A new way to design road infrastructures and equipment

Espié S.[1], Auberlet J.M.[1], Tripodi A.[2]
Researchers, INRETS- French National Institute for Road and Safety Research
Researcher, Reggio-Calabria University

SYNOPSIS

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Nowadays, road design is achieved by refering predefined design codes (e.g. Higway Design Codes in USA) which provide detailed rules about construction geometry. The locations of the road equipment are then defined by following some heuristic or normative rules. All the applied rules are put down on "cookbooks" which are used by road engineers. CAD tools are currently used for helping road engineers in the design process. 3D virtual models are more and more used for communication purpose (and as an aid in decision-making), either for politicians or for general public.

The design rules have been defined, more or less empirically, sometimes a long time ago. They are based on expected traffic level and driver's practices, which are sometimes far from the actual ones. Furthermore, they often aim to obtain the "best road" from its physical characteristics standpoint, and not the "best road" from the expected usage standpoint. This "absolute" quest for quality can result in a misuse (user practices incompatible with social rules).

Psychologists and physiologists have been studying driver's behaviours for a long time in order to understand the mechanisms that underlay perceptions and decisions making process. Some of the results are taken into account in road design but the cultural differences between road engineers and people from human factors field lead to a non-optimal use of this knowledge.

Thanks to new technologies, it is now possible to propose a new way to design road infrastructure and equipment. This approach of the "road system" combines driver behaviour identification, traffic simulation and driving simulator. The aim is to enable the the final users to see the engineers' concepts in action and to assess as soon as possible 1- the compatibility between users' practices and engineers' expectations 2- the traffic characteristics (capacity, safety) of the new concept.

In this paper we will present a system approach, called integrated approach, to design road infrastructure and equipment. We will describe the tools (behavioural traffic simulation and traffic-centred driving simulator) which allow this approach, and we will present an example of study which was carried out related to a new road concept assessment. This study consisted in behavioural analysis of the driver in cutting-in manoeuvre, in subjective and objective evaluation of the trouble endured by the driver according to the level of traffic, and in the evaluation of specific rules for truck drivers.

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INTRODUCTION

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INTEGRATED APPROACH

The aim of the integrated approach is to design and evaluate road infrastructure and equipment using a system methodology taking into account the various actors of the studied system. Thanks to recent technological enhancements, this new approach of the design of roads or equipment uses both a behavioural traffic simulation model and a driving simulator. It consists in (see Figure 1):
1. The identification of driver's behaviour in an actual situation or on a driving simulator (for example in the case where experiments cannot be conducted in actual situations) for the future traffic system (design, validation and analysis of a new concept);
2. The modelling of the new behaviours within the traffic simulation model;
3. The traffic simulation with these new behaviours;
4. Analysis of the traffic behaviour relative to the traffic simulation and;
5. When needed, the study of the driver's behaviour immersed in the future traffic system (modified traffic behaviour).

The last step can be very important when dealing with traffic system modifications related to the introduction of on-board driver support systems, since these systems induce new interactions between drivers, particularly when all vehicles are not equipped. For example when an alert system is partially introduced, the equipped vehicles could decrease their speed (due to an alert) whereas the road traffic situation appears as normal. Since the non-equipped drivers could misinterpret this "abnormal" low speed, some strong (and possibly unsafe) interactions could occur.

As suggested above, we promote an approach of the traffic phenomena modelling based on the identification of the motives of its various participants' behaviours. Our thesis is that traffic phenomena occur due to individual and sometimes-individualistic behaviours; each participant in the traffic system having its own knowledge, goals and strategies. For example, road operators try to obtain a collective optimum whilst drivers try most of the time to obtain an individual optimum. In some cases, particularly for dense traffic situations, optimal actions of the various actors are conflicting.

Using such a concept for traffic modelling implies the need to design a new kind of traffic simulation based on individual practices, as identified by researchers in psychology. INRETS research in that area started at the end of the "eighties" within the framework of the ARCHISIM project which involved both a psychologist and a computer scientist. The aim was to design a "traffic virtual world" in order to study both current and future road traffic situations.

ARCHISIM: A BEHAVIOURAL TRAFFIC SIMULATION MODEL BASED ON PSYCHOLOGICAL FUNDINGS

Most of the traffic simulation models are based on the identification of traffic phenomena: road engineers measure traffic parameters by the way of traffic sensors, then reproduce pre-identified traffic flow laws when simulating (9, 10, 11). For microscopic simulations the law is mainly called "car following rule" and statistically reports the way vehicles follow each other. This rule comes from pre-identification of traffic phenomena, and does not take into account motives that generate the situation. Due to this fact, it is very difficult (and not reliable) to use such an approach of traffic simulation for studying future situations (i.e. situations which do not already exist and thus are not identifiable). This is particularly the case for new concepts of infrastructure and equipment (on-road or on-board).

Identifying generic rules underlying driver's decision-making process is the method we have chosen within the ARCHISIM project. This work was achieved (and is of course still continuously being enhanced) by conducting experiments in actual road situations (12). In-depth analysis of the various data obtained by experimental car sensors and driver's verbalisation, both during their trip and during a post confrontation with the video of their journey, was conducted by the psychologist (13). The identified generic rules take into account the current road situation (infrastructure, traffic) and the anticipated one. That last point reflects the fact that driving is anticipating. In our analysis we have found that traffic simulation models which use car following rules are inadequate for study interactions between the various actors of a road situation, and thus to study impact of a change (new concept in infrastructure or equipment) in the traffic system.

In order to provide such a generic model of driver's decision (based on driver recognition and anticipation of situations) we designed an original software architecture (6, 7), which use multi-agents techniques. This architecture of simulation is able to provide each actor of the simulated road situation, at each simulation step, with symbolic data that describe its environment. Example of such a description is illustrated in fig. 1: top-right, picture view by an actual driver, bottom-right, symbolic description send to simulated driver. Calculation of each actor’s behaviour is achieved using parallel computation scheme (each actor is provided with a "picture" of the simulated world at the same t time) (cf. Figure 1).

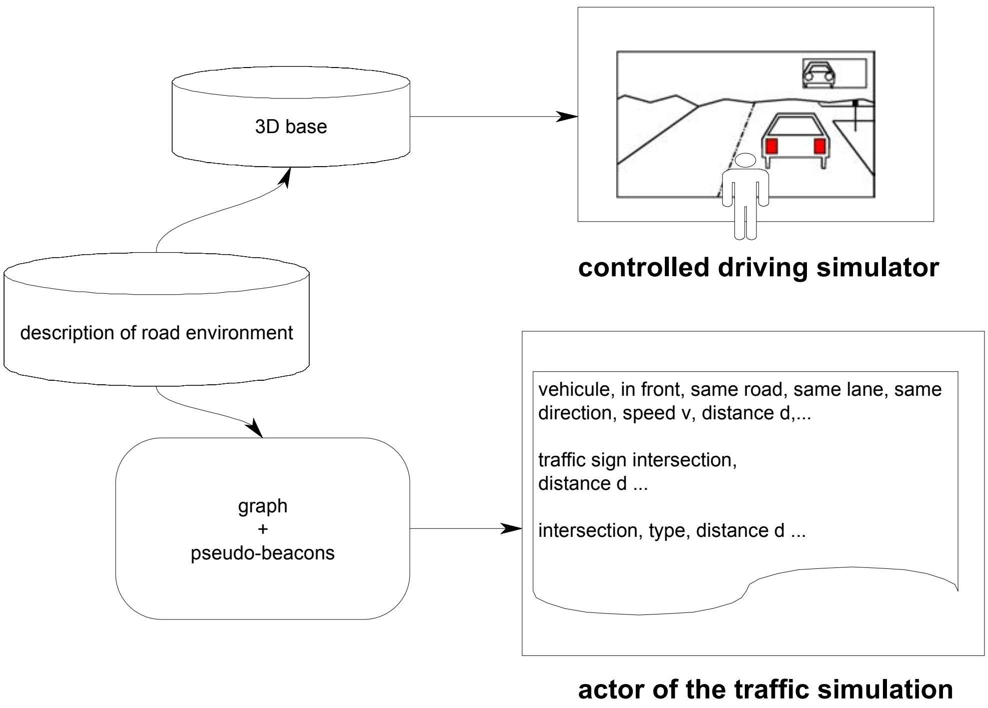


Figure 1: simulation architecture

With this kind of behavioural approach, traffic phenomena result automatically in the simulation as by emergence. Input of the simulation is the traffic demand, the infrastructure geometry and the distribution of driver's characteristics (such as desired speed, preferred time-headway, cost of manoeuvres...), output is traffic. Most of phenomena come from the heterogeneity of driver's behaviour. As with expert systems, the simulation process can be considered as a "theorem demonstrator" for the generic rules it uses, since the system converges for all the encountered situations if and only if there are no specific (i.e. not generic) rules.

The calibration process with such a behavioural simulation is quite simple: it consists in finding the distribution of driver's characteristics which gives the correct traffic characteristics. We don't have to determine parameters, section by section, as our simulated drivers adapt continuously their behaviour to the context (infrastructure, traffic). The fact that the simulated traffic flow doesn't match the actual one comes, most of the time, from a bad description of the infrastructure (missing description of a slope within the network geometry, missing road sign,...).

We validate our approach for motorway situations, first in the framework of European project Diats (4th FP), and then by a collaboration with Reggio-Calabria University, and also with the traffic research department of the French SRILOG company (3, 4, 5, 15). Figure 2 shows the results of the validation for the volume distribution (experimental data come from video recording), figure 3 demonstrates the results of the simulation for a peri-urban motorway near Paris (including peak hour). The precision calculus is made with the statistical indicator called RQMD (i.e. Relative Quadratic Mean Deviation). We are currently working on urban situation (two doctoral students), focusing on traffic simulation within complex intersection. For this problem, our aim
is to simulate the way drivers use the full space in the intersection.

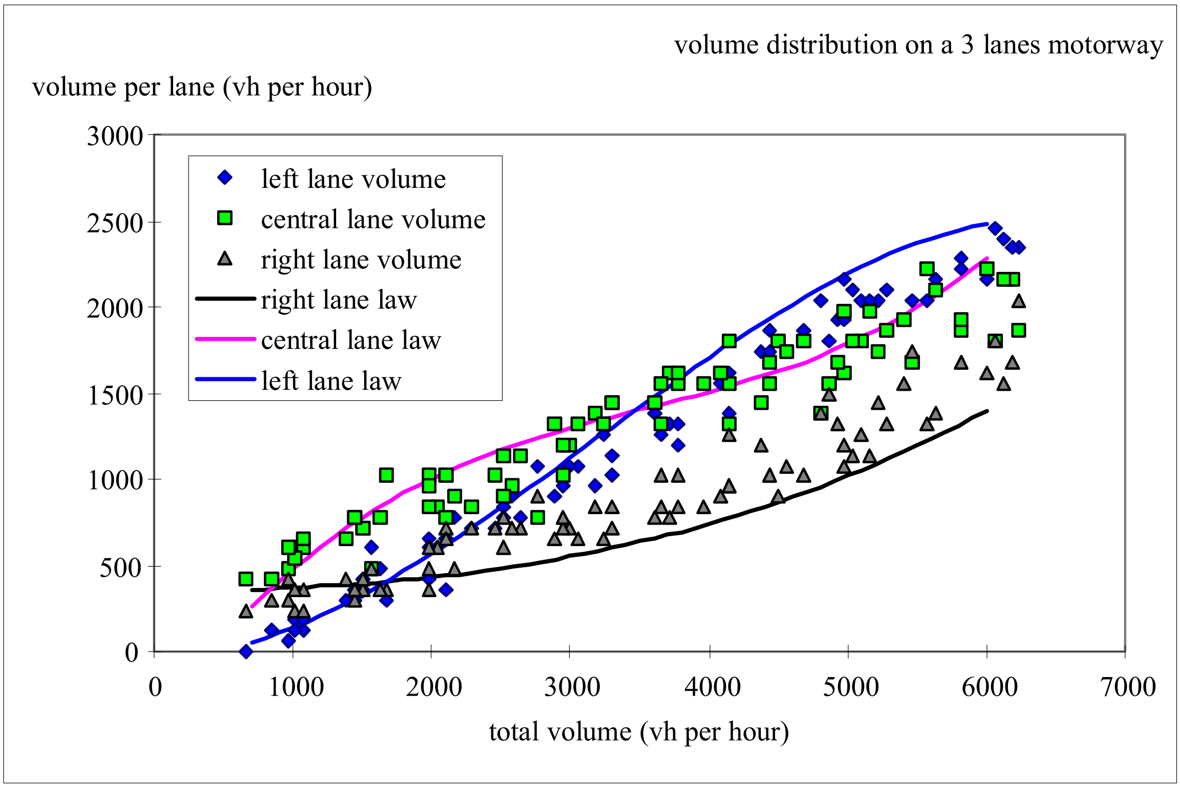


Figure 2: validation for volume distribution

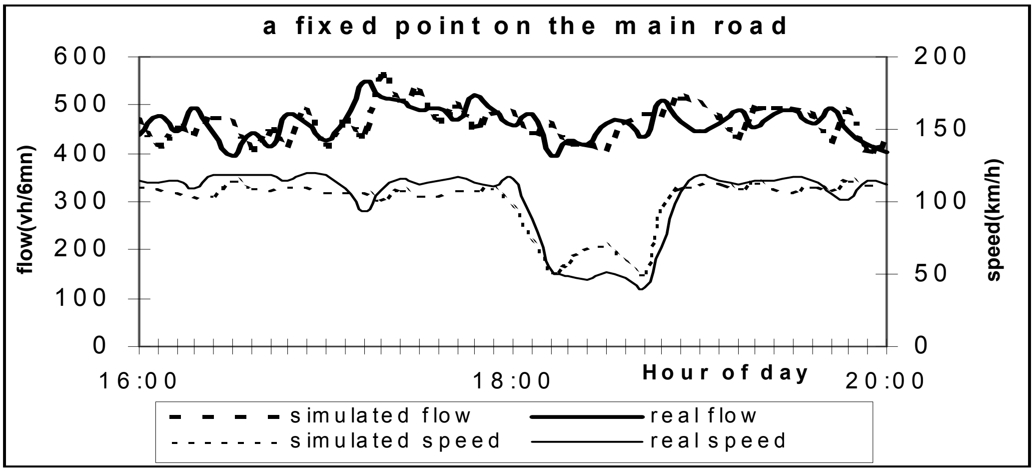


Figure 3: validation for dense traffic
(flow RQMD = 8 ; speed RQMD = 9)

One original aspect of our simulation architecture is its ability to host a driving simulator and thus to immerse an actual driver within the traffic model: driving the simulator the driver achieves its journey whilst interacting with the other actors of the road situation (8).

SIM²: A TRAFFIC CENTERED ARCHITECTURE OF DRIVING SIMULATOR

We call SIM² (for SIMulations X SIMulators) this architecture, which allows immersing a driver within a "virtual world" of traffic. From the point of view of the driving simulator, this architecture is original because it allows to immerse "subjects" within a "true" traffic model and not, as with nearly all existing driving simulators, with a traffic "animation". This is due to the fact that the kernel of our simulator architecture is a traffic model (ARCHISIM) and not a car dynamic model.

This feature allows us to study both impact of simulator driver behaviour on traffic and impact of simulated traffic on simulator driver. We can, for example, study the impact of the deployment of new ATT systems at both individual and collective level. We can also study compatibility between equipped and non-equipped drivers. Data can be recorded both for subject vehicles and for traffic. We simulate either instrumented car data recording, either traffic sensor data recording (temporal or spatial sensors).

The simulators use either a full cab or a mini cab, the visual restitution can provide up to 360° immersion and is achieved using either high cost Silicon Graphics or low cost PC 3D cards. Sound restitution is spatialized and reproduces sounds from subject vehicle as well as sounds from traffic.

We operate such simulator architecture at INRETS since 1998 (Arcueil and Bron sites), and for 2 years we have been providing the architecture to other research labs (3 sites). We have just started a collaboration with 3 more sites (1 in US, 1 in Italy, 1 in France). Figures 4 show two examples of our driving simulators (a full cab, and a low cost mini-cab design in collaboration with Faros company)

Figures 4: examples of INRETS driving simulators

EXAMPLE OF USE FOR STUDYING A NEW ROAD CONCEPT

This example of study, supported by the French national company SETRA, deals with the prototyping and the evaluation of three variants of a new profile for medium traffic demand (less or under 7000 vehicles/day). For a direction, the road profile consists in consecutive sections of 1 lane and 2 lanes. The 2-lanes section is provided in order to allow over-taking manoeuvre. The variants differ 1- by the length of the transition sections used to go from 1 to 2 lanes and 2 to 1 lane (3 variants, each allowing a different time to make the cut-in manoeuvre), 2- by the gap length between the over-taking areas (2 variants). The evaluation has to cope more with real usage than expected one and, of course, the characteristics of the infrastructure at both safety and level of service have to be studied.

Some studies can be done in order to assess the quality of the infrastructure from a traffic engineering standpoint. The problem here is that the traffic regulations for the infrastructure are not known and have to be predicted. Currently, and in most cases, the traffic regulations are adapted by taking into account normative predicted uses. The misfit between the predicted uses and the current ones can be wide and give way to a bad evaluation of the quality of the infrastructure. Furthermore, since the studied profile does not exist at this time, the experiments in actual situations are not possible. Some studies can be conducted on road with profiles more or less equivalent, but since the requested studies deal with safety criteria (study of the cut in the manoeuvres), they are difficult, expensive and risky.

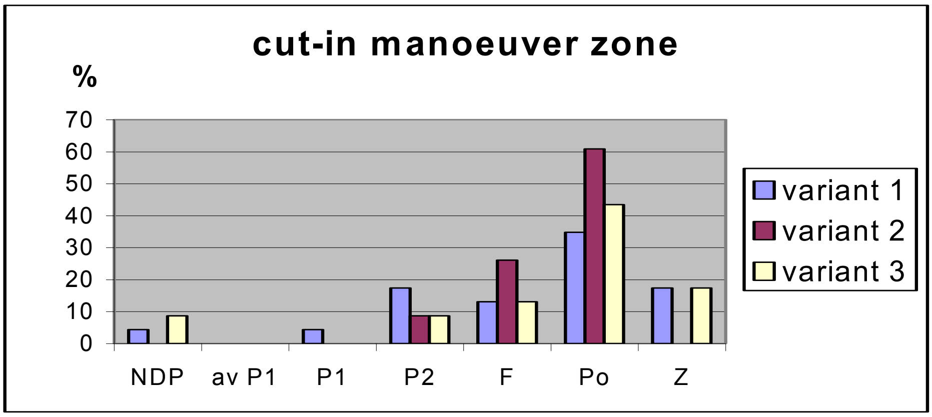
The proposed road profiles have to be studied both from the driver point of view and from a traffic point of view. The use of the integrated approach becomes then an appropriate method for an overall study of the kind of road profile.

Behavioural Assessment

In the first step, due to the previous limits, the use of a driving simulator is thus of great help in order to conduct in-depth psychological studies of specific situations. The aim of these investigations is to identify the actual way the drivers will use the studied new infrastructure. The study particularly focuses on the cut-in manoeuvre, to identify the possible changes in the driver's behaviour due to the shape of the end of the overtaking zone on the new studied roads, so we studied the 3 transition section variants. The experiments consist to define scenarios and to immerse a driver in relevant situations; 20 subjects took part in the experiments. A few scenarios have been defined to answer several questions raised from a test study. The scenarios focus on the beginning and the end of a 2-lanes section (figures 5), and take into account the presence or the absence of trucks. The main result obtained from this study is that the way the driver makes the cut-in manoeuvre is more influenced by the expected traffic situation (traffic situation in the one lane section) than by the shape of the end of the overtaking zone.

Figures 5: Two kinds of possible situation at the end of the overtaking zone

Indeed, for each scenario, the shape does not influence the choice of the driver. The following scenario illustrates this result: the subject overtakes a first low speed platoon (2 cars and 1 truck) and he is caught behind a second low speed platoon (car – truck –car- truck). If the subject does not break the rules (speed limitation), he cannot overtake all the vehicles of the second platoon. Figure 6 shows that, for each variant, most of the subjects pulled in before the last traffic sign which indicates the end of the overtaking zone.



Legend :

NDP : the subject does not overtake the group of vehicles in front of him,
Av P1 : the subject pull-in before the first traffic sign (300 m before the end of zone),
P1 : the subject pull-in on the level of the first traffic sign,
P2 : the subject pull-in on the level of the second traffic sign (150 m before the end of zone),
F : the subject pull-in on the level of the arrows of folding back,
P0 : the subject pull-in on the level of the last traffic sign which indicates the end of the overtaking zone,
Z : the subject pull-in crossing the "zebra".

Figure 6: location in the overtaking zone where the subject pull in

Traffic Assessment

As any change in driver's behaviour was shown by the first step, the next step in the integrated approach is the traffic studies. The aim of this study is the evaluation, from the capacity point of view, of the «low cost» motorway profile for a medium traffic demand (less or under 7000 vehicles/day). The percentage of heavy vehicles is taken into account for this traffic study.

The ARCHISIM behavioural traffic simulation model allows the user to simulate traffic sensors (such as magnetic loops) and thus to record microscopic traffic data. This feature is used in order to study traffic phenomena by quantitative indicators. Virtual sensors are put along the road at specific locations. The locations are chosen in the vicinity of the enlargement / shrinking. In total, 24 virtual sensors have been put for each variant.

Several simulations with ARCHISIM were performed with different scenarios. Six traffic scenarios have been studied. Each scenario is a combination between a peak hour traffic demand volume and a percentage of trucks. The interpretation and the comparison of the six scenarios make it possible to quantify the quality of the 3 variants from the capacity point of view. Figure 7 shows the six scenarios parameters.

Scenario	**Description**	**Total traffic** (veh/h)	truck rate
T0	Medium traffic and truck rate	300	15%
T1	Medium traffic – high truck rate	300	30%
T2	Low traffic – medium truck rate	150	20%
T3	Very low traffic – very high truck rate	80	40%
T4	High traffic – low truck rate	600	5%
T5	High traffic and high truck rate	600	30%

Figure 7: table of the six traffic *scenarios*

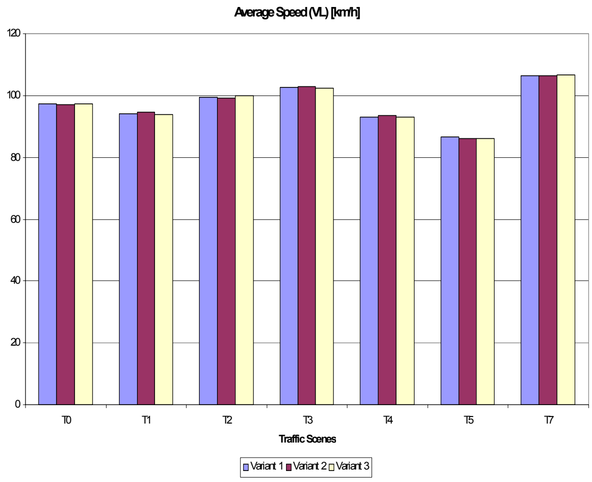
The designed speed for these roads is 110 km/h. Thus we assume that the speed distribution (desired speed) is in average 110 km/h with a variance of 11 km/h for average cars, 88 km/h with a variance of 8 km/h for the trucks.

From a traffic point of view, one issue related to this kind of roads is the driver's disturbance due to slow speed vehicles in one lane section. In order to compare the result within the scenarios we define the following indicators:

1. *Driver's disturbance:* A vehicle is considered disturbed at the measurement point if its instantaneous speed is lower than its desired speed and if its headway time is less than 3s.
2. *Mean travel time:* Mean travel time is the average of the travel times of all the vehicles of the same type.
3. *Mean speed:* Mean speed is the length of the travel divided by mean travel time.
4. *Mean disturbance time:* It is the average time spent by the vehicles of a same type in a disturbed situation.
5. *Mean delay*: Mean delay is the average of the delays of the vehicles of a same type during travel. A vehicle delay is the difference between effective travel time and travel time at desired speed

Since the topic of this paper includes other topics in addition to the above traffic study, here we give only a limited part of the results.

Figure 8 illustrates the results about the speed indicator. Due to the studied traffic volume level (a rather low density) the results clearly demonstrate that the three variants have the same level of service regarding the speed indicator: the mean speed is quite the same for both cars and heavy vehicles.



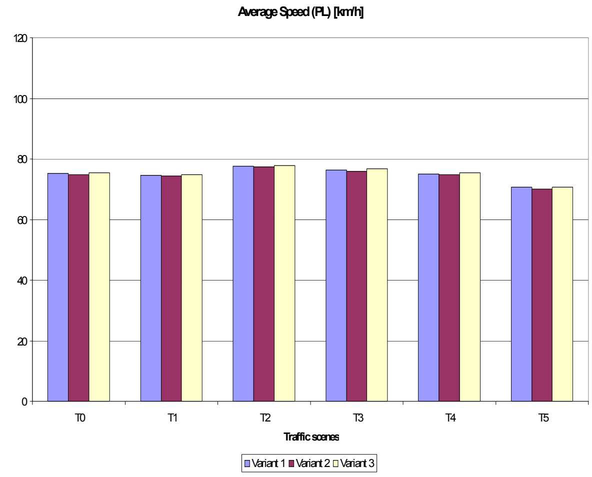


Figure 6: average speed of cars (VL) and trucks (PL) for each variant of road profiles per traffic scenario

Thus the indicators for the three networks are almost similar for each traffic scenario. For the scenario T0, the disturbance induced by this kind of network is characterised by the following indicators cf. Table 1):

vehicle type	*mean travel time (TT) (min)*	*mean speed (km/h)*	*mean disturbance time (DT) (min)*	*TT/DT*	*mean delay (min)*
car	***21.7***	***97***	***9***	***40%***	***2.5***
truck	***28***	***75***	***5***	***18%***	***3.7***

Table 1: traffic indicators for one variant network with the traffic scenario T0

The traffic indicators show that, if we consider the traffic scenario T0, this kind of network could take the two following traffic scenarios with a small increase of the disturbance for the driver:

- a similar level of traffic with a higher truck rate (scenario T1) or,
- a higher level of traffic with a small truck rate (scenario T4).

The results demonstrate that the capacity of the studied infrastructure is sufficient for the expected traffic volume and that the three variants have the same level of service. Finally, one of the major questions is how the driver will accept the disturbance and the impact of their possible impatience on their behaviour in cut-in manoeuvres at the end of the 2-lanes sections. This study will be continued by new experiments on the driving simulator.

CONCLUSIONS

In this paper we presented the so-called integrated approach to design road infrastructure and equipment. We briefly described the traffic simulation model and the driving simulator architecture. We then illustrated the use of such tools for the study of a new road infrastructure.

Domains of use of the « integrated approach » are wide and include not only the design of road infrastructure and equipments but also the design of ITS technologies. In that field, our approach had been used for evaluating the impact of ATT systems within the framework of two European projects: DIATS (4^{th} FP) for inter-urban situations and STARDUST (5^{th} FP) for urban situations. We also use that approach for studying various driver support systems (vehicle to vehicle alert systems, system for collecting and broadcasting motorway informations...) within the framework of various research projects at a national level.

Sustainable development of urban metropolis is a big issue and we will focus our research work in designing tools for helping the decision process. We currently work at enhancing the simulation of complex intersections (use of the inner space by drivers, interactions between pedestrians and car traffic...). We also work at designing tools for studying pedestrians' behaviour, particularly when crossing roads.

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