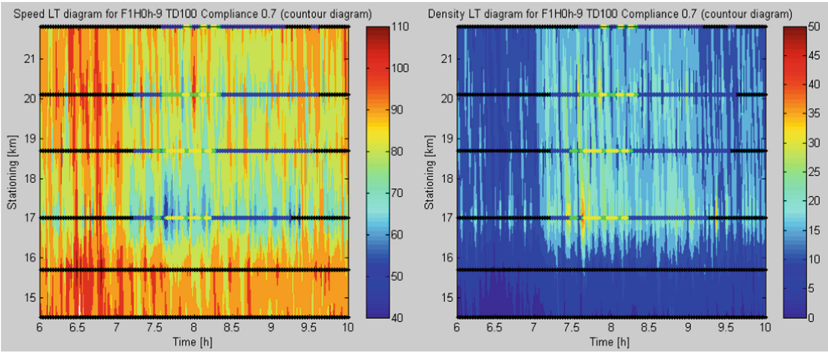

Fig. 7. LT diagram for VSL algorithm and drivers with lowered compliance factor of 0.7.

understanding of the most suitable traffic management tools deployment in general.

Authors strongly believe that results of the performed experiment will allow creating a reliable view of the parameters of the traffic stream in Czech Republic in light of compliance and reaction to the various speed limitation and intelligent highway management systems. With use of tools such as logistic regression and data about synthetic drivers population and reliable driver behaviour model can be established for future utilization in analysis, calibration and finally deployment of new Variable Speed Limit and other Traffic Management systems. In step 2 of the research, authors plan to gather reliable statistical data about drivers population in Czech Republic and utilize newly constructed model on replicated synthetic drivers population. Exploiting driver behaviour model which "explains" driver reaction based on their sociodemographic data, allow adapting microsimulation parameters to simulate exact reactions of the drivers on the streets and therefore improve calibration of the planned VSL algorithms as to improve their effectiveness before expensive implementation.

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