A VISSIM based ADAS simulation platform to complement the UKCITE real world connected vehicle test environment


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A VISSIM based ADAS simulation platform to complement the UKCITE real world connected vehicle test environment

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Abstract:
UKCITE, an InnovateUK funded project, provides a test environment on a mix road network in the UK. This paper presents the simulation counterpart of the real world test environment. It uses the VISSIM microscopic traffic simulation environment together with MATLAB, python and C++ to simulate advance driver assistance systems (ADAS). Vehicle specific simulation parameters are tuned based on human factor studies carried out on driver simulator as well as published data. Driver models are implemented using the VISSIM DLL interface to replicate expected drivers responses to ADAS. Within the scope of this project, various driver-warning systems were implemented. This paper focuses on cooperative adaptive cruise control (CACC) and emergency electronic brake Light (EEBL). Individual vehicle behaviours were evaluated using a model of the Gaydon test track. The impact of these algorithms on the traffic was evaluated using a calibrated model of a portion of the M42 smart motorway.

Keywords: CACC, EEBL, driver modelling

Introduction

Connected and autonomous vehicles require increasingly complex systems exploiting a wide range of information captured by a multitude of sensors. In addition to being able to evaluate each vehicle functionality, there is a need to test the interaction of the vehicles with various environments. The latter involves many different conditions and external actors and factors e.g. vehicles, pedestrians, variable message signs, weather, and visibility. There is therefore a need for a (systems-of-systems)-of-systems or vehicle-environment approach.

Significant road testing is required to fully test both the connected vehicle and its interaction with the connected and unconnected environment. The UKCITE (UK Connected Intelligent Transport Environment) project is creating a real-world-lab to test connected and autonomous vehicles (CAV) interaction with a mix road and communications infrastructure. It is acknowledge that fully testing all advance driver assistance systems (ADAS) for higher level of automation is prohibitive. There is therefore a need to be able to simulate both the vehicle system and the vehicle's interaction with other road users in a realistic environment.

This paper presents the work carried out to complement the real world UKCITE test facilities with a microscopic traffic simulation test facility to evaluate the impact of advance driver assistance systems on the drivers and other road users. The ADAS features considered in the simulation environment include advance warning systems (road work, emergency vehicle, slow vehicle, and congestion), flashing brake lights, emergency electronic brake light (EEBL), Adaptive cruise control (ACC) and cooperative ACC (CACC). This paper considers CACC and EEBL.

Key to the success of connected technology is the reliability and robustness of the communication networks exploited by the vehicles and the infrastructure. A good review of communication technology and their impact on connected vehicles can be found in [1]. Current standard series describe dedicated short range communications (DSRC) for V2V whist LTE-V 5G is at the draft stage. In ideal environments, communication latencies are of the order a few milliseconds to 10^{th} of milliseconds. In practice latencies depend on for example: the weather, the technology used, the distance between the antennas and receptors and the network topology. Example of topology include Predecessor follower, Leader follower, Pre-predecessor follower, bi-directional [2]. Predecessor follower is the most commonly used network topology as the probability to receive information over the network from predecessor is the highest. Leader follower strategy broadcast simultaneously to all followers, resulting in similar delays between all the vehicles involved in the platoon. The communication hardware and software maturity plays a key roles in the robustness and predictability of the latencies. Communication protocols will dictate the update rate and add to the transmission delays. For example, V2V CACC data should be updated every 0.1s [3].

EEBL enables connected vehicle to receive notification, via the human machine interface, of hard braking events performed by connected vehicles. The purpose of this system is to reduce rear end collision by providing advance warning to the driver. This should be particularly useful when there is no direct line of sight between a braking event and the vehicle receiving the EEBL signal. The drivers reaction to EEBL messages depends on many factors including the environment, the driving conditions, the driver's behavioural patterns, the driver's trust and desensitization to ADAS features, the perceived safe distance and negligence. Drivers receiving an EEBL message are not necessarily expected to carry out emergency braking, however they are expected to increase their level of alertness and slow down or change lane. In conventional vehicles, drivers respond to a breaking incident by observing the brake lights. Driver reaction time, which is the difference between the time the driver receives the message and the time the driver takes an action, varies from 0.4s to 2.7s with an average of 1s [4]. There is to date only limited research available on driver's reaction to EEBL, see for example [4].

CACC combines adaptive cruise control (ACC) with vehicle connectivity to enable the platoon leader to communicate with all the vehicles in the platoon. According to [3] V2V CACC transmits 13 required sets of data and 3 optional. Data relating to vehicle environment, weather, variable speed limits can be exploited by the control algorithm to simultaneously reject disturbances and anticipate changes in the leader's speed. However, this paper considers only vehicle speed and acceleration. Similarly to ACC, CACC vehicle act on the throttle and brake control to achieve the desired vehicle response. According to the ISO/DIS 20035, the expected performance improvement over ACC include more accurate control of vehicle following gap, smoother ride quality, faster responses to speed changes by all the vehicles in the platoon. The accompanying expected performance improvement include: shorter vehicle-following gap, increased driver confidence, willingness to use ACC under a wider range of traffic conditions; fewer cut-ins due to the shorter gaps, damping of traffic flow disturbances, improved traffic flow dynamics, increase effective capacity on motorway traffic and reduced energy and emissions.

Delays due to controller implementation are an order of magnitude smaller than delays due to communication which are themselves an order of magnitude smaller than the vehicle response to a throttle or brake command. The main issue is that the uncertainty associated communication delay is less predictable and consistent than the other delays. Communication latency and delays in the control loop can lead to time gap oscillation between the vehicles in a platoon, known as the string stability problem. Uncertainties associated with delays and latencies can exacerbate this problem.

The most widely implement ACC/CACC solution in vehicles is a two degrees of freedom feedforward Proportional+Derivative (PD) controller. The feedforward term provides the tracking response and the PD controller the rejection to disturbance. Other control approaches proposed to overcome the lack of adaptability of PD to parameter changes and noise in a platoon include fractional order controller, model based predictive control, sliding mode and robust $H\infty$, see [6] and references therin. PD based strategies suffer from having fixed controller gains to accommodate different situation, speed and acceleration changes. However, practical implementation complement traditional controller with calibrated maps and finite state machine enabling the algorithm to cope with both the vehicle's nonlinearities and be able to respond to the wide range of scenario a vehicle may encounter. Adaptive controller gains tuning have been proposed as well as the use of smith predictor for the ACC part of the controller. Most of the published work rely on simulating CACC vehicles by fitting models to experimental data and then developing a controller based on the vehicle model. MATLAB/Simulink, Carsim are used to study CACC from a vehicle's dynamic and control systems design perspective. Microscopic traffic simulators such as SUMO, Aimsun and VISSIM are used to evaluate the impact of CACC in simulated traffic. This work adopts VISSIM to evaluate vehicle's response to different controllers and study their impact on the traffic. The appropriateness of the VISSIM traffic network calibration was evaluated using the GEH factor as recommended in the WebTag guidelines (UK Department of Transport, 2013). GEH should be less than 5.

The novelty of this paper lies in the design and VISSIM implementation of models to simulate drivers' reaction to ADAS features. The 'ADAS driver' is implemented within the VISSIM driver model DLL to replicate observed behavior for EEBL, flashing brake lights and warning systems as well as the automated vehicle speed controllers for ACC and CACC. The test tracks simulation enables to evaluate the performance of individual vehicle to the models and controllers investigated. The smart motorway section, calibrated for three different traffic conditions, is used to evaluate the impact on the road network of various number of vehicles equipped with ADAS features. The remaining of the paper is composed as follows. The next Section describes the test road network modelling. The third section describes EEBL. The fourth Section described ACC and CACC and finally Section 5 gives discussion and conclusions.

Modelling

There are several microscopic traffic simulation environments available, each with attractive features. In this work, use is made of VISSIM due to its ease of connectivity with other software platforms via the DLL and COM interfaces. The modelling approach adopted is to define the scenario using python or MATLAB. The control system, signal processing and estimation are designed using MATLAB. Visual Studio is used implement the algorithm in C++ and generate a DLL. The simulation results are then exported back to MATLAB which is used for analysis.

The driver model DLL replaces the standard VISSIM Wiedemann 74 and Wiedemann 99 driver behaviour models. In this work the DLL has been used to implement EEBL, ACC, CACC for programmable platoon lengths, communication topology, and control algorithm together with the communication latency. An alternative implementation of the communication using the COM interface has also been realised. The resolution of the delays implemented is limited to discrete increments of the VISSIM sampling time of 0.1s. Whilst this sampling time does not allow accurate vehicles dynamics to be modelled, it is sufficient for traffic simulation as it is $1/10^{th}$ of the overall delays and time constant in the system. The time it takes for a vehicle to react to a desired speed change (i.e. brake or accelerate) is of the order of seconds for standard saloon vehicles. In addition, conventional brake response time for alert drivers is in the range 0.7s to 1.3s. Other delays include the HMI processing on the vehicle (0.1 to 0.3s) and the delay in transmitting and updating the transmission estimated to be 0.2s + 0.2 Tre-transmit). In this work, the overall latency for EEBL was selected to be in the range 1.2 to 2.4s, whereas CACC considers a 0.2s overall delay obtained by adding the communication sampling of 0.1s to a processing time of the message and a controller implementation of 0.1s.

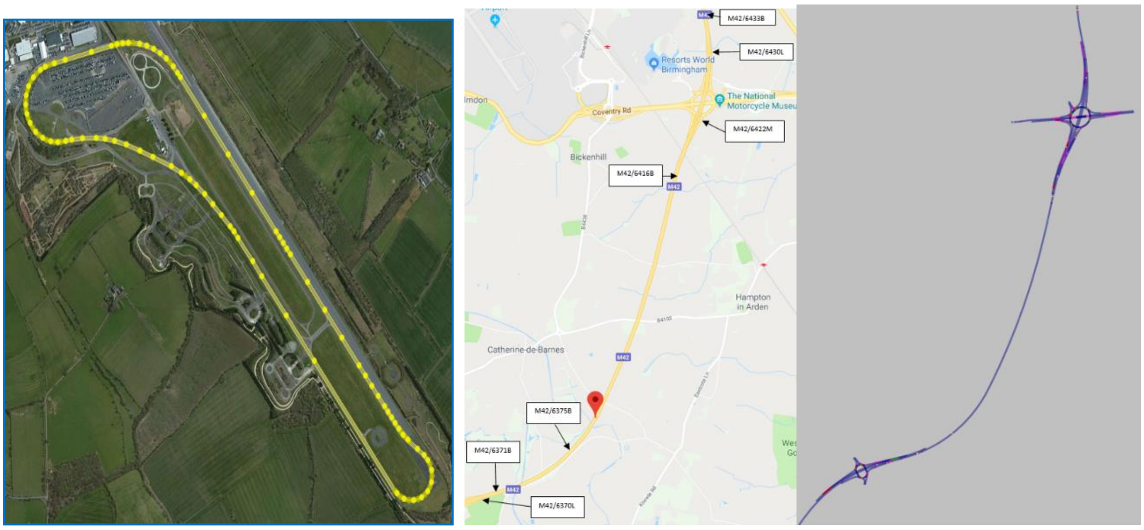
The simulation are set up such that it is possible to allocate to each vehicle in the simulation a specific driver model. This enables to simulate a mix of vehicles. Note that CACC vehicle only operate in platoon if they encounter other CACC enables vehicles. Similarly, EEBL equipped vehicle can only transmit information to connected vehicles.

The road network modelled include the Gaydon test track, see Figure 1a. This test track enables the simulation of the network coverage and speed of transmission together with replication of data from the test vehicles. This track is used to evaluate the control algorithms with a limited number of vehicles.

The M42 smart motorway southbound from the A45 exit to the A41 been modelled to evaluate large amount of connected vehicles, see Figure 1b. The roads are represented by links and connectors overlayed onto a realistic map. To improve the performance of the simulation, the length of the upstream links on the edge of the network were artificially increased. This allows the appropriate localisation of routing decisions and reflects the fact that drivers know their destinations.

Highways England traffic count data from MIDAS (https://www.midas-data.org.uk/) have been used for model calibration. These consists of the flow (vehicle count) by length category, Flow (vehicle count) by lane, Average speed ($km.h^{-1}$) by lane, Average headway (deciseconds) by lane and Occupancy (%) by lane. Two vehicle inputs were used. These inputs correspond to the counter locations M42/6433B and M42/6422M, which supplies two merging lanes. The hourly flow rate derived from the data collected were used to set volumetric flow at every time interval for the vehicle inputs. Three levels of traffic were modelled, Low (5:30 to 7:00), Medium (11:30 to 13:00) and Peak (7:30 to 9:00). The total simulation time was 90 minutes with 15 minutes warm up as well as cool down periods. This ensures that the network was well populated before data collection starts.

The volume composition was set to include the 4 aforementioned vehicle categories. Each vehicle category was modelled by 2 types. One for connected and one for non-connected vehicles. The non-connected vehicles were simulated using the VISSIM driver models. The connected vehicles were simulated using the DLL which interacts with the standard driver model.



a) Gaydon test track **b) M42 smart motorway**

Figure 1 traffic networks implemented in VISSIM to evaluate 'ADAS drivers'

Different driving behaviour models based on minimum measured headway have been specified for the different links. The driver models defined for non-connected vehicles is the Freeway (Free lane selection) which uses the car following type Wiedemann 99 model. The Wiedemann 99 model is recommended for motorway modelling. The time headway parameter is one of the crucial parameters for calibration of a motorway. In this work it was set at the following values depending on the link considered: Headway time={1.2s, 1.6s, 1.7s, 1.8s 1.9s). The other model parameters modified in this work were: Maximum deceleration=-8.5$m.s^{-2}$, Maximum acceleration=3.5$m.s^{-2}$, Following variation=4.00m, Negative following threshold=-0.35, Positive following threshold=0.35, Speed dependency of oscillation=11.44, Oscillation acceleration=0.250$m.s^{-2}$, Threshold for entering following=-8, Standstill distance=1.50m, Standstill acceleration=3.50m.s^{-2}, Look ahead distance=250m, No. of observed vehicles=4.

The sensor location were modelled in VISSIM using counters. The data obtained per lane were aggregated per link (sum of all lanes) and collected at these locations every 60 seconds. The modelled flow obtained using VISSIM, and the measured flow were used to calculate the GEH.

EEBL

The EEBL algorithm transmits, with some delays, the information enabling the target vehicles to display the hard braking warning on the vehicle HMI. The situations where EEBL would be advantageous are illustrated in Figure 2. The vehicle subject to hard braking indicated by a rectangle with a 0 inside is transmitting information enabling other vehicles to locate its position and direction of travel. Note that the simulation assumes that only the vehicle travelling in the direction of travel of the braking vehicle will take the decision to display the EEBL warning, i.e. vehicles 1 and 3. If the zone of interest is longer than the communication range, then the EEBL signal will have to be retransmitted. In this work it is assumed that each retransmission adds 0.2s. Vehicles not equipped with communication capabilities (e.g. vehicle 2) will not receive the EEBL warning message. It is assumed that the vehicle with direct line of sights will behave differently to those not having direct line of sight. In particular vehicle travelling relatively close to a braking vehicle are expected to react to the brake warning light concurrently to their vehicle displaying the EEBL warning. All the vehicles not in a direct line of sight (no_dlso) will however receive the EEBL warning at the same time and therefore brake at approximately the same time.

The Wiedemann99 model, used for the standard vehicle simulation, will brake at the time necessary to prevent a collision. The braking intensity will depends on the model parameters. The model will however not allow collisions to occur.

To evaluate the benefits of EEBL, other braking systems were simulated and compared to the driver model used by the traffic simulator. Flashing brake light was implemented in a C++/DLL driver model. It assumed that the driver will react 19% faster than would normally be the case with standard brake lights.

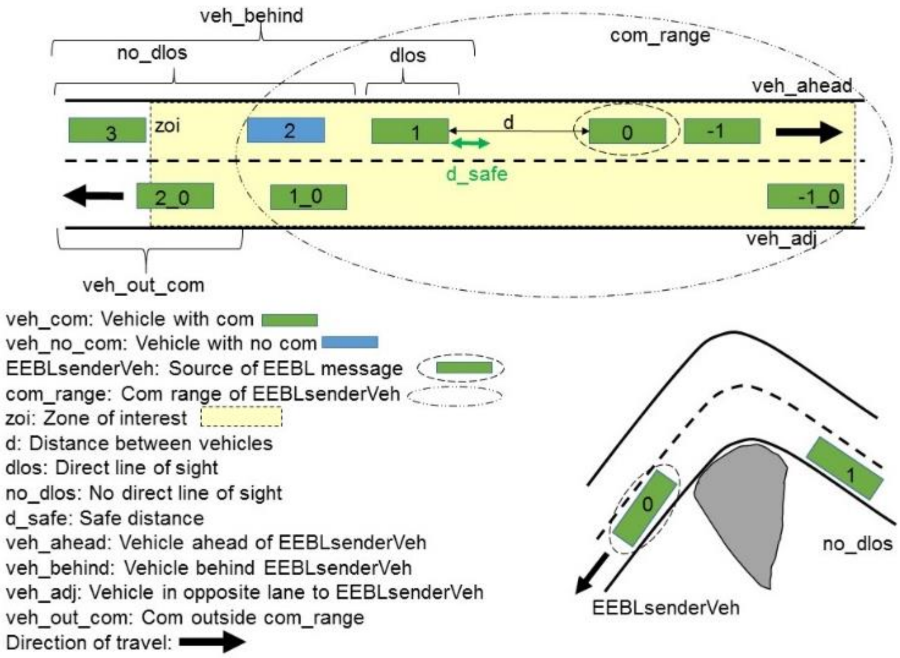


Figure 2 Illustrating EEBL

CACC

The ACC and CACC controllers implemented in this work are similar to that in [6]. To minimise potential issues with noise the derivative of the error was filtered by a median filter. Additional low pass filters were also implemented to use as optional set point filtering as well as error signal filtering. The set point filtering is used to smooth changes in acceleration of the lead vehicle. This filter is disabled when very high deceleration are required.

Vehicles are by default using ACC until they meet a leader. If the time gap between vehicles is large, the vehicles operate in ACC mode. When a vehicle is engaged in a platoon but still too far from the preceding vehicle, the controller switches mode to gap closing. This is implemented as an identical PD controller but with different gains.

The VISSIM implementation requires replacing throttle and brake control action with a desired acceleration command that the DLL will send to the VISSIM driver model. The latter will then interact with the VISSIM vehicle model to provide a realistic change in acceleration. The resulting acceleration may differ from the required acceleration depending on the vehicles dynamics modelled within each vehicle type.

Results

This Section presents the results of the simulation studies carried out in VISSIM. Individual vehicle trajectories are initially used to evaluate EEBL, flashing brake light and CACC in terms of vehicle and driver behaviour. The motorway simulation is then used to evaluate the impact of CACC on traffic.

To evaluate the benefits of EEBL, other braking systems were simulated and compared to the driver model used by the traffic simulator. The scenario involves vehicles travelling on the Gaydon test track at 60 km/h and separated by a 2 s interval. At time 30s the lead vehicle performs a hard braking manoeuvre. The Wiedemann99 model, used for the standard vehicle simulation, is observed to brake at the time necessary to prevent a collision. The braking intensity will depends on the model parameters. The model will however not allow collisions to occur, see Figure 3

. Using the selected set of driver model parameters the vehicle is required to perform very hard braking -7m.s-1. The flashing brake light reacts 19% faster as programmed. This earlier reaction means that the headway between the vehicles is larger at the time of each vehicle braking event. This makes the model brake less hard than for the Wiedemann99 model. The simulation of EEBL illustrates that the vehicle with direct line of sight of the braking event will start braking before the other vehicles due to the various systems latencies. It uses a similar model than the FBL model in terms of reaction time. The other vehicles without direct line of sights are braking at approximately the same time. In this simulation they braking after the first follower. This advance braking results in better time headway than non connected vehicles and therefore reduces the risk of collision. Note that whilst the assumed behaviour was successfully simulated, initial experiments on the driver simulator and on test track suggest that drivers may not actually brake as hard as they should if they do not have line of sight.

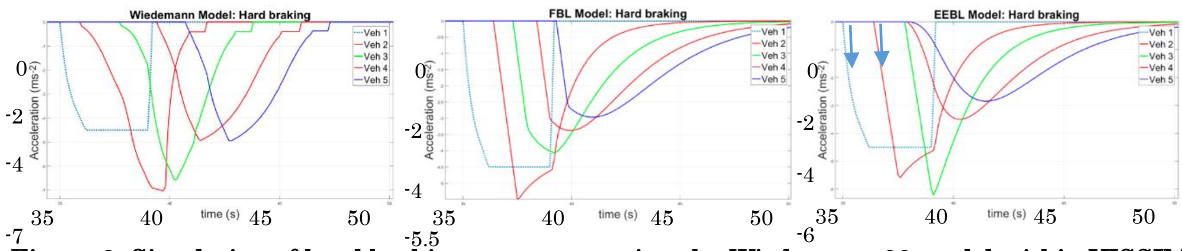


Figure 3: Simulation of hard braking maneuver using the Wiedemann 99 model within VISSIM, the flashing brake lights C++/DLL model and the EEBL C++/DLL

Similarly, CACC was first evaluated using vehicle trajectories. The lead vehicle follows an arbitrary drive cycles such as the NEDC or WLTP. The simulation illustrated in Figure 4 shows the behaviour of a platoon of vehicle involved in the NEDC. The time gap between each vehicle is between 0.6 and 0.64s except at the time where the vehicle decelerate and accelerate from a stand still position, when the set point filter is disabled. The images on the right in Figure 4 illustrate the relative location of the vehicles during the CACC manoeuvres with the lead vehicle (black or blue) operating in ACC mode and the following vehicles (green) operating in CACC. To evaluate the ability of vehicles to forms platoon independently, a larger of vehicles were simulated. The platoon length was set to 5. The lead vehicle operates in ACC mode and the next 4 vehicles in CACC mode. If the number of vehicles exceed 5, then a new platoon is formed. Figure 4 bottom right illustrates the creation of this new platoon with the new platoon leader being initially red switches to blue to engage in platooning. Having verified that the performance of the CACC algorithm was acceptable the next step was to evaluate the impact of CACC in a motorway environment. To ensure that results were realistic, the model was calibrated against measured data obtained from Highways England. The simulation were repeated 50 times for each time interval and the average value compared to the measurements. The GEH values for each data collection point is less than 5, therefore the model is suitable for the purpose of traffic simulation, see Table 1.

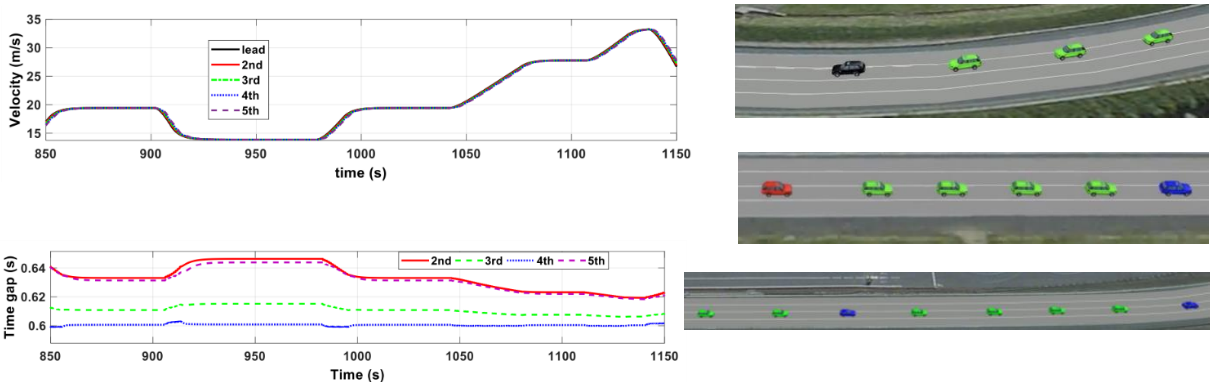
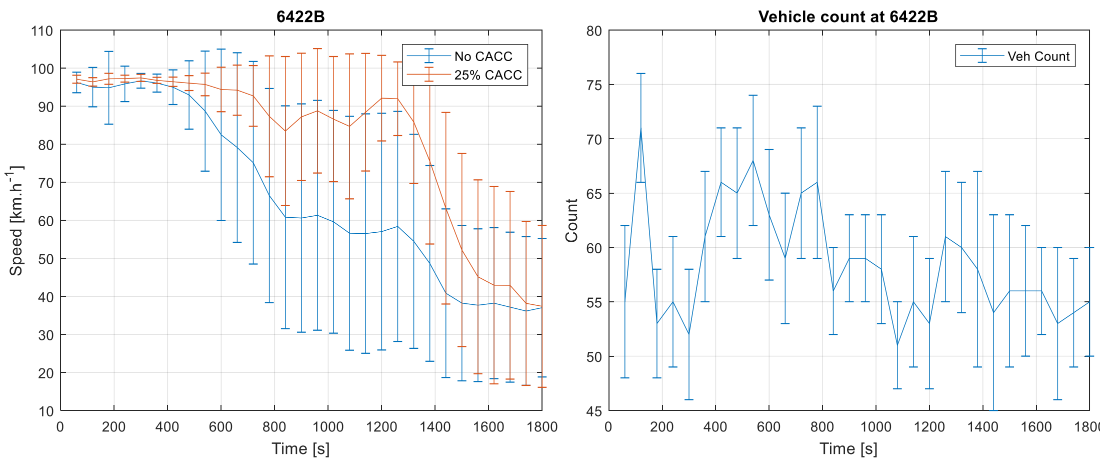


Figure 4 Performance of the CACC controller evaluated in terms of time gap and velocity profiles

Table 1 M42 model calibration given in terms of GEH

Location	6433B	6430L	6422M	6416B	6375B	6371B	6370L
GEH, 5:30 to 7:00	2.29	2.25	1.29	0.23	2.07	1.91	0.42
GEH, 11:30 to 13:00	1.32	0.39	4.45	0.76	2.89	1.57	2.37
GEH, 7:30 to 9:00	1.13	1.79	4.05	1.96	1.92	1.05	0.10



a) Comparison between 0% and 25% CACC **b) vehicle count (mean, +/- 1 standard deviation)**

Figure 5: Speed data 6422B

Three different CACC vehicle concentrations were evaluated: 0%, 100% as well as 25% which is the expected connected vehicle penetration rate according to [3]. In the latter case, it is assumed that cars (vehicle categories 1 and 2) will be equipped with CACC. Two data collection groups are considered. 6422B and 6416B which are located before and after the merging traffic from the slip on-ramp, see Figure 5. Vehicular speed data is collected at 60 seconds time interval. A total of 50 simulation runs with different random seed values is averaged at each time interval and plotted for 0% and 25% CACC. As expected the presence of CACC vehicles is found to delay the onset of congestion with a free flow speed maintained. Tables 2 and 3 show that for both 25% and 100% of CACC vehicles the travel time is reduced due to the increase vehicle speed and reduced queues in the network.

Table 2 Travel time results

Location	Distance Traveled (m)	Travel time results (s)		
		No CACC	25% CACC	100% CACC
6433B – 6416B	2200	128.52	111.45	85.29

Table 3 Speed variation and Queue length on the slip roads

Location	Mean speed ($km.h^{-1}$)			Standard deviation speed ($km.h^{-1}$)			Max Queue Length (m)		
CACC %	0	25	100	0	25	100	0	25	100
6422Ma	73.85	89.72	92.85	12.43	1.18	0.73	59.58	10.32	0
6422Mb	64.79	77.15	92.39	22.59	13.25	1.47	225.71	51.28	0

Conclusions

This paper has presented the simulation environment developed to evaluate connected vehicles. The paper confirms findings in the literature relative to the benefit of CACC in terms of improved journey time, reduced speed differences between vehicles and hence risks of accident. The EEBL simulation has shown that it is possible to adjust VISSIM driver models to overwrite some of the standard model behaviour whilst keeping desirable features of the built-in vehicle and driver models. All driver models DLL are available on demand (email o.haas@coventry.ac.uk)

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