Validation of a Unified Model of Driver behaviour for train domain

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Abstract: In this paper, authors goal is to present part of the work carried out within the European project ITERATE. The objective of ITERATE is to develop a Unified Model of Driver (UMD) behaviour and driver interaction with innovative technologies in emergency situations. Such a UMD could be used when designing innovative technologies for assessment and tuning of the systems in a safe and controllable environment, when guiding designers in identifying potential problem areas, when adapting systems to the drivers before being available on the market and providing better support to the driver in emergency situations, or, for authorities, as a guide in assessing and approving innovative technologies. Authors will mainly focus on the UMD validation process on a miniature railway platform. An exhaustive presentation of the COR&GEST platform is given to understand how the comparison with a numerical simulation is possible. The command of the miniature train model is demonstrated and the visual interface for driver is depicted. Then, the data collected during experiments and the process to analyse the results are indicated. Finally, the numerical SiMUD tool and the experimental results are compared to assess the validity of the UMD.

Keywords: Driver behaviour, Human factors, Train control, Railways simulation, European Train Control System, NMRA

1. INTRODUCTION

In this paper, authors want to present all developments carried out on the Railway Driving & Traffic Monitoring platform named COR&GEST to validate a Unified Model of Driver (UMD) behaviour. Experiments and results presented in next sections have been collected through the "IT for error remediation and trapping emergencies" ITERATE project from Seventh Framework Programme of the European Commission and are fully discussed by Hjälmdahl et al. (2012).

In the early stage of ITERATE project, a theoretical Universal Model of Driver behaviour has been developed by Oppenheim et al. (2010a) and resulted in the ITERATE Unified Model of Driver behaviour presented by Shinar and Oppenheim (2011); Oppenheim et al. (2010b) in Figure 1. Drivers experience, driver state (fatigue or alert), attitude (whether sensation seeker or not), workload (different levels induced by secondary task, denoted WL) and culture (regional or company/organisational) are factors that will be considered together with influences from the environment and the vehicle. The next stage in ITERATE was then to collect data that could be used for testing the relationships of the factors within the model as well as provide input to development of the numerical model. This was done during portable experiments where train simulators were build and shipped between the five participating countries to make sure that identical experiments were carried out and that the cultural effect was studied in a correct way. In parallel to the experimental work, the numerical simulation tool was developed (SiMUD) using inputs from the initial theory and from the experiments (Forsman et al., 2011).

The UMD validation must be realized across the comparison between the model and the simulation, *i.e.* comparing SiMUD to the real drivers in a train simulator. For the simulation the criterion is that it should reproduce the same behaviour as is generated on group level in the simulator with real drivers and the main effects should be comparable. So, for example, if sensation seeking drivers (SS) are shown to drive at a higher speed than non SS, then should the modelled SS drive faster as well. For trains a new simulator with new train drivers on a new track was used. For practical reasons however the speed control by beacons system (French KVB) used differed somewhat from initial European Train Control System (ETCS) even though it deals with speed warning and control as well.

In the first section, the railway simulation platform COR&GEST used for validation protocol will be detailed. All explanations to transform a miniature railway in an scientific experimental platform are given. In the second section, the behaviours of drivers experimented on our platform across collected data are presented. Finally, in

⋆ The research leading to these results has received funding from the European Commission Seventh Framework Programme (FP7/2007-2013) under grant agreement n218496 Project ITERATE.

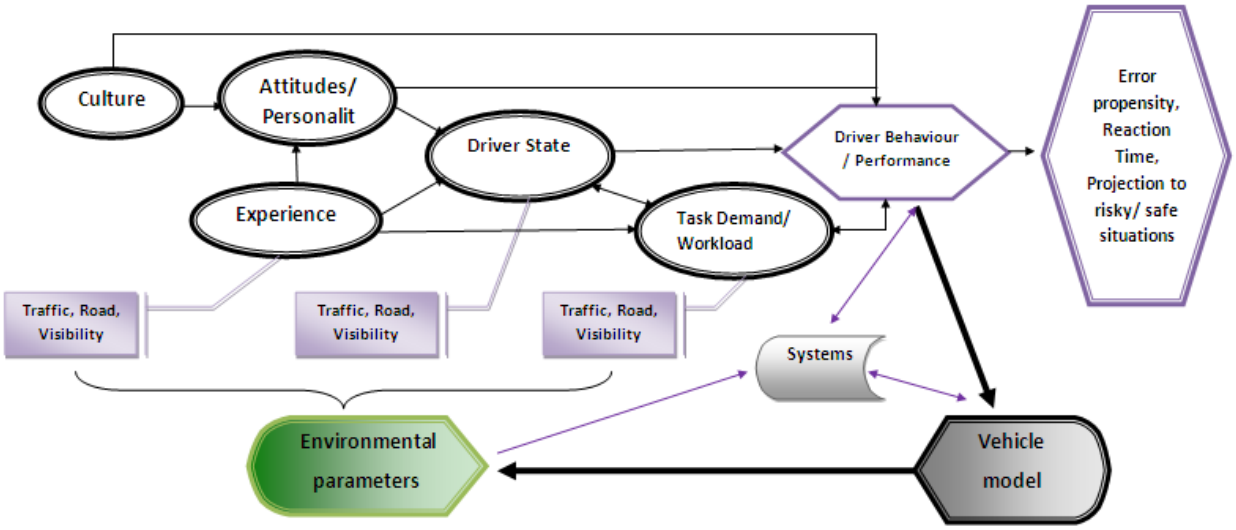


Fig. 1. The ITERATE Unified Model of Driver behaviour

the third section, the comparison between UMD tool and collected results is realized to validate the effectiveness of the approach.

2. THE RAILWAY SIMULATION PLATFORM COR&GEST

Many standards defined by the National Model Railroad Association (NMRA) are widely followed by the industry and modellers, including their HO scale track and their Digital Command Control (DCC) standard set. Concerning the train, the ZIMO MX6 decoder family is used to command the miniature train. For the environment, the COR&GEST platform is a miniature railway made up of about 33 meters of HO tracks and switches divided in 41 sections in Figure 2. HO is one of the most popular scale of model railway and his ratio is about 1:87. Nevertheless, another scale, the N scale (1:160), was used for landscape and all environment because it takes less space than HO scale. Switches and signal lights can be piloted from monitoring and scenario workstation. It allows commanding the set of elements constituting the railway tracks. To ensure a good communication between all elements, a minimum period of 110 ms (approximatively 9 Hz) is necessary to guarantee the digital interface and the miniature train to operate correctly. In next subsections, details will be given about the train model used on the platform and the train driver interface developed for the UMD validation.

2.1 The train model

Different methods exist using Configuration Variables (CV's) to program speed curves and optimize the driving characteristics of a miniature train. On COR&GEST platform, the train speed is calculated depending on the real observed behaviour of train on the platform. In Table 1 are given some of the NMRA codes from 0 (stop) to 126 (maximum speed) to command directly the miniature train with NMRA codes. A camera is located in the head of the miniature train, and, when a driver pilots the train, the perception of the landscape (which is N scale) should be reflected in displayed speed and coherent with

Table 1. From NMRA codes to observed speed (HO to N scale) conversion table

NMRA	Speed (Km/h)
0	0
20	12
33	31
46	60
57	91
83	139
90	151
96	**160**
111	183
126	203

his sensation of speed. The full NMRA codes (HO train scale) to observed speed (N landscape scale) conversion table is illustrated in Figure 3. Moreover, acceleration and

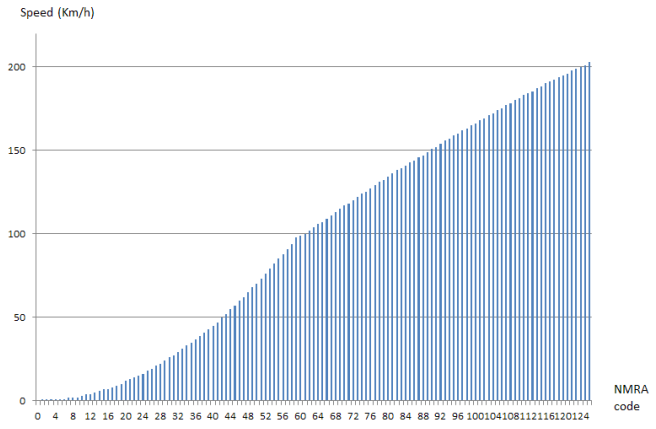


Fig. 3. The train speed commanded with NMRA codes

braking are commanded depending to train experiment. For instance, maximum speed, acceleration and braking power are adapted to scenario to be tested and cannot be implemented through CV's if desired behaviours are too much complicated regarding what manufacturers have planned for their decoders. In the ITERATE validation scenario, maximum speed of the train has been limited to



Fig. 2. The COR&GEST railway platform

160Km/h, *i.e.* 96 converted in NMRA code. The acceleration power increases with speed but is of course reduced as the train reaches his maximum speed. Many rules have been created to make the train behaviour as realistic as possible avoiding linear acceleration. Braking power has been set to guarantee that braking is always more powerful than acceleration. Finally, a natural decrement of speed has been simulated and so the train speed will decrease till train stop if no acceleration command is given by driver for a long period. One variable, stack, will be calculated and updated with sample rate of the experiment in Equation 1.

$$stack_t = stack_{t-1} + ThrottlePosition_t \div 16 \times \Delta \div 1000 \quad (1)$$

with $ThrottlePosition_t$ a numerical value included between [-16;16], respectively for full braking and full acceleration, and Δ is the sample rate time in milliseconds (time elapsed between t-1 and t). $stack_t$ is calculated and used in the Algorithm 1 to command the miniature train in speed through NMRA codes. For instance, if the train is starting

Algorithm 1 acceleration and braking algorithm

if $ThrottlePosition_t > 0$ **then**
  if $stack_t \geq 0.4$ & $NMRAcode_t < 20$ **then**
    $NMRAcode_t \leftarrow NMRAcode_{t-1} + 2$
  else if $stack_t \geq 0.6$ & $20 \leq NMRAcode_t < 33$ **then**
    $NMRAcode_t \leftarrow NMRAcode_{t-1} + 2$
  else if $stack_t \geq 0.6$ & $33 \leq NMRAcode_t < 83$ **then**
    $NMRAcode_t \leftarrow NMRAcode_{t-1} + 1$
  else if $stack_t \geq 1.2$ & $83 \leq NMRAcode_t < 90$ **then**
    $NMRAcode_t \leftarrow NMRAcode_{t-1} + 1$
  else if $stack_t \geq 1.8$ & $90 \leq NMRAcode_t < 96$ **then**
    $NMRAcode_t \leftarrow NMRAcode_{t-1} + 1$
  end if
else if $ThrottlePosition_t < 0$ & $stack_t \geq 0.4$ **then**
  $NMRAcode_t \leftarrow NMRAcode_{t-1} - 2$
else if $stack_t \geq 5$ **then**
  $NMRAcode_t \leftarrow NMRAcode_{t-1} - 2$
end if
$stack_t \leftarrow 0$

from a stop at station and if actual NMRA code is between 33 and 83, as soon as $stack_t$ will be greater than 0.6, NMRA code will be increase by 1. This will occur in 0.6 second if the train driver fully accelerate, 1.2 seconds if fifty percent of full acceleration ($ThrottlePosition_t = +8$) and so on. On the other hand, if train actual speed is 60Km/h (NMRA code 46) and if driver want to stop the train with full braking (($ThrottlePosition_t = -16$), NMRA code will be decrease 2 by 2 every 0.4 second.

2.2 The driver interface

During initial experiments, the ETCS was used to collect data to configure SiMUD tool. ETCS was selected because it gathers all existing technologies and systems supporting the operator across countries (Lai et al., 2010; Barnard et al., 2010a). For validation stage, an adapted version of the KVB french system was selected to compare results. The video resulting from the camera located in the head of miniature train and the signal is encapsulated in a visual displayed to drivers in Figure 4. On the upper left corner of Figure 4, the yellow triangle on blue square flag give to the driver the information about the remaining distance before next section (the distance in meters is displayed one thousand meters before). The driver gets information on how to perform the speed reduction thanks to this information and the original KVB display (depicted just after). On the lower left corner, pressure gauges of the train give information of braking power applied. From left to right, the original KVB display panel, the current maximum permitted speed (120 km/h in green), the actual speed (0 km/h on the horizontal graph), the throttle position (100, which means no acceleration or braking power), the simulation time (11:03:52) and a timetable for drivers (with station name, arrival time and departure time) are included. Finally, the driver is able to pilot miniature train with "raildriver" joystick presented in the lower right corner. One of the throttle is configured and used to accelerate or brake the train.

3. BEHAVIOURAL RESPONSE OF TRAIN DRIVER

During the train driving scenario the drivers were asked to drive the train according to a given timetable. The train driving scenario included several changes in speed limit and stations at which the driver were to stop. The changes in speed limit and the stops included different track alignments, *i.e.* slopes, and levels of the permitted speeds. The



Fig. 4. Train driving interface

driver was assisted by a modified version of the ETCS that issued a continuous warning to the driver if the speed limit was exceeded. In the approach to changes in speed limit and stop at stations the system indicated the required braking through a permitted speed profile. A continuous warning was issued to the driver if the permitted speed profile was exceeded during the deceleration to new lower speed limit or to stop at a station. To understand how ETCS is functioning, in Figure 5 the driver is driving at 140 km/h and then gets a notification about a new lower speed ahead, in this case 90 km/h. The bar on the left says that he has 845 meters left to the new speed. Also note the small square in the upper left hand corner. This square will grow as we approach the point where braking has to start to be able to safely reach the new speed.
During validation experiments, a simulation of the on-board computer who generates two speed-thresholds based on the received signals from the beacons has been developed. If the train is over the speed limit, passing the first speed-threshold, an audible alarm sounds and the control panel indicates to the driver to adjust the train speed without delay. If the second speed threshold is passed, the KVB automatically engages emergency brakes on the train. This automatic braking has been shunted in our experiments to

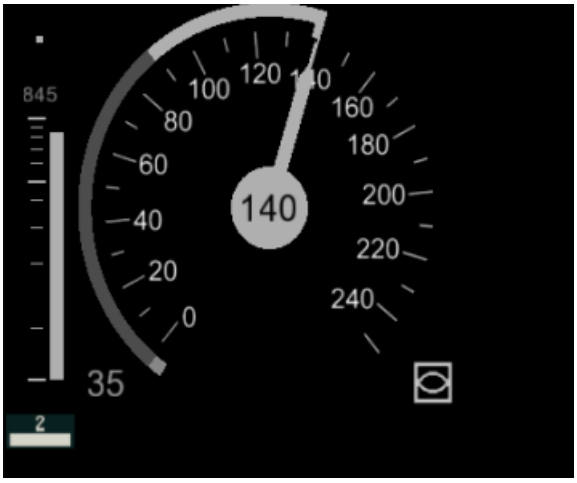


Fig. 5. The original ETCS display

let operators the opportunity to drive as fast as possible without the risk to be "punished" by the advanced driver assistance system. To manipulate workload level in the train experiment the same count backwards secondary task with subtraction by 7s or by 1s that was used in the initial

experiments was used. A full description of the task has been realized by Barnard et al. (2010b). Three levels of workload are still remaining (High, Medium and Low, low should be considered as baseline situation). Three types of events can be defined:

- Strong speed reduction is an event in which the train driver has to reduce speed in the approach to a potentially dangerous area. (in general the allowed speed is 30 km/h within the station area if there is a track change and a station stop).
- Speed reduction while driving is an event in which the train driver has to reduce speed along the track. The required speed reduction is lower in the speed reduction while driving events compared to the strong speed reduction events.
- Braking for station stop are events in which the train driver is required to stop at a station. The speed reduction during these events is in general from 30 km/h to zero.

For the validation step of the ITERATE project, only the two first speed reduction events have been used in further developments because they were easy to compare directly to data from car simulation (same type of speed reduction events) in order to validate the UMD. In the train experiment, the following performance indicators were used in the analysis:

- Difference between permitted and measured speed (i.e. permitted speed - measured speed, km/h) at specific positions.
- Mean difference between permitted and measured speed (km/h) between these positions.

Others indicators, like the resilience one, have been studied in the project by Enjalbert et al. (2011); Ouedraogo et al. (2013) but were not kept because it would have been too difficult at this stage to implement them in UMD numerical tool. An example of strong speed reduction that illustrates the points and sections is shown in Figure 6. For each speed reduction event , the difference between measured and permitted speed behaviour indicators will be calculated at three points (PI, PII and PIII) and over the two sections connecting these three points (SI and SII). PI corresponds to the start of the event, PII is defined as the point at which the driver is supposed to reduce the speed event and PIII is the end point of the event (the point at which the new speed should have been reached, information given by ETCS to drivers). SI is the section in between points PI and PII. Similarly, SII is the section between points PII and PIII. For the sections, SI and SII, the performance indicator used is the mean difference between permitted and measured speed. In this example, PI located 1000 m before new speed limit (KM 43148), PII at 41 m from new speed limit (KM 43907) and PIII is the new speed limit point (KM 44148). SI is defined as the section between PI and PII. Finally SII is the section between PII and PIII. Note that, in the example, the difference between permitted and measured speed will be negative at point PIII and over section SII for participant FR#2. If the train driver exceeds the permitted speed, the KVB system issues a continuous warning. These performance indicators will be observed in validation experiments and compared to those of numerical UMD simulation in next section.

Table 2. Parameters selected for comparison with SiMUD tool

Parameters	Value
CULT	FR
DS	Alert
EXP	Novice & Experienced
ATT	Low Sensation Seeker & High Sensation Seeker
WL	Low & Medium & High

4. UMD BEHAVIOURAL VALIDATION ON COR&GEST PLATFORM

To validate the simulation, a simulator trial with 32 subjects distributed for two levels of experience and two levels of sensation seeking was carried out. For numerical simulation different parameters, presented in Table 2, have been selected to simulate driver behaviour in SiMUD tool. Two of them, culture and driver state, have been set to France and alert to make it possible to compare experimental results. Considering the factors experience and attitude, drivers were selected to include both novices and experienced and High/Low sensation seekers. Finally, three levels of Workload were manipulated during simulation. The difference between permitted and measured speed have been analysed for the reduction while driving and strong speed reduction events. P-values from the analysis of variance of the performance indicators of the train driving experiment are shown in Table 3 -Table 4. Factors that are found to be significant at the 0.05 level are highlighted in the tables. None of the factor turned out as significant in this validation experiment. This result is coherent with the one obtained during initial experiments. Only second order interactions can be observed with significant effect. For example, considering Experience & WorkLoad for the speed reduction while driving events, when workload is low or high the novices seem to loose their ability to control their speed and to anticipate deceleration like experimented do. Many cases have been studied and discussed in original work but results will be limited in this paper. If we consider only the mean differences of speed between permitted and measured for the speed reduction while driving events, when comparing the results generated from the simulator experiment in Table 5 and the numerical simulations in Table 6 a good overall coherence that needs to be explained was found [1]. For instance, in Figure 7, the differences of speed between permitted and measured for the speed reduction while driving events for experienced and low sensation seeker drivers comparison are presented. It can be first observed that UMD tool predicts more or less the same behaviour whatever driver workload level, *i.e.* the three SiMUD experienced & low sensation seeker speed profiles may be surimposed. Then, during first part of curve (from PI to PII), UMD software keep speed few kilometres per hour under maximum permitted speed whereas real drivers anticipated deceleration. Then, during the second part (from PII to PIII), SiMUD initially decelerates then recovers to new to maximum permitted

[1] For high sensation seekers, no experience level is needed because of SiMUD model, *i.e.* SiMUD will behave same if sensation seeker degree is set to high despite of the experience level

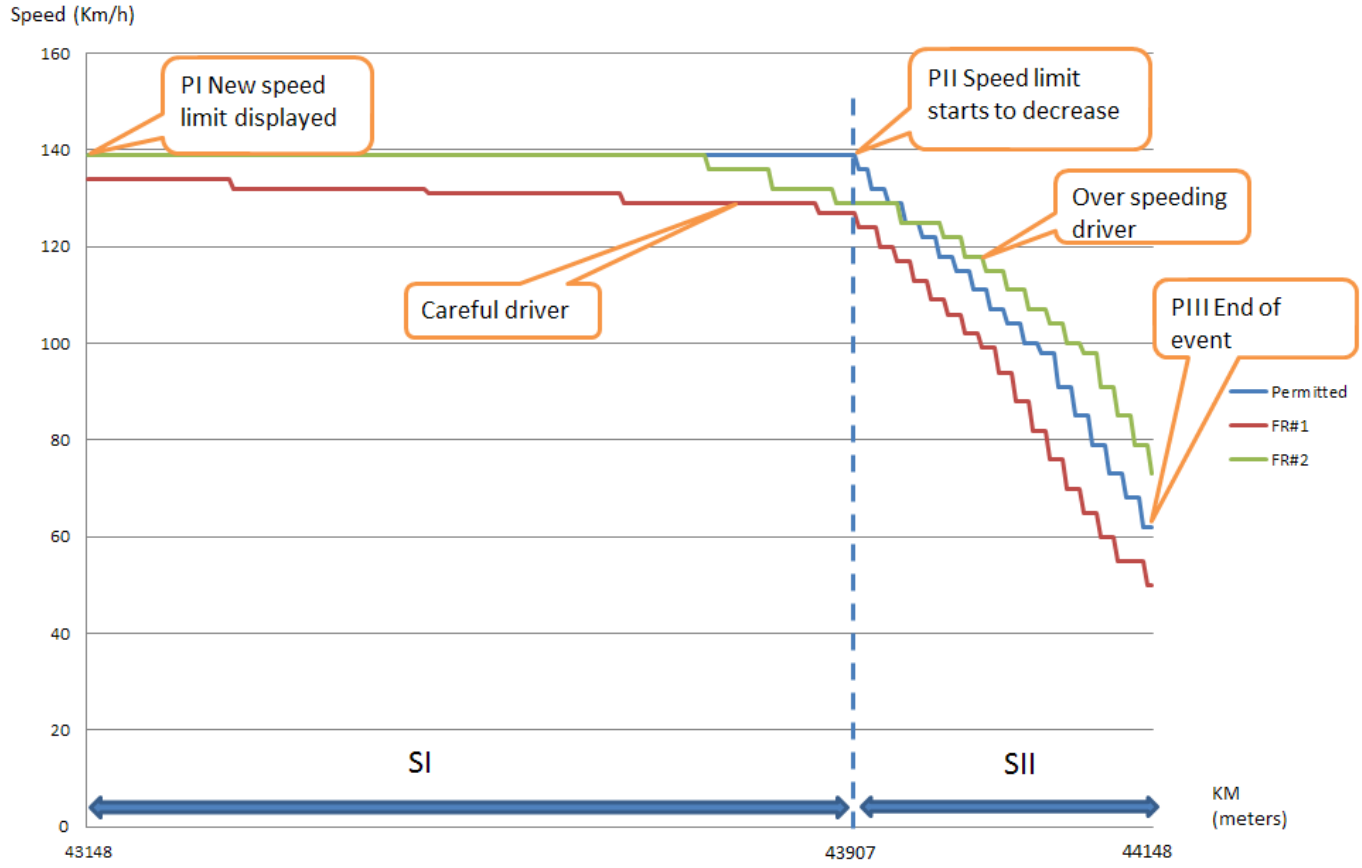


Fig. 6. Example of strong speed reduction event including speed profiles for two participants

Table 3. Analysis of variance: p-values, difference between permitted and measured speed for the strong speed reduction events

Difference between permitted and measured speed	PI	SI	PII	SII	PIII
Intercept	.000	.000	.000	.000	.000
Experience	.264	.848	.439	.221	.130
SensationSeeker	.983	.377	.563	.920	.763
WorkLoad	.093	.554	.532	.417	.564
ParticipantID (Experience * SensationSeeker * WorkLoad)					
Experience * WorkLoad	.738	.975	.879	.836	.716
SensationSeeker * WorkLoad	.249	.913	.984	.862	.818
SensationSeeker * Experience	.083	.115	*.010*	*.002*	*.003*

Table 4. Analysis of variance: p-values, difference between permitted and measured speed for the speed reduction while driving events

Difference between permitted and measured speed	PI	SI	PII	SII	PIII
Intercept	.000	.000	.000	.000	.000
Experience	.754	.080	.052	.371	.996
SensationSeeker	.781	.858	.160	.294	.466
WorkLoad	.242	.641	.311	.341	.702
ParticipantID (Experience * SensationSeeker * WorkLoad)					
Experience * WorkLoad	*.046*	.260	.404	.425	.506
SensationSeeker * WorkLoad	.998	.959	.643	.786	.623
SensationSeeker * Experience	.533	.686	.369	.523	.708

Table 5. Mean difference of speed between permitted and measured (in kilometres per hour) for the speed reduction while driving events during validation experiments

Experience	Sensation Seeker	WorkLoad	PI	SI	PII	SII	PIII
Novice	Low sensation seeker	Low	3.167	6.890	14.003	4.847	3.000
		Medium	2.583	8.990	17.667	8.007	4.000
		High	3.667	7.727	13.177	5.490	2.310
Experienced	Low sensation seeker	Low	4.875	14.760	22.250	10.385	6.500
		Medium	4.875	16.145	24.440	12.685	7.750
		High	3.375	14.995	22.750	9.940	6.000
	High sensation seeker	Low	3.150	15.480	21.426	9.770	5.150
		Medium	4.100	13.998	21.376	10.220	5.600
		High	3.750	12.496	18.900	8.188	4.750

Table 6. Mean difference of speed between permitted and measured (in kilometres per hour) for the speed reduction while driving events with SiMUD

Experience	Sensation Seeker	WorkLoad	PI	SI	PII	SII	PIII
Novice	Low sensation seeker	Low	6.190	6.280	6.410	14.750	1.500
		Medium	6.030	6.090	6.150	12.000	1.480
		High	6.020	6.060	6.080	14.380	1.420
Experienced	Low sensation seeker	Low	4.690	4.750	4.810	13.900	1.000
		Medium	4.740	4.820	4.940	15.700	0.890
		High	4.760	4.810	4.840	13.940	0.890
	High sensation seeker	Low	4.030	4.130	4.220	13.310	0.800
		Medium	4.010	5.040	4.170	13.210	0.640
		High	4.060	4.100	4.320	13.290	0.630

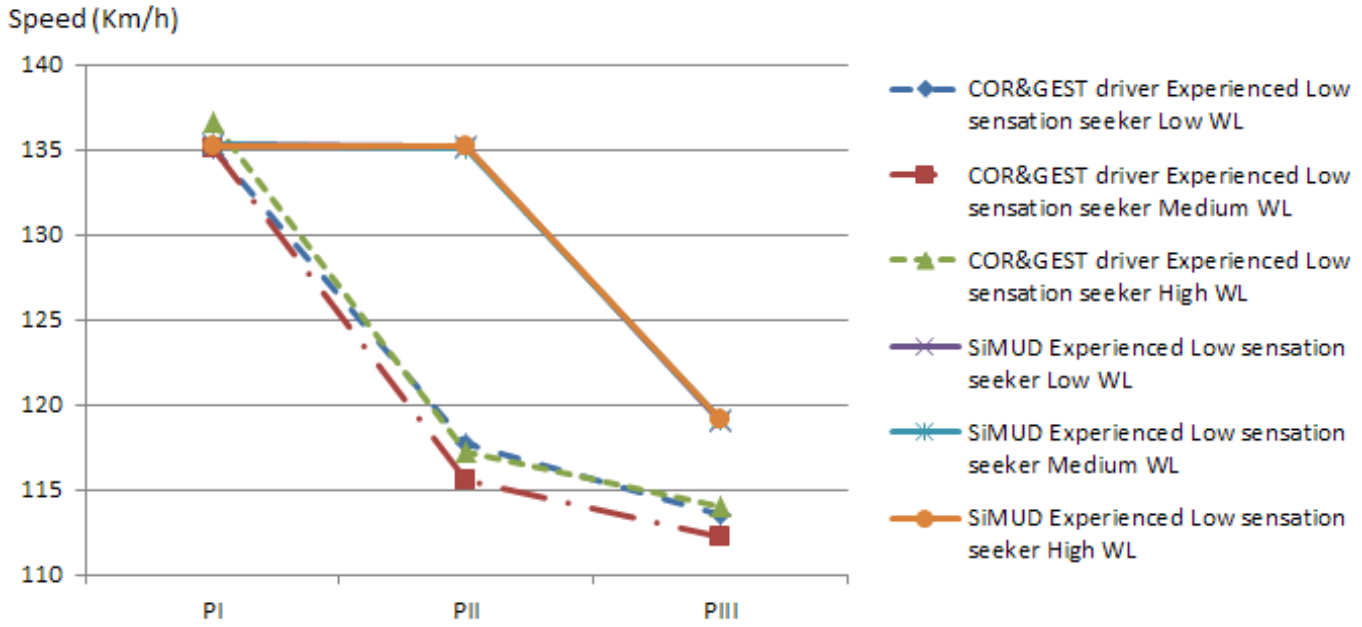


Fig. 7. Example of speed (in kilometres per hour) for the speed reduction while driving event(140 km/h to 120 km/h) depending on Workload (Experienced & Low Sensation Seeker)

speed and real drivers, that had previously anticipated deceleration, only recover few kilometres per hour under new limitation. Observed differences in speed profiles are consistent regarding differences of platform design between initial experiments (data used for SiMUD parametrisation) and validation experiments. The results show that the numerical simulation manages to repeat the behaviour of the French drivers on a general level in that sense that it adopts approximately the same speed profile. The simulated driver reduces speed at last moment before deceleration point without any anticipation and the braking is smoother. This effect is most likely due to the fact that the portable simulators used to tune the model did not give the same sensation of speed to drivers and so they anticipated a lot and they brake harder during these experiments. Some specific limits on train simulation were here highlighted. Tuning of SiMUD tool for experimented support system and platform is needed for more accurate results:

- Train model of SiMUD should be updated to fit better with experimental platform.
- Piloting is necessary to calibrate anticipation and confidence drivers have on the KVB/ETCS warning system.

5. CONCLUSION

The aim of this study was to show that the UMD model and the SiMUD tool developed within ITERATE project are valid and can be used to predict behaviour of real train drivers. A simulator experiment with 32 test drivers was performed. The numerical simulation developed and tuned by data from the initial experiments was put to the test in this experiment. The simulator experiment carried out at LAMIH from UVHC on COR&GEST platform was repeated using the SiMUD tool for trains. The same environment was implemented in the UMD and simulations were carried out for French drivers, experienced and novice, High & Low sensation seekers and workload was varied throughout the numerical simulation.
Moreover, the description of the COR&GEST miniature railway platform has been realized and validated. Urban guided transportation are a new application domain that will be investigated in next projects with a new model of tramway to be implemented and a new visual display according to "on sight" driving and low speed material.

ACKNOWLEDGEMENTS

The present research work has been supported by
The International Campus on Safety and Intermodality in Transportation,
The Nord-Pas-de-Calais Region,
The European Community,
The Regional Delegation for Research and Technology,
The Ministry of Higher Education and Research,
The Scientific Research Group on Supervisory, Safety and Security of Complex Systems,
The European Research Group on Human-Machine Systems in Transportation,
And the National Center for Scientific Research.
The authors gratefully acknowledge the support of these institutions.
The authors also cordially thanks Rudy Dahyot, development engineer, for all the work realized on the COR&GEST platform.

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