CHALMERS
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Desktop Simulator for System Simulation

Master's thesis in Automotive Engineering

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Abstract

Simulation is today an important tool during the development and verification of new products in the automotive industry. Volvo Group has a Simulink-based simulation model of a powertrain, called GSP, which is used to simulate all the components of the powertrain. It can for instance be used to find the fuel consumption during different driving cases. GSP uses a virtual driver model that responds to a driving cycle and gives the powertrain model inputs by the throttle and brake pedal. Recently, a real-time version of GSP was connected to a driving simulator rig with the intent of putting a human driver in the loop. This connection enables the powertrain model to get real throttle and brake inputs by a driver sitting in the simulator rig.
The purpose of this thesis is to evaluate the driver model, improve the connection and investigate other possible benefits of connecting GSP to a driving simulator. This has been tested by letting five test drivers drive in the simulator under different conditions. To provide the drivers with different driver aids and with information normally found on a dashboard, a separate Simulink model has been developed. Two driver aid systems have been developed, one that shows the height profile of the upcoming road and one that shows the current operating point of the engine.
The test results show that the driver model provides results similar to those from a real driver, even though the real drivers input more fluctuating throttle signals. When using the driver aids, the wanted driving behaviour has been achieved. It has also been found that changes of parameters in GSP can be felt by the driver in the simulator. This makes the setup suitable for developing new systems including autonomous functions, and to a certain extent tuning powertrain parameters. Furthermore, the setup can be used to test driving situations that would be complicated to program the driver model to drive.

Key words: Desktop simulator, System simulation, Matlab, Simulink, Driver model, Driver in the loop, Fuel consumption

Contents

Preface

This Master's thesis has been carried out from January to June 2018 at the Strategic Development department at Volvo Group Powertrain Engineering with support from the division of Vehicle Engineering and Autonomous Systems at Chalmers University of Technology.

I would like to thank my supervisor at Volvo, Rickard Andersson, for his continuous and extensive support during the project and for always being available for answering questions. I also want to thank my examiner at Chalmers, Fredrik Bruzelius, for his great support and interest in the project. Furthermore, I would like to express my gratitude to the Strategic Development department for making the Master's thesis possible and letting me use their facilities and equipment. I am also grateful for Per Nordqvist's assistance during the beginning of the project for showing me how Drivesim works. Finally, I would like to thank the test drivers Erik, Jens, Klara, Lars and Marcus for the tests they did to provide me with data crucial for the project.

Göteborg, 2018-06-08

Johan Lindqvist

1 Introduction

The project is about integrating a powertrain simulation model with a driving simulator to assess the possibilities of putting a human driver in the loop and to evaluate the simulation model's built-in driver model. The project is carried out at the department of Strategic Development at Volvo Group GTT Powertrain Engineering. The details about the project are presented in the sub-sections below.

1.1 Background

There are many benefits of using simulations in the automotive industry. They can be used early in the development process, even before there are any available prototypes. The long-term cost for the simulations is usually also significantly lower than real-world testing with a prototype or finished model, also when doing changes to the test setup. Additional benefits are the possibilities to test systems that still are unsafe to test with real drivers in real cars, and that simulations can be done of events that seldom happen during normal driving or that are hard to replicate during testing. The environmental impact is also lower. The interest of using driving simulators when learning about eco-driving is also increasing, partly because of the possibility of setting up different scenarios in a safe and controlled environment (Scott, Knowles, Morris, & Kok, 2012; Beloufa, o.a., 2012). A study about eco-driving with trucks showed that an eco-driving campaign managed to decrease truck drivers' fuel usage with more than 5% per transported ton (Días-Ramires, o.a., 2017).
The testing and evaluation of the powertrain is usually done by using simulations, calculations and prototypes. The method of using driving simulators for evaluating powertrains is uncommon. However, a study was made with Porsche's driving simulator that showed the suitability of doing this (Baumgartner, Ronellenfitsch, Reuss, & Schramm, 2017). Small changes in the powertrain could be felt by the drivers which means that tasks such as choosing and tuning powertrain components could, at least to a certain extent, be conducted in a driving simulator.

1.2 Problem description

Volvo Group has a simulation model that is used to simulate the trucks' powertrains to estimate the performance, including the fuel consumption. The model is named *Global Simulation Platform* (GSP) and is implemented in Simulink. It consists of a virtual driver that drives a vehicle with specified parameters and powertrain parts along a defined driving cycle. The virtual driver has never been verified to mimic the behavior of a real human. A merge of GSP and a simulator-software has recently been done which enables GSP to get driver inputs from a real driver instead of the driver model. Therefore, the request from Volvo Group is to evaluate the new simulator set-up, to find the possibilities of putting a human driver in the loop and to evaluate the driver model with its limitations and benefits.

1.3 Purpose

The main purpose of the project is to investigate the possible benefits from integrating GSP with a driving simulator and to evaluate the driver model in GSP by comparing it to a real driver.

1.3.1 Evaluation of GSP's driver model

The driver model hasn't been compared with data from a driver in the loop before, thus the realism of the model's behaviour is unknown. The model will be compared to real drivers regarding the fuel consumption.

1.3.2 Benefits of combining GSP with a driving simulator

There could be additional benefits of combining GSP with a driving simulator except from evaluating the driver model. Tests will be done to find out if changes in GSP can be noticed and evaluated in the simulator, if so the system could be used to understand and use GSP's functions to a larger extent than before.

1.3.3 Usage of GSP as driver-assistance

Because GSP contains information about the vehicle and road, it should be possible to use GSP to feed the drivers with valuable information to reduce the fuel consumption. This will be tested by plotting suitable data for the drivers to give them a deeper understanding of the driving situation and by comparing the results with the tests done without additional information.

1.4 Delimitations

The following delimitations are defined to limit the extent of the project:

- Only fuel consumption and speed will be taken into account when comparing the behavior of the different drivers, not the number of gear shifts or sudden accelerations that could make it uncomfortable for a driver.
- Only one truck model with a specified powertrain will be considered during the tests.
- Only highway driving will be considered. City driving would also be of interest to test but is not available due to the currently limited access to other roads in Drivesim.

2 The existing connection

The previously developed simulator connection between Drivesim and GSP real-time is explained in this chapter.

2.1 Drivesim

Drivesim is the name of the simulator software used by Volvo Group in their truck simulators. It is Linux-based and is normally used for evaluating active safety-features, driver behavior and similar tasks. Its powertrain model is limited and produces much less useful information for the powertrain developers compared to the information from GSP. In the driveGSP setup explained in chapter 3, some changes are applied to Drivesim so that the speed isn't computed internally but instead received by GSP Real-time. The throttle and brake signals are sent to GSP Real-time. Since GSP only handles longitudinal dynamics, the lateral dynamics is kept within Drivesim.

2.2 GSP

GSP is a Simulink-based simulation model developed by Volvo Group. It uses a driver model and a driving cycle to compute powertrain data such as fuel consumption, gear shifts and also torques and rotational speeds at the different parts of the powertrain. The different parts of the simulation structure are presented in Figure 1.

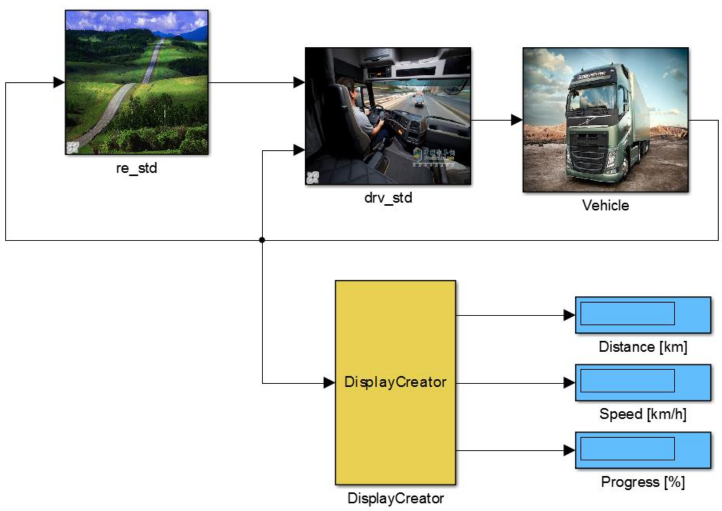

Figure 1 - The main structure of GSP.

2.2.1 Road and environment

The road-block reads information about the current road-profile. The road data contains distance and height but also temperature, air density etc.

2.2.2 Driver model

The driver model interprets the road data and replicates the behaviour of a real driver by sending out suitable throttle and brake signals to the powertrain in the vehicle block. The driver model can only see a short distance ahead, similar to a real driver. There is also a cruise control-system that can be turned on by the driver model if the simulation settings allow it.

2.2.3 Vehicle

The vehicle model consists of blocks for each component in the powertrain together with a block for the chassi. The engine gets a torque demand from the accelerator pedal in the driver model, but also from other parts of the powertrain that needs power to function properly. The power created from the engine in form of rotational speed and torque of the crank shaft flows through the powertrain. It gets slightly reduced between the components due to mechanical losses and by the components that requires power. When the power flow reaches the wheels, the friction force between the wheel and ground is created and sent to the chassi block where the acceleration of the chassi is calculated.

2.3 GSP Real-time

The GSP Real-time is based on GSP, but with a few changes. One block is added that takes care of the UDP communication with the other computers and syncs the simulation time with Drivesim which makes the simulations run in real-time. Some changes are also made in the driver model block to connect the external pedal signals to the model. The name *Real-time* does not indicate that it is a so-called real-time computer, only that it tries to run the simulation in synchronization with Drivesim.

2.4 The connection between Drivesim and GSP real-time

Drivesim and GSP real-time communicate via the network connection by a protocol called UDP that is supported by Simulink. The throttle and brake input from the drivers are sent from Drivesim to GSP real-time together with simulation time. GSP real-time calculates the longitudinal motion and sends the speed back to Drivesim that shows the motion for the driver.

3 DriveGSP

The main goals of the project are to evaluate the driver model in GSP and to find possible benefits of connecting GSP to the simulator. Since the previously developed Drivesim and GSP Real-time have been connected, GSP can be run with a so-called Driver-in-the-Loop. Then test data from the driver model can be compared with corresponding test data from simulations with a real driver. To provide a realistic driving experience for the driver, another program needs to be developed to be used as a dashboard to provide the driver with important data. This program called TelDisp, short for Telemetry Display, is developed during the project and is presented in the next subchapter. The system of Drivesim, GSP real-time and TelDisp are together called driveGSP, see Figure 2.

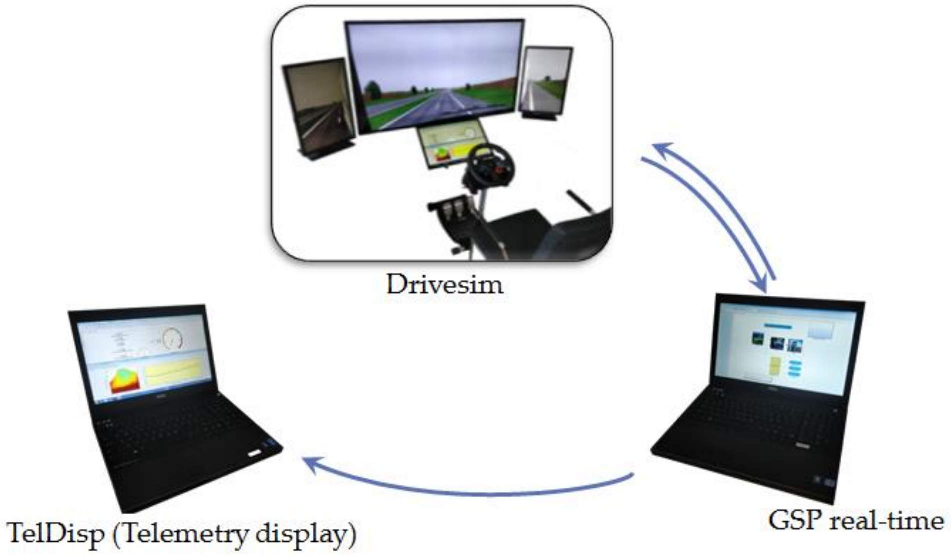

Figure 2 - The main components of driveGSP. The arrows symbolize the data exchange.

3.1 TelDisp

TelDisp is created in Simulink. The main reasons to have it on a separate computer is because it requires a newer version of Matlab than what GSP Real-time currently is running on, and to make sure that enough computer power is available for GSP Real-time. It has been developed during the project and has several functions. The most important one is to show the current speed to the driver, since no visual Speedometer is available in Drivesim. This is included in the part of TelDisp called Dashboard. There is also a road plot and an engine map plot available, and all the functions can be displayed together on the same screen for the driver to analyze. The plots are updated several times per second so that the driver can get immediate response from changes in throttle or brake. The different parts of TelDisp are presented in the sub-sections below.

3.1.1 Dashboard

The dashboard consists of 5 different displays, see Figure 3. The most important display shows the speed and the recommended speed interval. There is also a dial for the current slope since the possibility to perceive the gradient from Drivesim is limited. This is mainly due to the limited immersiveness from the screens since they only fill a part of the entire field of vision, and the lack of motion feedback. To assure that the different tests are done in a similar amount of time, a recommended speed for the driver is calculated by comparing the current test with the data from the driver model's test and dividing the remaining distance with the remaining time. Then the recommended speed for the remaining part of the test can be presented for the driver. The test progress and the truck current fuel are also shown, both collected from GSP.

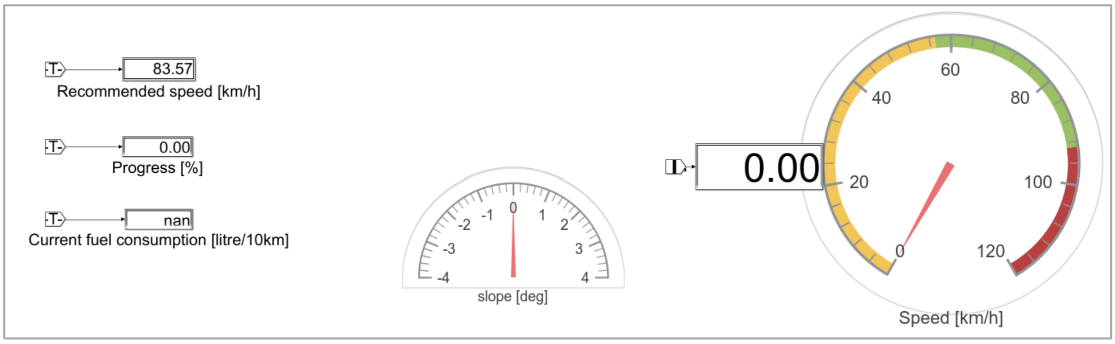

Figure 3 - The layout of the dashboard

3.1.2 Road plot

The road plot that can be seen in Figure 4 presents both the vertical road profile for the upcoming road and the estimated speeds along the road. The road profile is retrieved from the road data in GSP. The speeds are calculated based on the truck specifications and speed but also on the current power to the driven wheels. Since the power changes with changed speed for a constant torque, the speeds are found by iterating with a new power output for each distance interval.

Figure 4 - Road plot that shows the height profile of the upcoming road. The numbers along the road shows the speed that the truck is estimated to have at those points. The yellow, green and red colour fields indicate if the speed will be too slow or fast.

The main forces on a truck come from engine, brakes, rolling resistance, aerodynamic drag and gravity. Because of this, the estimated future speeds are found by calculating the current potential energy, adding the assumed propelling energy on the wheels from the powertrain and then subtracting energy due to rolling and air resistance together with energy taken from the height difference. The remaining kinetic energy can be used to find the new speed. The procedure is shown in more detail by Equation 1 to Equation 8.

$$E_{kinetic,1} = \frac{mv_1^{\ 2}}{2} \tag{1}$$

$$E_{potential} = mg\left(h_2 - h_1\right) \tag{2}$$

$$E_{drag} = F_{drag} d = \frac{1}{2} \rho C_d A v_1^2 d \tag{3}$$

$$E_{roll} = F_{roll} d = \mu_{roll} mgd \tag{4}$$

$$E_{prop} = P_{prop} \frac{d}{v_1} = T_{prop} \omega_{prop,1} \frac{d}{v_1} \tag{5}$$

$$E_{kinetic,2} = E_{kinetic,1} + E_{prop} - E_{potential} - E_{drag} - E_{roll} \tag{6}$$

$$v_2 = \sqrt{\frac{2}{m} E_{kinetic,2}} \tag{7}$$

$$\omega_{prop,2} = \omega_{prop,0} \frac{v_2}{v_0} \tag{8}$$

When v_2 is found, all the equations are repeated with v_2, h_2 and ω_2 as the new v_1, h_1 and ω_1. v_0 and $\omega_{prop,0}$ are the current values from the truck.

By knowing the upcoming road profile and estimated truck speed, the driver should be able to make better decisions about when to accelerate or brake. One example is to release the throttle before the top of a hill if the speed will be sufficient to make the truck roll over the top and speed up again during the following downhill driving. Otherwise the truck would burn more fuel on the way up and the energy would be wasted because of the need for extra braking downhill. Another example could be to save some extra speed after a downhill if the road profile shows that the truck is approaching an uphill section.

3.1.3 Engine map

The engine speed and torque are sent from GSP Real-time to TelDisp, and this makes it possible to plot the engine's current operation point in an so-called engine map as seen in Figure 5. The engine runs more efficiently at high loads and medium speeds and this can be utilized by the driver. Switching between no power and the high efficiency operation points could make the engine use less fuel than when running steadily at a low efficiency.

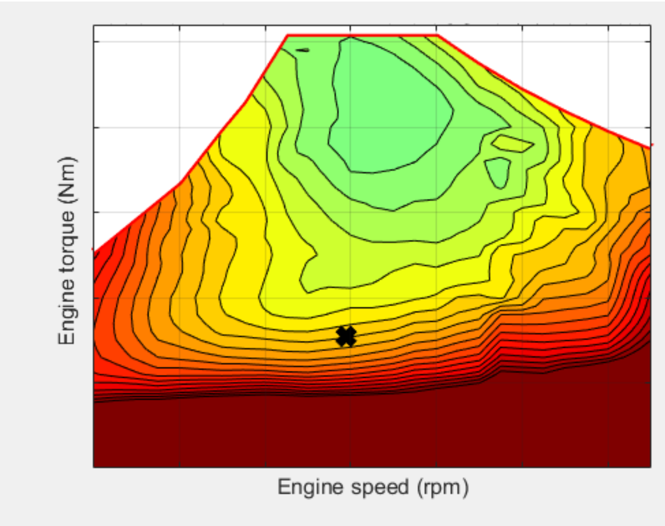

Figure 5 - Engine map where the engine's current operating point is shown with the black cross. The green area is where the engine runs most efficiently.

3.2 Simulator hardware setup

The test setup shown in Figure 6 partly consists of a 55 inch Full HD TV that is connected to the Drivesim computer and shows the main view through the truck's windscreen. The TV has one computer screen on each side that shows the rear-view mirror projections. Below the TV is a computer screen that is connected to the TelDisp computer and shows the dashboard for the driver. The driver sits on a chair in front of the TV behind a steering wheel and pedals mounted on a stand.

Figure 6 - Simulator setup

As shown in Figure 7, the TV fills roughly 60 degrees of the driver's field of view. Despite this, the field of view in Drivesim is set to 80 degrees to show more of what the driver would see in a real truck where the actual field of view is much wider, otherwise it would be harder for them to get a realistic overview of the road situation. It has been found that the relation between the actual field of view and the displayed field of view has a big impact on the driver's perceived driving speed (Colombet, Damien, Mérienne, & Kemeny, 2010). This is not further taken into account in this project; the focus is only on presenting a reasonable view for the drivers.

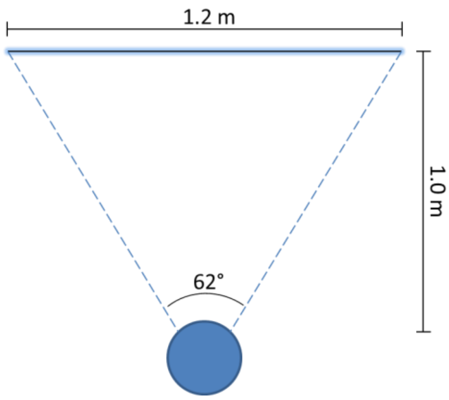

Figure 7 - Field of view in the simulator. The blue line represents the screen and the blue circle represents the driver.

Neither the TV nor the chair can be adjusted in height; this makes different drivers experience different gradients when they are driving. If the horizon on the TV is above the height of the eyes when the truck is on level ground it still seems like the truck is going uphill, and vice versa. Because of this, each driver test is started with tuning the angle of the main view in Drivesim. By rotating the view up or down, the horizon moves accordingly until the driver feels that the truck's actual heading is aligned with the visual heading on the TV.

3.3 The Truck

The truck model simulated in the project is a Volvo FH with a 500 horsepower engine and a weight of 40 tonnes. The set highway cruising speed for the truck is 85 km/h. Since this speed is used by the driver model, it will also be used by the test drivers during the project.

3.4 The Track

The simulations are done on a highway track called BLB (Borås-Landvetter-Borås), which corresponds to driving from Borås to Landvetter and back again. The entire track is almost 90 kilometres and since that would result in long driving times, a 40 kilometres part of the track is used. It takes about 29 minutes to drive when following the cruising speed and starting from stand-still. This specific part is called BLB-40km in the report. The height profile is shown in Figure 8.

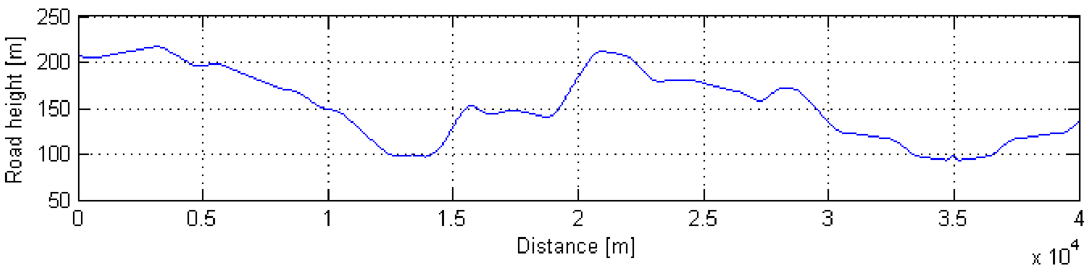

Figure 8 - The height profile of the test track taken from BLB.

The graphical representation of the track in Drivesim is not connected to the track coordinates but created separately. This means that changing the driving cycle in DriveGSP would require the development of new graphics. Since this is outside of the scope of the project, only the BLB track from Drivesim is used and its coordinates are imported to GSP.

The shape of the road in Drivesim should be identical to the real road, but the surroundings are not. All features such as highway ramps, bridges and water streams have been replaced by simple textures of surrounding meadows, houses and forests. This limits the test drivers' chances of recognizing where on the road they are even if they have been driving there before. It also removes the impact that ramps and other objects can have on the driver behaviour. Figure 9 shows an example of the graphical surroundings.


Figure 9 - Screenshot of the graphics in Drivesim

3.5 Traffic

Drivesim supports 150 vehicles driving simultaneously during a simulation. Since the track is 40 kilometres long, the traffic is distributed evenly to interact with the driver during the entire test. One row of 30 slow vehicles is placed in the right-hand lane, with 1300 metres between each vehicle. Their speed is 72 km/h and they start when the driver is within 1000 metres from them. Another row of 110 vehicles is placed in the overtaking lane behind the drivers' start point over a total distance of 7500 metres. Their speed is 110 km/h. No traffic changes lane. Since the drivers should keep an approximate speed of 85 km/h, the slow vehicle will force the drivers to overtake while watching out for the vehicles in the overtaking lane. The traffic setup is not based on any real traffic situation, it is only a simplified example of how traffic could behave.

3.6 Ghost cars

Drivesim supports so-called ghost cars, which is cars that drives a pre-defined driving cycle. This means that an earlier test can be shown by assigning the time and speed data to a car model in Drivesim. The ghost cars can be used for different purposes, for instance to see if the current driver is driving slower or faster than a previous test.

3.7 Test drivers

There are five test drivers doing the tests in the simulator during the project. All of them are engineers working at Volvo who volunteered to do it. The only criterion was that they should have a truck driver´s licence and some experience of truck driving. This is to get test data that is typical to the behaviour of a truck driver, which might differ from a car driver. The simulator setup doesn't require anything but steering, brake and throttle so it is not the technical knowledge that is required from the test drivers, only the truck driving strategy.

Because of the relatively low number of test drivers, no statistical analysis will be done on the test results; there will instead be focus on individual results and possible tendencies.

4 Test method

All the tests done to evaluate GSP and its driver model are presented in this chapter. The test drivers are engineers from Volvo who have truck driver's licenses, in hope that their truck driving experience make the test results more authentic compared to a driver without a license. All the tests that are done on the full-length test track are intended to be done in the same amount of time with a small margin of error. If the driving times for the same driving distance are too varying, the fuel consumptions would not be fair to compare since the main wish from trucking companies is to reach the same destination in a similar (or shorter) time with reduced fuel consumption.

4.1 driveGSP

The first part of the tests is to verify that driveGSP produces the same results as GSP when the driver model is used. This means that any test with a driver in driveGSP would be comparable to all previous tests in GSP with the same settings. If the results are different, some error has been made when adapting GSP to driveGSP. This test is done by running the same driving cycle with the driver model in both GSP and driveGSP and comparing the results.

4.2 Driver model

The driver model is evaluated by comparing it with the test results from real drivers. Except from a standard test, the drivers also run a test with traffic simulated by Drivesim to show how this could influence the driving behaviour and fuel consumption. Traffic cannot currently be simulated in GSP so the drive model can always drive smoothly at its preferred speed, which could lead to misguiding results that the truck would use less fuel on the road than it actually does during normal driving.

4.3 GSP as driver aid

The road plot and engine map described in the previous chapter are presented separately for the drivers during two tests. If they help the driver to reduce the fuel consumption, it could indicate that the information in GSP can be useful when developing driver aids.

4.4 Evaluating functions in GSP

The so-called pedal mappings will be changed and tested in driveGSP. The pedal mapping is the relation between the pedal travel and the outputted signal to the brakes or engine. If the changes can be noticed by the drivers, driveGSP could be a suitable way of evaluating GSP's different functions. Since the possible acceleration of the relatively heavy truck is much lower than the deceleration when braking, focus will be only on the braking pedal since those changes are easier to notice.

The pedal sensitivity will be tested by letting the drivers follow a so-called ghost car for roughly 5 minutes. The ghost car will have a varying speed, and the drivers' task is to try to follow the ghost car with a constant distance. In that way the difference between the two pedal mappings can be analysed.

The original and the changed pedal mapping are shown in Figure 10. The idea behind the changed mapping is that it should be easier for the driver to use since it is less sensitive because of the usage of the entire pedal travel. The original pedal mapping only uses 50% of the travel, from when the pedal is pushed down 20% to the upper limit of 70%.

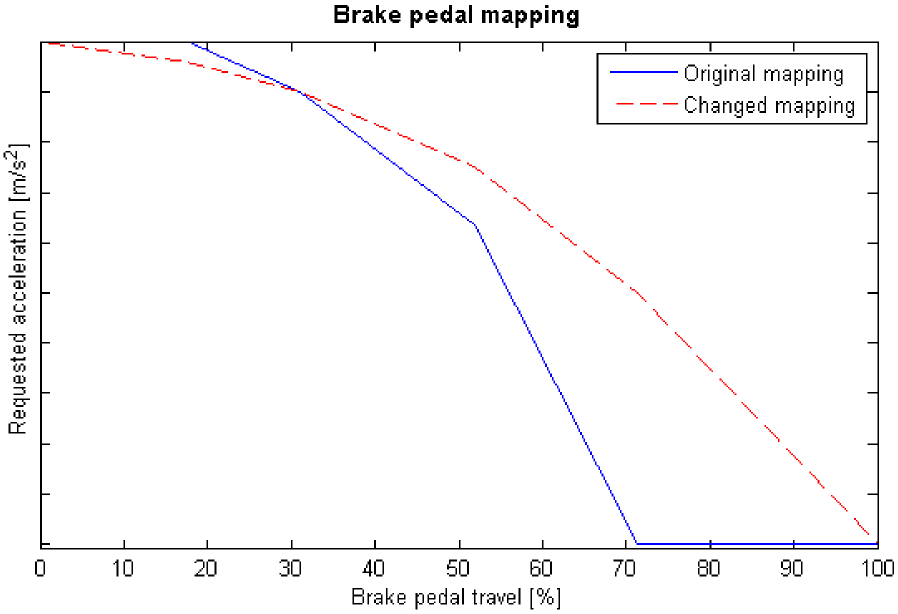

Figure 10 - Brake pedal mapping

4.5 Test schedule

The tests with the drivers follow the schedule presented in Table 1. The test schedule is started with the tuning of the main camera angle. Since none of the drivers have tested driveGSP before, the test schedule is then continued with five minutes of introduction where the drivers can get a better understanding of how the truck behaves and how the dashboard works.

Table 1 - Time plan for driver tests

Time	Task
5 min	Presenting driveGSP and the tasks for the driver
5 min	Tune camera settings
5 min	Driving introduction
30 min	Normal test (Benchmark test to compare with driver model)
30 min	Test with traffic
30 min	Test with road profile
30 min	Test with engine map
10 min	Test with pedal mapping

5 Results

A summary of all driver tests is presented in Table 2. The RMS value is calculated from the recommended speed of 85 km/h from the moment when the drivers first reach 79.2 km/h (22 m/s). It visualizes the variation of speed during the test. The added energy is the energy out from the differential, all the losses in the power flow from the engine to the differential is therefore taken into account. The same power value is divided by the power flow from the used fuel to find the engine-to-wheel efficiency. The total braking energy is found with the use of the brake torque and wheel speed.

Table 2 - Test results from the tests with real drivers. Not all drivers had the time to do all tests, hence the empty fields.

Scenario		Driver 1	Driver 2	Driver 3	Driver 4	Driver 5
Normal	Time	1728.0	1755.1	1728.7	1733.5	1735.7
	RMS	6.85	8.32	8.29	8.14	7.42
	Fuel [kg]	9.599	10.133	9.663	10.250	9.303
	Added energy [MJ]	150.58	158.04	147.44	159.84	139.95
	Braking energy [MJ]	25.34	35.99	21.92	36.05	16.87
	Efficiency	0.366	0.364	0.356	0.364	0.351
Traffic	Time	1769.8		1749.1	1754.6	
	RMS	8.11		9.04	10.17	
	Fuel [kg]	11.504		11.178	13.104	
	Added energy [MJ]	184.19		177.24	210.22	
	Braking energy [MJ]	64.16		54.92	86.53	
	Efficiency	0.373		0.370	0.374	
Road plot	Time	1728.8	1760	1741.9	1739.7	1748.5
	RMS	5.41	10.29	6.43	8.16	7.03
	Fuel [kg]	8.949	8.3857	9.2006	8.7539	8.7102
	Added energy [MJ]	136.95	130.39	137.74	131.34	129.37
	Braking energy [MJ]	14.58	7.49	13.91	8.93	8.83
	Efficiency	0.357	0.363	0.349	0.350	0.346
Engine map	Time	1723.4		1718.1	1714	1739.6
	RMS	7.00		7.76	8.63	7.28
	Fuel [kg]	9.783		9.801	9.7975	8.8319
	Added energy [MJ]	153.81		149.23	151.37	135.41
	Braking energy [MJ]	29.88		25.82	25.51	12.86
	Efficiency	0.367		0.355	0.360	0.357
Brake mapping 1	RMS	1.11	1.23	1.05	0.82	
	Fuel [kg]	2.623	3.080	2.498	2.972	
	Added energy [MJ]	43.14	51.22	39.82	48.80	
	Braking energy [MJ]	28.21	36.38	25.10	34.08	
	Efficiency	0.383	0.388	0.372	0.383	
Brake mapping 2	RMS	0.66	0.45	0.64	0.54	
	Fuel [kg]	2.633	2.570	2.378	2.461	
	Added energy [MJ]	41.3	39.2	36.5	37.6	
	Braking energy [MJ]	26.4	24.8	21.8	22.9	
	Efficiency	0.366	0.355	0.358	0.357	

The results from the different tests both with and without drivers are presented more thoroughly in the following sub-chapters.

5.1 driveGSP

When the driver model with cruise control switched on is simulated with both GSP and driveGSP on BLB-40km, the results are very close to identical as seen in Table 3.

Table 3 - Comparison between GSP and driveGSP

Scenario		GSP (with driver model and CC)	driveGSP (with driver model and CC)
Normal	Time	1720.5	1718.5
	RMS	6.99	6.99
	Fuel [kg]	9.027	9.026
	Added energy [MJ]	131.60	131.60
	Braking energy [MJ]	5.86	5.86
	Efficiency	0.340	0.340

The difference in time and fuel comes from the first seconds of the simulation, where GSP is idling for about 2 seconds more than driveGSP before the truck starts to move forward. This leads to 0.001 kg more of fuel consumption which is visualized in Figure 11. The idling is shown by the linear part in the second plot, followed by the significant increase in fuel consumption when the acceleration starts.

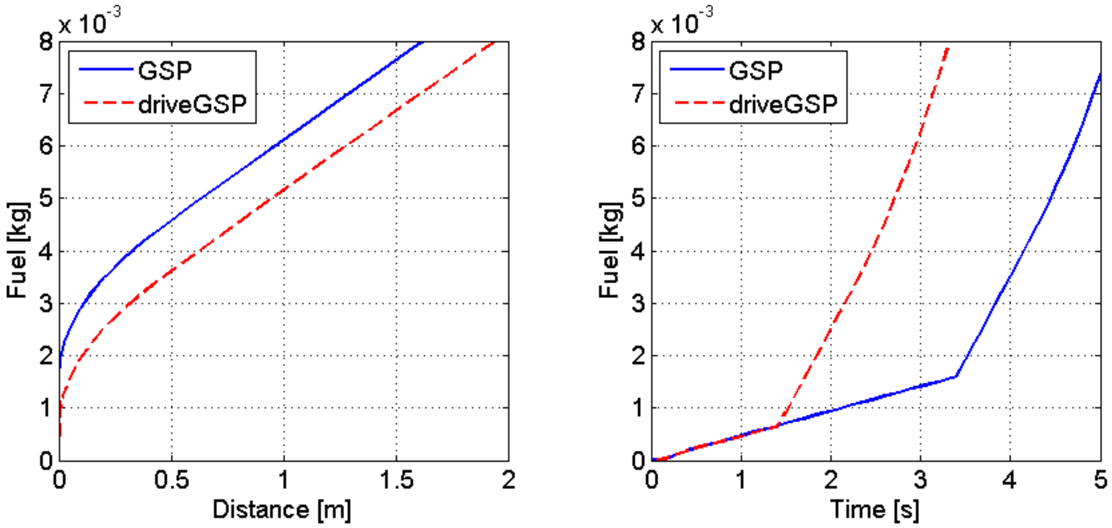

Figure 11 - Comparison between GSP and driveGSP during the first seconds of the simulations

5.2 Driver model

Table 4 - Comparison between the driver model and the test drivers shows the same data as the first plot in Table 2 but with the driver model tests included.

Table 4 - Comparison between the driver model and the test drivers in driveGSP

Scenario		Driver model with CC	Driver model	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5
Normal	Time	1718.5	1722.8	1728.0	1755.1	1728.7	1733.5	1735.7
	RMS	6.99	6.77	6.85	8.32	8.29	8.14	7.42
	Fuel [kg]	9.026	9.122	9.599	10.133	9.663	10.250	9.303
	Added energy [MJ]	131.60	130.11	150.58	158.04	147.44	159.84	139.95
	Braking energy [MJ]	5.86	4.82	25.34	35.99	21.92	36.05	16.87
	Efficiency	0.340	0.333	0.366	0.364	0.356	0.364	0.351

There is a big difference between the different drivers, and no one could match the lower fuel consumption of the driver model. The added energy at the wheels is higher for the drivers, partly because of the higher amount of energy that is lost by the brakes. However, by looking into the data from Driver 5 that is plotted against the driver model in Figure 12, it becomes clear that the driver is consuming as much fuel as the driver model except during one period after almost 5 kilometres driven. The driver braked harder than intended which reduced the speed to 7km/h below the recommended speed. Additional fuel was needed when regaining that speed which made the driver fall behind the driver model in terms of fuel consumption. But as seen in the second plot, the fuel difference remains almost constant after that. That braking is also the reason for 8 of the 17 seconds that Driver 5 drove slower than the driver model.

The biggest difference between the drivel model and Driver 5 is the use of the accelerator. The driver’s movements are much more fluctuating.This leads to fluctuations in speed for the driver that can be seen in plot 3 and in the higher RMS-value of 7.44 compared to the driver model’s value of 6.99. However, this different throttle behavior makes the engine run more efficiently, the engine-to-wheel efficiency is 35.1% instead of 33.3%.

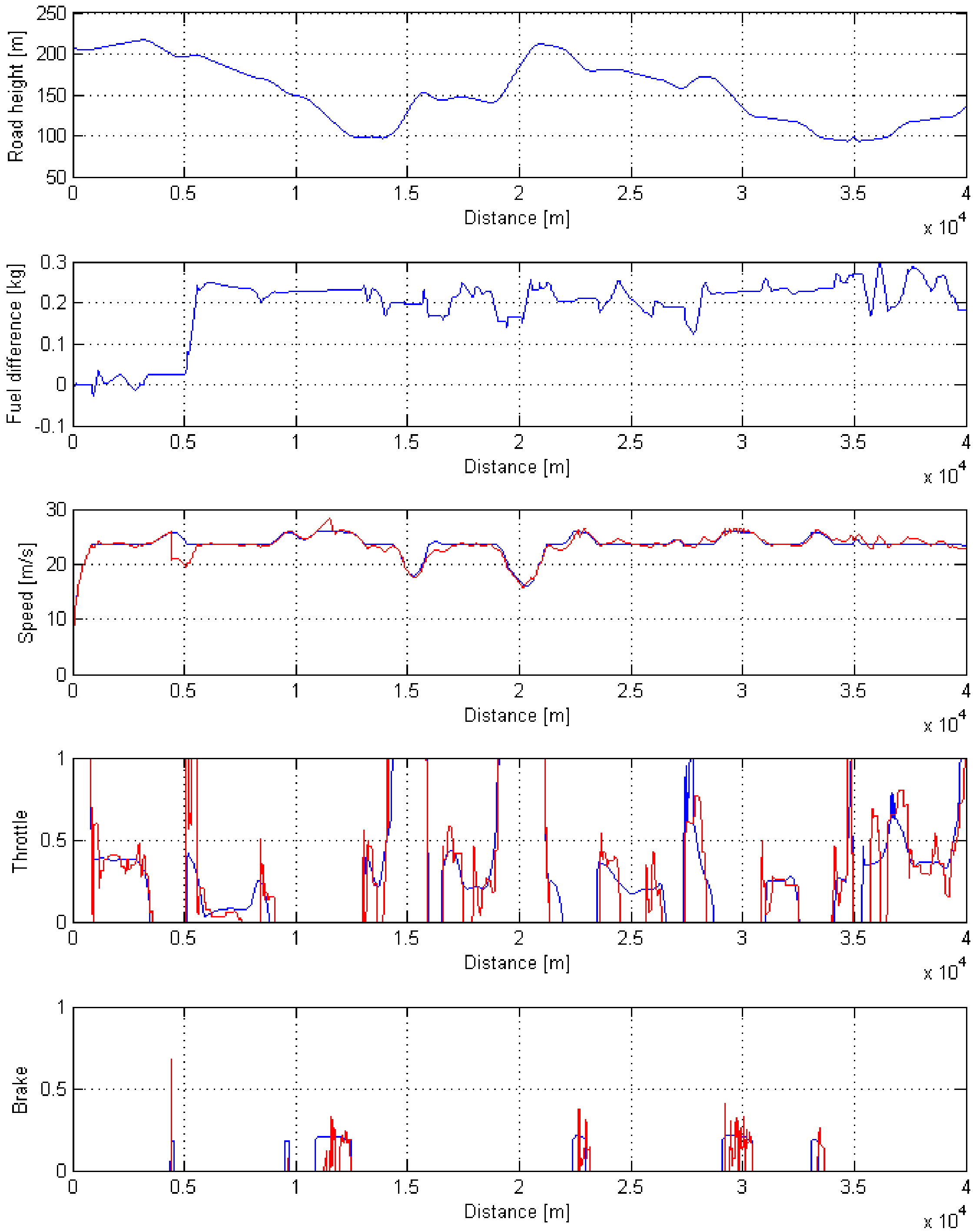

Figure 12 - Driver model vs. Driver 5. The Driver model is plotted with the blue lines, Driver 5 with the red lines.

Table 2 also shows the impact that traffic can have on the fuel consumption and behavior. The RMS-value increases significantly for all drivers that did the traffic test. This indicates that the speed fluctuated to a higher degree than during the normal test due to the need for braking when catching up with the slow vehicles if there is vehicles in the fast lane. This driving behavior increases the braking energy and therefore also the added energy needed to drive along the road, hence the increase in fuel consumption of roughly 20, 16 and 28 percent for the three drivers. This together with the higher use of the brake and accelerator pedals are shown in Figure 13, where the data for Driver 1 with and without traffic is plotted. The speed changes are also clearly visible.

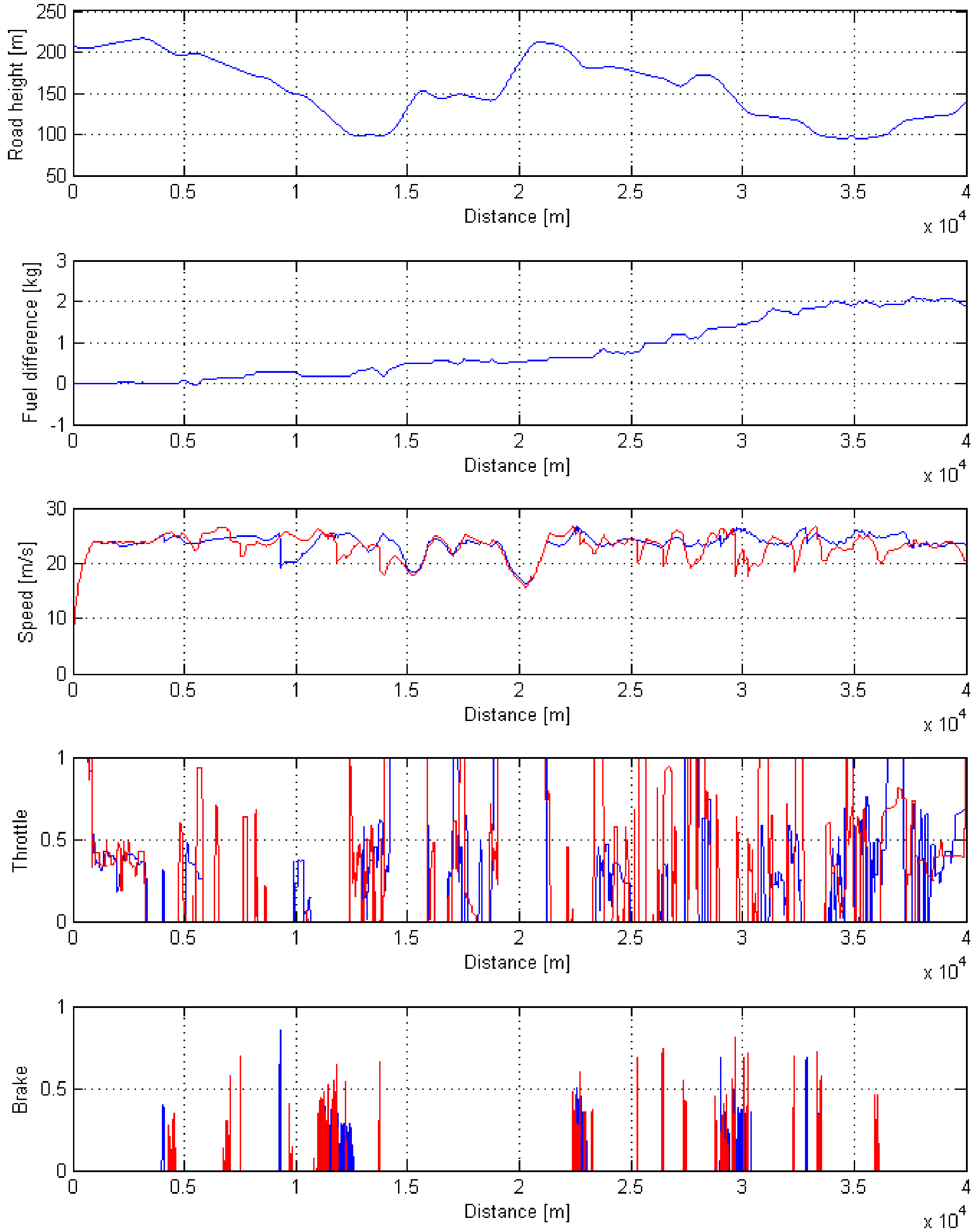

Figure 13 – Driver 1 with and without traffic. The original simulation without traffic is plotted with the blue lines, the red lines shows the simulation with traffic.

5.3 GSP as driver aid

The two functions that are implemented as possible driver aids are the engine map and the road plot. They are presented in the subchapters below.

5.3.1 Road plot

As shown in Table 2, all test drivers needed less fuel for the test with the road plot compared to the original test but still keeping almost the same average speed. Since Driver 5 had the best original test, those results are compared with the road plot test to see how the lower fuel consumption is possible. Some of the improvement comes from the unnecessary breaking in the original test as shown in 5.2, but also because of smarter decisions during the driving. One example is after 27 kilometres when the driver approaches an uphill, see Figure 14. During the first part of the uphill, the accelerator pedal is pressed down more than during the original test to build up speed before the steeper part of the hill. But when the speed is high enough, the driver reduces the throttle significantly to coast over the crest. Since the road plot shows the road 3 kilometres forward, the driver can see the long downhill after the crest and understand that the truck will regain speed without any extra throttle. The throttle signal in the figure is slightly misleading since it shows the driver's input and not the actual throttle. The pedal only uses roughly 80% of the total travel and the output is also exponential to the pedal input, which means that the difference between the two tests is bigger that it looks like in the plot. This driver behaviour resulted in about 50 grams of fuel savings.

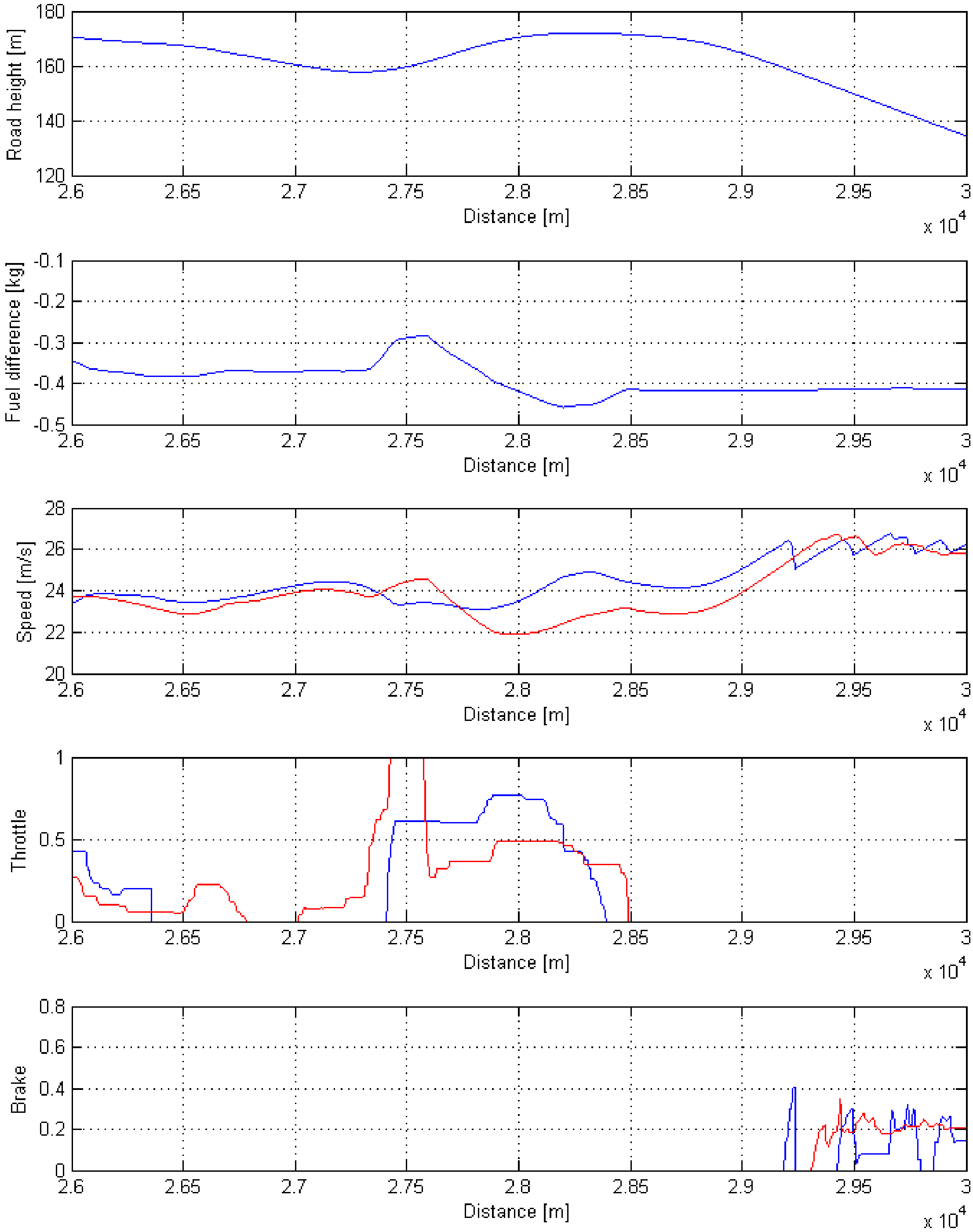

Figure 14 – Example of Driver 5's fuel-saving driving behaviour with road plot.

Another effect of the road plot can be seen in Figure 15. The driver is approaching a long uphill and manages to build up speed to enter the hill with roughly 2.5 m/s (9 km/h) more speed. This makes the driver being able to drive past the hill with higher overall speed, and with a reduced number of downshifts which reduces the fuel consumption and compensates for the fuel usage during the initial boost.

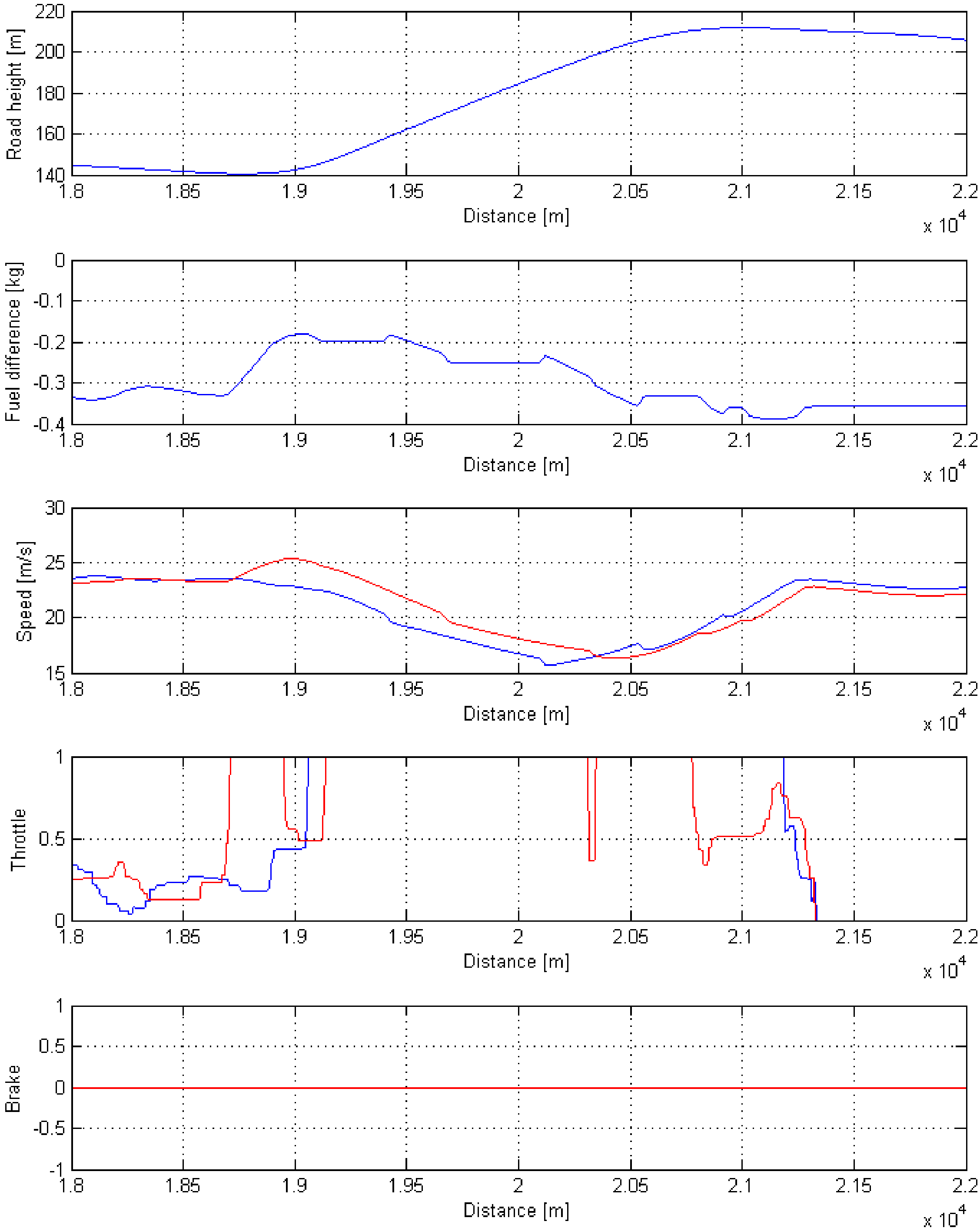

Figure 15 - Example of Driver 5's uphill driving with road plot.

5.3.2 Engine map

The tests with the engine map had varying results. Driver 1 and Driver 3 raised their fuel consumption, while Driver 4 and Driver 5 reduced it. However, the engine efficiency for Driver 4 was reduced which implies that the engine map didn't work as intended. Only Driver 5 managed to improve the efficiency effectively, from 0.351 to 0.357. Figure 16 shows a summary of all the engine's operating points for Driver 3. There it can be seen that the strategy works, the engine runs more in the efficient zone compared to the original test. The same behaviour can be seen for all drivers.

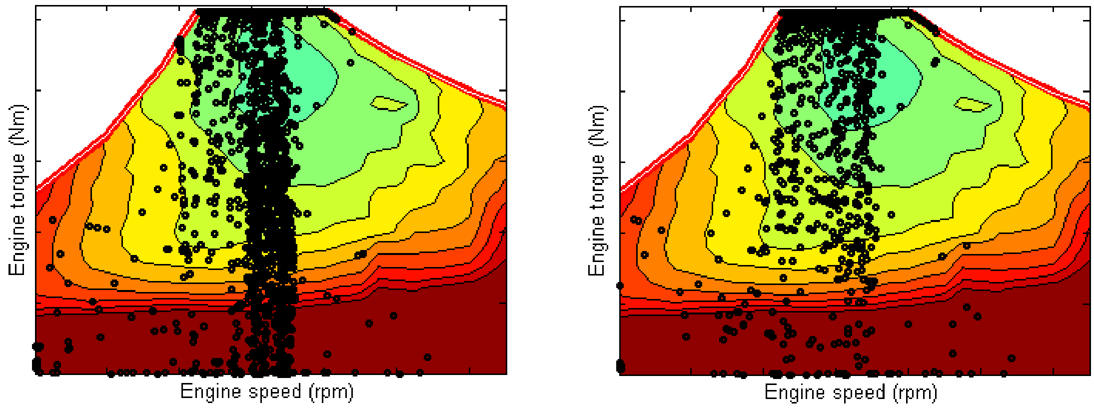

Figure 16 - The engine's operating points for the original test and the engine map test for Driver 3

By plotting the engine efficiency for the entire test, it becomes clear that it takes time for the engine to reach full efficiency when throttle is applied, as shown in Figure 17 for a few seconds of the test. Almost four seconds of fuel flow is needed before the efficiency is maximized. Note that the efficiency in the following figures is for the engine, not for the entire powertrain as presented before.

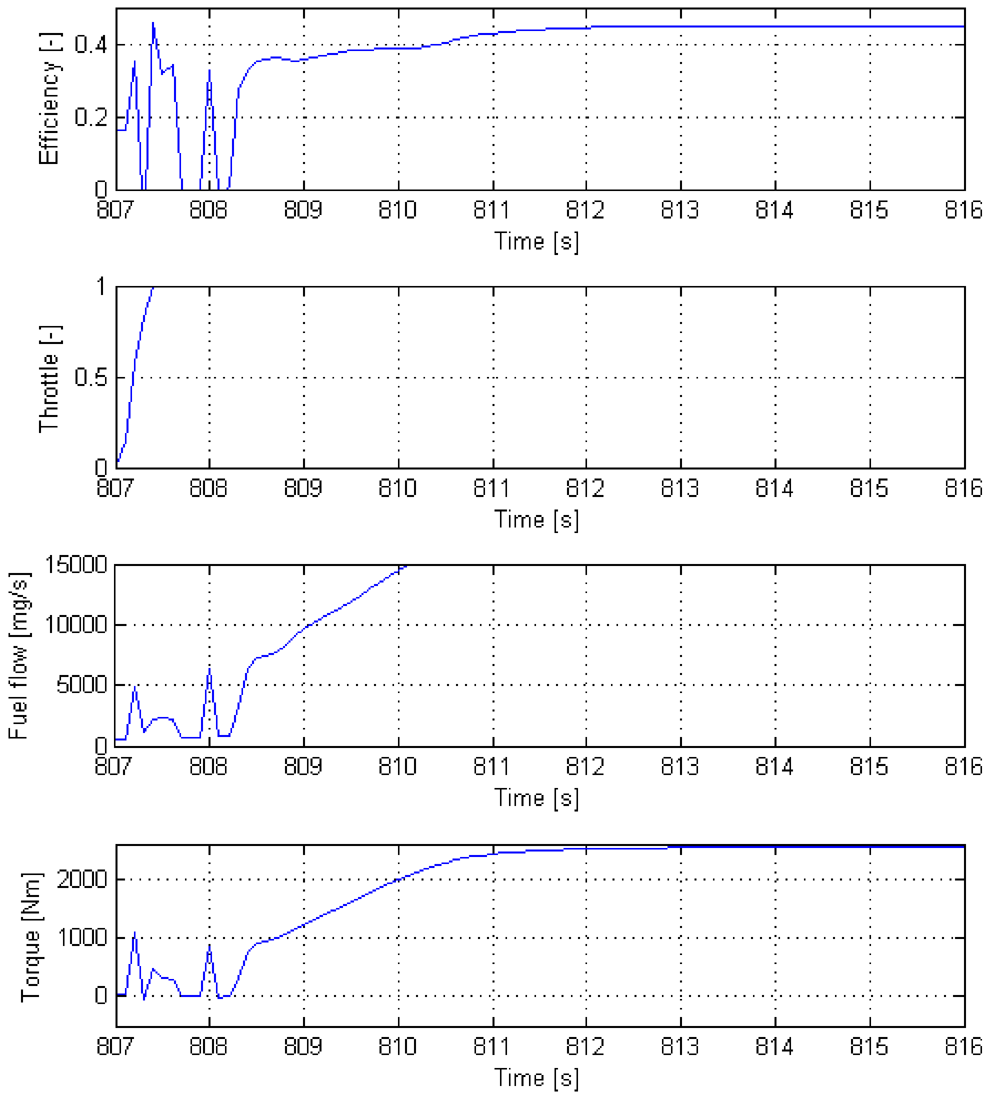

Figure 17 - Efficiency development after throttle input

As a further investigation of this, driver models with two different driving strategies were developed. The first one uses constant throttle to keep a speed of 85 km/h, the other model is switching between using the operating point with highest efficiency to accelerate up to 90 km/h, and coasting without engine torque down to 80 km/h without any throttle. Both were tested on level ground to minimize differences between the tests due to changed behaviour on the slopes. A part of the data is plotted in Figure 18. The same phenomena can be seen in the varying-speed test, where it takes time for the engine to reach maximal efficiency after the fuel flow starts. The total efficiency for the constant speed test was 0.421, while it was 0.417 for the varying-speed test. Another observation is the behaviour of the fuel flow and the torque for the varying-speed test. When the throttle is released, the powertrain sometimes disconnects the clutch and sometimes not. When the clutch is disconnected, the engine needs some fuel to keep running, but there is no braking torque affecting the wheels. When the clutch is left connected, the fuel flow stops, but the truck gets slowed down by the engine and therefore reaches 80 km/h faster.

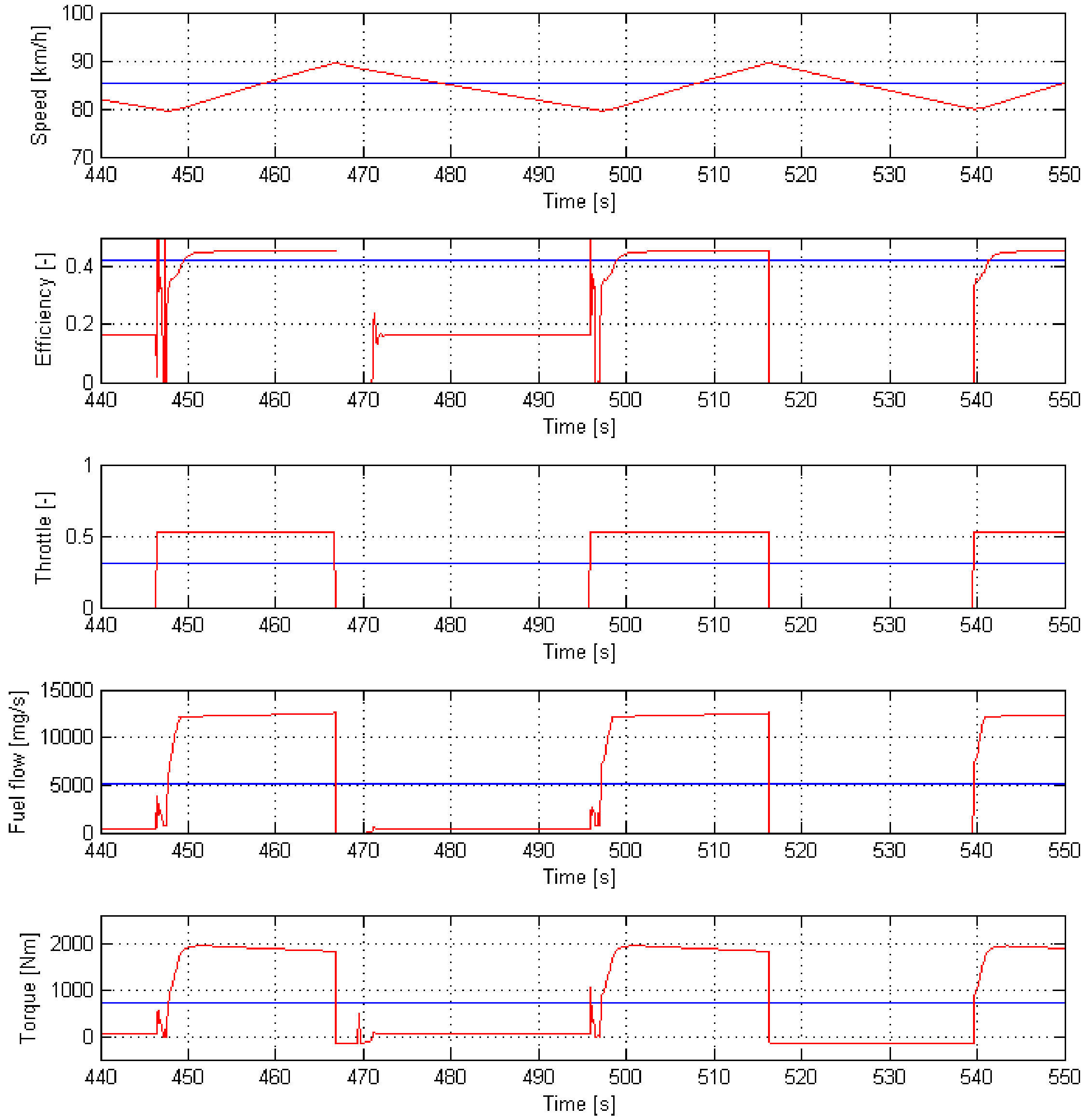

Figure 18 - Efficiency for constant throttle (blue line) and switching throttle (red line).

When the total efficiency for the time intervals shown in Figure 19 are calculated, the efficiency for green area where the clutch gets disconnected is found to be 0.424. The yellow area where the clutch is left connected has an efficiency of 0.398. Since the clutch is left connected for about a third of all cases during the simulation, this lowers the overall efficiency.

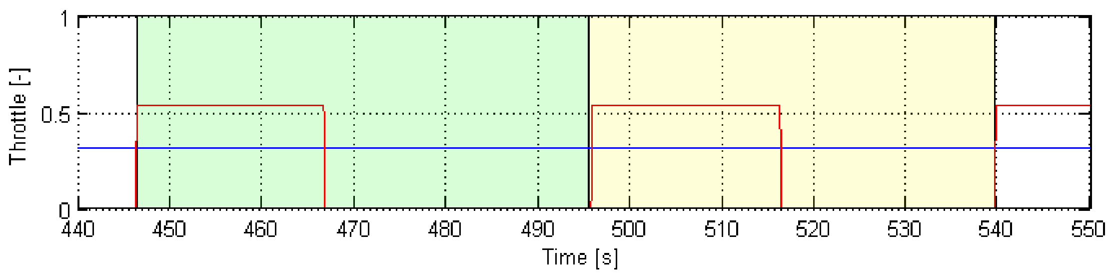

Figure 19 - Time intervals used for efficiency calculations

To sum the analysis, the usage of the plot works as intended, but it does not produce the intended outcome. This is partly due to the delay before the engine reaches its maximum efficiency when changing the operating point, but also because of the unpredictable clutch strategy in the powertrain model.

5.4 Evaluating functions in GSP

The speed profiles for all the test drivers without and with changed brake pedal mapping are shown in Figure 20. It can be seen that the drivers managed to drive much smoother with the changed pedal mapping, with fewer exaggerated acceleration and deceleration moments. This is confirmed by Table 2 where all the drivers lower the RMS-value for the test. The value is the RMS of the difference in speed between the ghost car and test driver, meaning that lower RMS-values indicates less difference in speed.

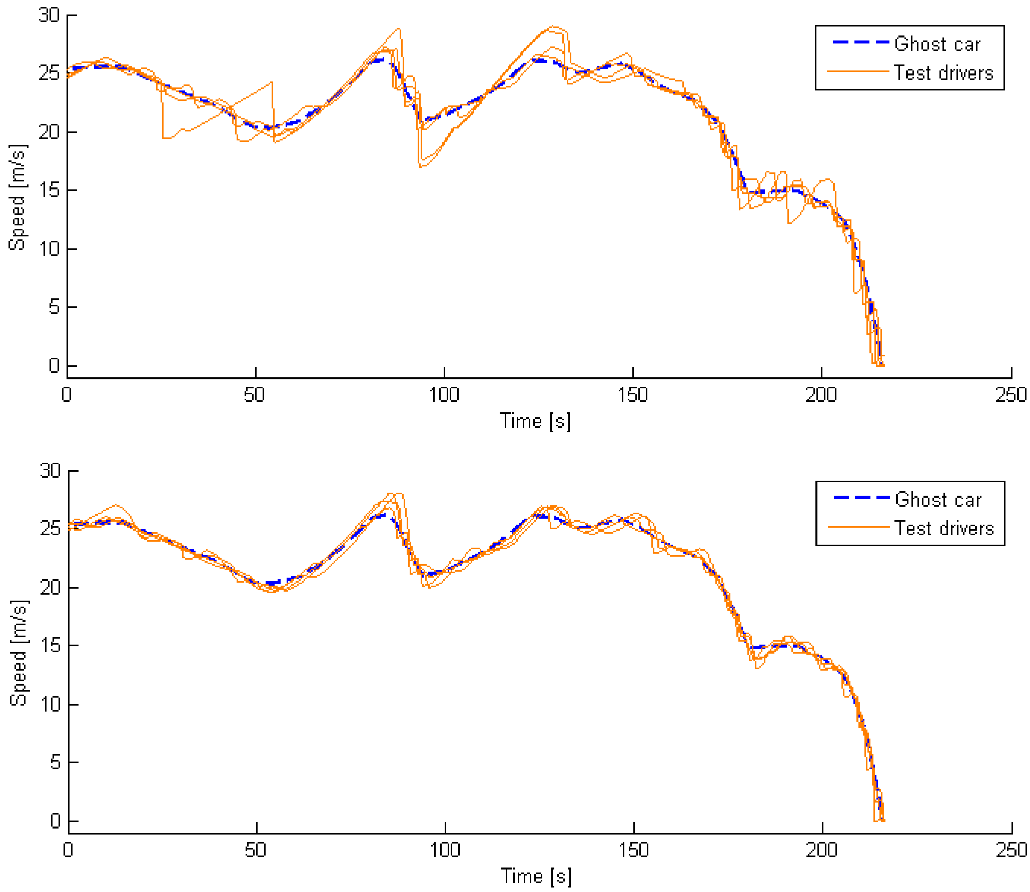

Figure 20 - Speed fluctuations for the test drivers. The upper graph shows the original pedal mapping, the lower graph shows the changed mapping.

6 Discussion

The results of the different tests are discussed in the following subchapters. Subchapter 6.5 also presents other findings made during the project.

6.1 driveGSP

Because of the way the real-time synchronisation block is made, it takes a few seconds before the simulation's time step stabilizes. Because of this, driveGSP doesn't behave exactly as GSP in the beginning of the simulation, hence the differences in the simulation data. But from the point when the truck actually starts to drive, the results from both simulations are identical. Because of this, driveGSP is considered to be verified as a simulation tool that gives the same results as GSP. The total difference in time between the tests is 2 seconds and the difference in fuel consumption is 0.001 kg which is negligible in most cases. The synchronization block can probably be adjusted to reduce the initial error, but that is outside the scope of this project.

6.2 Driver model

The driver model's fuel consumption was lower than for all the test drivers. However, this is the first test the drivers do in the simulator without anything but 5 earlier practice minutes. Still, as explained in 5.2, Driver 5 actually manages to keep the same fuel consumption as the driver model except for a short period. This indicates that the driver model probably gives a good representation of an experienced driver trying to drive fuel-efficiently. Unfortunately, there was not enough time to let the drivers practice more before the tests, otherwise the results might have been different and closer to the driver model. As shown in Table 2, 4 out of the 5 drivers manage to get well below the driver model when they get the information from the road plot. That is not a fair comparison since the driver model doesn't know anything about the upcoming road, but it still shows that the driver model isn't impossible to beat, at least with some knowledge of the road.

Another thing that could be noticed is that the driver model is much smother on the accelerator compared to the real drivers. The drivers were not as good keeping constant speed, but this might be partly because of the limited speed perception in the simulator and the limited preciseness of the pedals. Since the driver model only rely on input data such as actual speed to determine the proper amount of throttle, it has an advantage over the drivers that are used to other inputs such as wind noise and vibrations that aren't simulated in Drivesim. This would mean that the drivers have to look at the speed constantly to be able to fine-tune the throttle for the speed as good as the driver model do. Drivers probably also behave differently when driving, being a bit more aggressive on the throttle compared to a control system (which the driver model is).

The traffic simulations show that GSP doesn't always produce realistic results. When driving on an empty road, the results could be similar, but driving in traffic changes the driving behaviour drastically with much higher fuel consumption as a result. Since only one traffic setup was used and without any connection to real traffic data, the results from the traffic simulations should only be used to understand the tendencies.

6.3 GSP as driver aid

The results from the driver aids are presented in the sections below.

6.3.1 Road plot

The road plot clearly helped the drivers to reduce the fuel consumption. Since none of the test drivers had any experience with driving driveGSP before the tests, there is a risk of them improving their driving through the tests and therefore affecting the results. There is also a possibility that the results got better partly because of the improved possibility to understand the current slope of the road. The drivers had some problems interpreting from the screen how steep the hills were, which could result in unnecessary amount of throttle or brake. The road plot clearly shows the slopes which could get the drivers to reduce the fuel consumption because of another reason then intended. However, because of the big improvement and the strategic decisions made by the drivers as shown in 5.3.1, most of the improvement is considered to be a result of the road plot, which shows that the idea of GSP as a driver aid works.

The road plot could in different ways be changed to show more accurate information. One way would be to have shorter iteration steps to calculate the estimated speed each 100 metres instead of each 200 metres, but that might only make it harder for the driver to take in the information. The focus hasn't been to find the most easily understood way to present the data to the driver, it was only verified that the test drivers could understand the plots. Another parameter that hasn't been evaluated is the current plotted road length of three kilometres.

6.3.2 Engine map

The tests show that the engine map might not work in practice. When driving on flat ground, the clutch would need to be disconnected during each coasting interval. This might be the case during real driving, since the GSP gearbox model could be slightly different to the real algorithm. The driving strategy is also affected when driving in slopes instead of flat ground. If this was the case, and the engine could be run at its optimum point for longer periods of time, the system could work in reality. This would result in big changes in speed, which might be unsuitable for highway driving considering regulations and other road-users. Also, the gain in efficiency would not be so high, since the change when going from constant speed to switching between 80 and 90 km/h was from 0.42 to 0.424.

However, the point of testing the engine map was not primarily to find a way to reduce the fuel consumption but instead to test if the possibility to use GSP as driver aid. And since all the drivers managed to run the engine more in the high-efficiency region compared to their other tests without the engine map, the driver aid is considered to be working. It was also found when testing the driver aids that GSP is suitable for testing those thanks to the high amount of data that is easily accessible. In a real truck, it would require more work to access all needed data for the calculations and plots.

6.4 Evaluating functions in GSP

The ghost car tests showed that the change of brake mapping helped the drivers to drive more smoothly. It probably takes some time for the drivers to get used to the task, which could be the case in the first part of the test with the original mapping, where the results are the worst. But even if that is the case, the improvement can be seen also in the later parts of the tests. They also have an acceleration part before the recorded distance where they have some time to practice, so even if the RMS-values aren't telling exactly how much better the new pedal mapping is, it still clearly shows the better tendency.

6.5 Additional findings

There are different possibilities and advantages with the driveGSP setup. Firstly, inputting pedal signals from a real driver has the benefit of a short setup time. If the driver model should do a certain manoeuvre, it takes time to program that. Instead, a driver can simply start a simulation and do the manoeuvre. It might not always be as exact as a programmed version, but it will be much quicker to get the results from. In this way, different throttle and brake manoeuvres can be done and evaluated significantly faster.

The traffic in Drivesim can be used by sending data from Drivesim's radar function to GSP real-time. If GSP gets radar data, adaptive cruise controls and autonomous features can be evaluated. Even if the driver doesn't drive the vehicle, it can still be useful to see the different choices that the vehicle makes. One example could be to see how the autonomous algorithms do the overtaking, if it feels unsafe for the driver and if it is worth trying the overtaking considering other parameters such as upcoming hills. NVIDIA is developing a similar system that will be used for testing and developing autonomous functions, where the developers can view the vehicle on screens or with a VR headset (NVIDIA DRIVE Constellation, 2018) The benefits of testing the autonomous systems in a simulator is that a wide range of events can be tested that is hard to experience in real-vehicle testing.

There is another benefit of testing autonomous systems in driveGSP, and that is that GSP provide realistic powertrain data that otherwise only can be estimated during real-vehicle tests. In this way, the systems could be tunes for the different powertrain components before they test the prototypes on the road for the first time.

It can also be easier to get an understanding for an event by looking at a visual representation instead of only analysing data afterwards.

An important advantage of driveGSP is the possibility to test different vehicle setups during different conditions to understand how the vehicle feels for the driver. The acceleration and spare power can be analysed in a normal GSP simulation, but in driveGSP it can be tested how the truck drivers will experience the truck's powertrain. Too small engines or unsuitable accelerator pedal mappings can make the truck feel slow and unresponsive. This can also be tested with hybrid powertrains, to see how a driver experiences the different driving modes.

7 Conclusions and Future Work

The purpose of the project was to evaluate the driver model and find possible applications of driveGSP. The driver model does not behave exactly as a real driver when it comes to throttle strategy and keeping the target speed, but produces reasonable results that can be reached by real drivers. It is considered to be a suitable model for a good driver. driveGSP is also verified to be good for testing driver aids since it contains a lot of easily accessed data, and both the tested systems resulted in the expected driver behaviour. Furthermore, driveGSP have been found to be a suitable way to evaluate the systems in GSP. Changes in the vehicle model can be felt by the drivers, this makes it possible to tune parameters early in the development process of new powertrain models. This is also suitable due to the short setup time in GSP. It only takes minutes to change to a new powertrain setup when doing the tests. driveGSP can finally also be used to understand and evaluate autonomous functions by observing the simulations on the screen, comparing to examining the data after the simulations.

There are several things that could be improved to make driveGSP better to use. Firstly, TelDisp should be made more adaptive. It currently used some manually assigned variables that should be imported automatically. And if using the road plot, the brake torque should be taken into account when calculating the future speeds. This is currently not the case. The real-time problems during the first seconds of the simulations should also be fixed. To make testing easier, a switch could be inserted in GSP real-time to enable the drivers to switch between the pedal inputs and the driver model with or without cruise control while driving. This would remove the need for stopping the truck when making changes.

To improve the driving experience, it would be beneficial to add wind noise in Drivesim to get a better speed perception. The perceptions could be helped by using a setup of three main screens which also would lead to a better sideway visibility. A future possibility could be to have motion feedback to give the driver a better understanding of the incline and speed by tilting or vibrating the platform. The steering wheel and pedals should also be changed from the current computer gaming model to real truck equipment for a more realistic experience.

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