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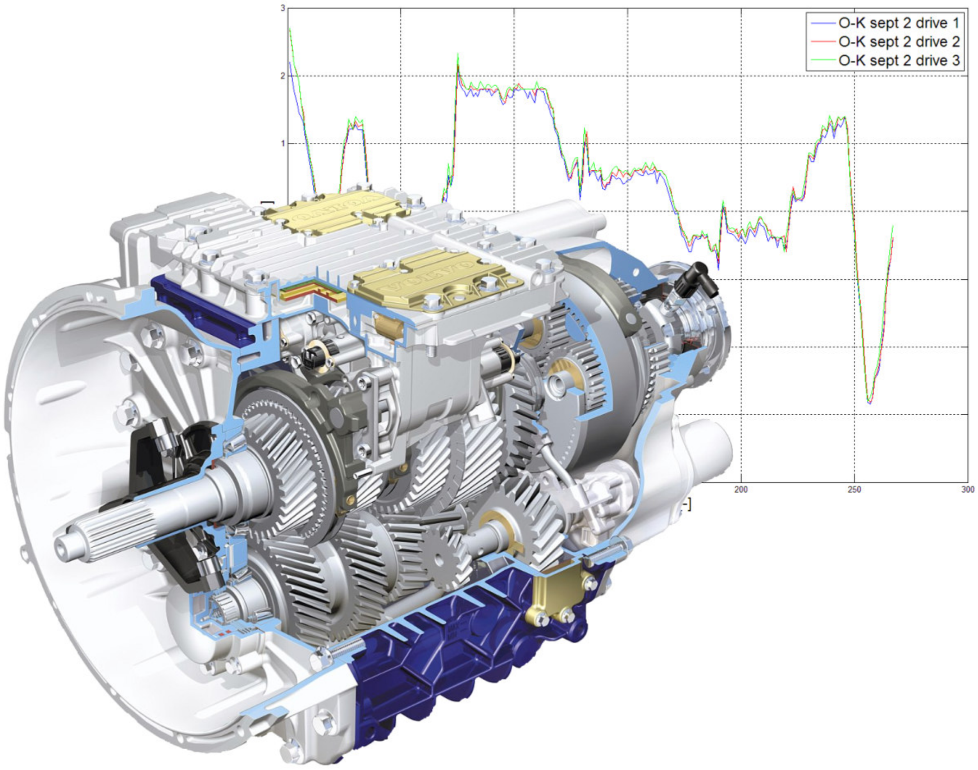

Route Recognition from Recorded Inclination Data Enabling Use of Preview-Based Fuel-Saving Functions

Master of Science Thesis

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Cover: [The I-shift that is examined within this thesis work and an inclination signal plot. Source for I-shift picture: www.volvo.com]

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Abstract

The purpose of this thesis work was to examine whether predictive fuel-saving transmission-functions, requiring road inclination preview information, can be satisfactory controlled without use of commercial map data and GPS. Thus, in this study, the inclination data was collected from the I-shift gearbox inclination signal and the vehicle positioning was made by correlating present inclination data with stored inclination data from previously travelled routes. These simulations were aimed at determining the following. Firstly, the noise level of the inclination signal, secondly if fuel savings using the I-shift gearbox inclination signal as preview information could be obtained and finally if it was possible to determine the position of the truck relative to the previously stored routes without the use of a GPS.

The confidence interval for the inclination signal was ±0.09 percent. This shows a low noise level on the inclination signal, since the resolution of the inclination signal is 0.2 percent.

It was found that fuel-savings of up to 1.0 % on the road from Landvetter to Borås and up to 1.3 % in the opposite direction was obtained when using the I-shift gearbox inclination signal as preview, relative to a truck not using preview. The fuel savings were corrected for changes in average speed.

The position-finding function developed in this thesis work was found to require a 1.9 km long road segment to locate the truck relative to pre-recorded inclination data in simulation. The developed position-finding function is possible to implement in the Transmission Electronic Control Unit.

Acknowledgements

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Last, but not least, we would like to thank our families and friends for their support.

Symbols

s^2	Estimated variance [-]
s	Estimated standard deviation [-]
v_{avg}	Average vehicle speed [km/h]
$Fuel_{avg}$	Average fuel consumption [l/10 km]
t_{active}	The time a function is active [s]
t_{tot}	Total time for the simulation [s]
$\Delta Fuel_{corr}$	Speed corrected change in average fuel consumption [%]
$\Delta Fuel$	Change in average fuel consumption [%]
Δv	Change in average vehicle speed [%]
k_{corr}	Fuel/speed correction factor [10^{-10}·m·h]

Abbreviations

B-L 0905	Test-drive from Borås to Landvetter made 2008-09-05
B-L 0912	Test-drive from Borås to Landvetter made 2008-09-12
CAN	Controller Area Network
e-Horizon	Electronic Horizon
GPS	Global Positioning System
I/O	Input/Output
L-B 0905	Test-drive from Landvetter to Borås made 2008-09-05
L-B 0912	Test-drive from Landvetter to Borås made 2008-09-12
PCB	Printed Circuit Board
Preview-based fuel-saving functions	These are the fuel-saving functions Preview-Ecoroll, Zeropedal and Crestroll
TECU	Transmission Electronic Control Unit

Contents

1 Introduction

One of the main aims in heavy truck development is to improve fuel economy and even fractions of a percent count. By lowering the fuel consumption, both the operational cost and the environmental impact of a truck will decrease. Traditionally these improvements have been made by optimizing the hardware of the truck, such as decreasing the losses in gearboxes and increasing the efficiency of engines. However it is an expensive process to change hardware, thus a “lower hanging fruit” can be to develop new software functions to save fuel. In this thesis work, the use of own-recorded preview information to control fuel saving transmission functions has been studied.

A previous thesis work, “Preview-Information-based Transmission Functions for Improved Fuel Economy in Heavy Trucks”, has been carried out at Volvo Powertrain and Volvo Technology. This study showed that preview-based fuel saving functions, i.e. Crestroll and preview-information-based Ecoroll, can lower the fuel consumption of a truck by several percent. This is achieved by choosing gears in an intelligent way in the vicinity of down hills and crests. These preview-based fuel-saving functions are dependent on reliable preview information about the road slope. [1]

The preview information used within the above mentioned thesis work was based on commercial road maps and a GPS for vehicle positioning. Commercial road maps available today contain most major roads [2]. However, the use of these commercial maps will create a cost when buying and updating the maps.

A complement or substitute to these commercial maps could be that the truck stores information about the roads it travels. This gives the possibility to learn any road and thereby use the preview based fuel saving functions on this road at a later occasion. In Volvo trucks, with the I-shift gearbox, the inclination of the road is possible to measure since it has a built-in accelerometer, which in combination with other sensors measures the inclination of the road [3]. This inclination information can be stored in the truck and used at a later occasion as preview information. If and how the inclination signal can be used as preview information and how to use it for positioning of the truck is what this thesis work will examine.

1.1 Objective

The objective of this thesis is to investigate whether or not it is possible to use, and if possible, how to implement, preview-based fuel-saving transmission functions without the use of commercial map data and a GPS for vehicle positioning. Instead, on-board recorded slope data from the I-shift inclination signal is used and the positioning is made by correlating present slope data with stored data from previously travelled routes.

This objective leads to three areas that have to be examined. These areas are the noise level and accuracy of the inclination signal, positioning of the truck using stored inclination data and evaluation of the fuel-saving potential using the stored inclination data.

2 Technical Background

The technical background chapter is divided into two parts; a hardware and a software part. The most relevant components in the hardware of the I-shift gearbox for this thesis work are the two microcontrollers, TECU 1 and TECU 2, the flash memory and the accelerometer. All these components are mounted on the transmission electronic control unit, TECU. The accelerometer itself will not be relevant for this thesis work, but the inclination signal will. The inclination signal is based on various sensor signals, one of which is the accelerometer signal. The software applications are the fuel-saving functions; preview-Ecoroll, Zeropedal and Crestroll.

2.1 Transmission Electronic Control Unit

The TECU is a four layer printed circuit board, PCB, attached to a three millimetre aluminium plate containing among others, the TECU 1, the TECU 2 and the accelerometer. The TECU 1 is first and foremost used for I/O regarding sensors, actuators and communication, TECU 1 also handles the real time functionality. The TECU 2 is used for calculations and simulations in order to predict the best possible gear strategy. [4]

2.2 Inclination Signal

The inclination signal is based on an accelerometer located in the TECU in the I-shift gearbox. Signals from the accelerometer and other sensors are combined, filtered and formatted so that the inclination signal on the CAN-bus is given in percent. The filtration of the accelerometer has a compensation for positive inclinations; this compensation is made so that an increase in torque, which makes the truck tilt backwards, does not incorrectly indicate an uphill. The inclination signal also has a continuous calibration function to ensure best possible accuracy. When new TECU software is loaded, the inclination signal gives no inclination information for the first 1 km. During this time, a main calibration is performed. After this, the inclination signal continues to fine-tune its value by more calibration which is done continuously but with increasing intervals. The inclination signal has a working range of ±25 percent and a resolution of 0.2 percent on the CAN-bus. [3]

2.3 Fuel-Saving Functions

The two main preview-based fuel-saving functions are Ecoroll and Crestroll. This section presents the purpose of the functions and explains how they work.

2.3.1 Ecoroll

Ecoroll uses the possibility to change to neutral gear while the vehicle is moving in order to free roll under certain circumstances. Ecoroll becomes active in downhill slopes to preserve the kinetic energy in the truck. This preservation of energy is done by shifting to neutral and thereby lowering the friction in the powertrain. This enables the truck to roll further before engaging the engine. During the Ecoroll, the engine is in idle which means that a small amount of fuel is consumed. [5] The version of Ecoroll that is implemented in Volvo trucks today uses only information describing the current circumstances. If information regarding future slopes were available, it would be possible to control the Ecoroll in a more fuel efficient way. This since criteria's previously used to avoid short activations can be changed, thus increasing the Ecoroll-time. [1]

2.3.2 Zeropedal

In downhill slopes it is also possible to use Zeropedal, i.e. stop injecting fuel into the engine. The main advantage of Zeropedal is that it does not consume any fuel. However the kinetic energy of the truck will be lost because of friction in the powertrain. [6] By using preview information, Zeropedal can be used in a more intelligent way, for example when a steep downhill is entered. In these slopes Ecoroll is activated shortly when no preview is used but with preview slope information, Zeropedal would be activated instead. [1]

2.3.3 Crestroll

Crestroll is a combination of Ecoroll and Zeropedal. This function is dependent on reliable preview information describing the slope of the road ahead. It is possible to save fuel by passing a crest using an intelligent combination of Zeropedal and Ecoroll. For example, Ecoroll can be used to free roll over the top of the crest and a limited decrease in speed can be allowed to save fuel. When the top is passed, the function can switch to Zeropedal in order not to exceed the maximum allowed speed. At the end of the down hill slope, the truck can switch back to Ecoroll in order to have as high speed as possible at the end of the down hill slope without engaging the engine. [1]

3 Mathematical Background

This chapter describes the main mathematics used within this thesis work. It is divided into two parts; the confidence interval calculations of the inclination signal and Pearson correlation. The confidence interval will show how high the noise level of the inclinations signal is. The Pearson correlation will be used to locate the position of the truck.

3.1 Confidence Interval Calculations for the Inclination Signal

This section contains the equations needed to evaluate the confidence interval for the inclination signal and thereby knowledge about the noise level of the measured inclination information.

The actual road inclination is represented by $\Theta(n)$ and the value of this variable is unknown. However the value of the inclination signal, $\hat{\Theta}(n)$, attained on the CAN-bus can be assumed to be the actual road inclination plus a noise function. The equation for this would then be

$$\hat{\Theta}(n) = \Theta(n) \pm w(n) \qquad (1)$$

where n is the position of the truck, $\Theta(n)$ is the actual road inclination and $w(n)$ is a normal distributed stochastic noise function.

The noise function w(n) is assumed be represented by

$$w(n) = sz(n) \qquad (2)$$

here *z(n)* is a normal distributed stochastic variable with unit variance and s is the standard deviation for $\hat{\Theta}(n)$.

The standard deviation s is estimated by the following calculations. First the variance in each position n is calculated as

$$s_n{}^2 = \frac{1}{(m-1)} \sum_{c=1}^{m} \left(\hat{\Theta}_c(n) - \overline{\hat{\Theta}}(n) \right)^2 \qquad (3)$$

where $\hat{\Theta}_c(n)$ is the value of the inclination signal on CAN-bus for measurement number c on position n and the variable m is the number of measurements in position n. This means that if a measurement stretch has been driven three times and is ten positions long, then c will go from one to three, m will be three and n will go from one to ten. $\overline{\hat{\Theta}}(n)$ is the mean value for all the measurements c in position n, that is,

$$\overline{\hat{\Theta}}(n) = \frac{1}{m} \sum_{c=1}^{m} \hat{\Theta}_c(n) \qquad (4)$$

When the variance in each position is known, the mean variance for the inclination signal is then calculated using

$$\bar{s}^2 = \frac{1}{l} \sum_{n=1}^{l} s_n^2 \qquad (5)$$

where l is total number of positions that variance calculation has been performed on. If the same example as above is used l would attain the value ten. This mean variance is then assumed to be the total variance for the function *w(n)*.

With a known variance it is now possible to calculate the standard deviation as

$$s = \sqrt{\bar{s}^2} \qquad (6)$$

where s is the standard deviation of the noise function *w(n)*. The size of s will show the noise level of the inclination signal. Here as low value as possible is preferable this since the lower the noise is the better the correlation will work. [7]

3.2 Pearson Correlation

Correlation is used to find the position of the truck on a previously driven road. This will tell us where the highest correlation is found when compared to the reference information.

The correlation between two vectors ***x*** and ***y*** can be calculated using Pearson correlation. In this correlation, the correlation coefficient, *r*, indicates how strongly the two vectors correlate. The correlation coefficient r is calculated using the Pearson equation

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (7)$$

Where ***x*** and ***y*** are two vectors of the same length and $\bar{x}$ and $\bar{y}$ are the mean value of ***x*** and ***y***. [7]

The correlation equation gives a correlation coefficient between minus one and one. Minus one corresponds to two totally anti-correlated vectors, zero corresponds to no correlation, and one indicates that the two vectors are identical. This is seen in Figure 1.

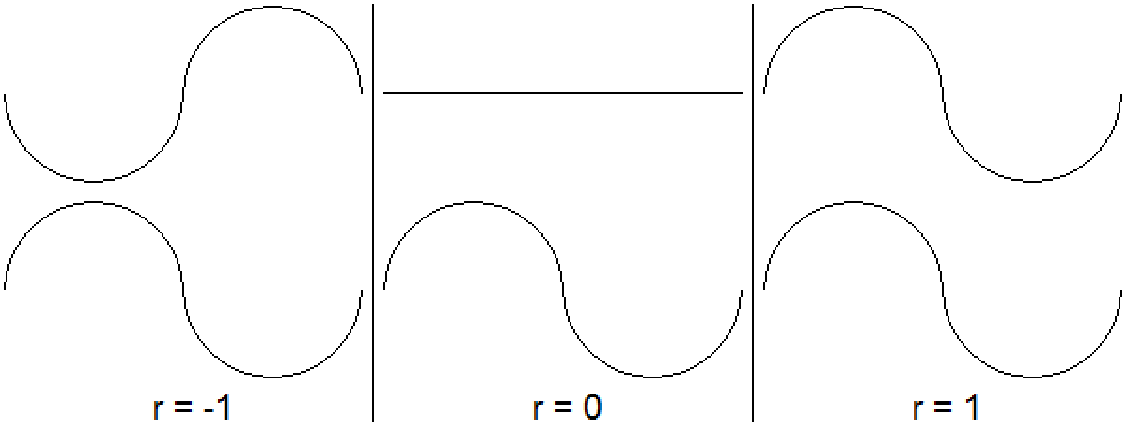

Figure 1. Visual representation of the correlation coefficient. When the correlation coefficient r = -1; that the curves are anti-correlated, when r = 0; no correlation exist and when r = 1; the correlation is perfect.

4 Simulation Environment and Reference Simulations

In this chapter, the simulation environment where the fuel-simulations are performed is described. The simulations presented within this chapter are set as references. They are needed in order to be able to evaluate how the inclination signal as preview information affects the fuel-consumption.

The road that is used within these simulations is road 40 between Landvetter and Borås. This road is used in both directions. Road 40 is chosen since altitude information is available and since it is close to Volvo Trucks development site in Göteborg.

4.1 Simulation Environment

All simulations performed to evaluate the fuel consumption of the truck were made in a modified version of VSim+. VSim+ is a model library in MATLAB Simulink that is used for vehicle simulation within Volvo. The main modifications that have been made in VSim+ are the possibilities to use Ecoroll, preview-based Ecoroll, Crestroll and to use CAN-data as preview information. The CAN-input makes it possible to use measured data from a truck as preview information in VSim+. However it has to be converted from inclination information to altitude information to fit into the VSim+ structure.

In Table 1, specification of the truck used within the simulations in VSim+ is presented. This vehicle configuration is the same for all simulations performed in this thesis work.

Table 1. The configuration of the vehicle used in VSim+.

Component	Type	Comment
EBS	EBS brake torque map	
Axles and wheels	Standard	Wheel radius 0.492 m
Chassis	FH, 44 000 kg	
Driver	Cruise controller	PID controller
Engine	d13a480ec06	480 horse powers
Final Gear	Ration 2.64	
Mechanical auxiliary load	Standard	Assumed constant
vref	85 km/h	
vmax	90 km/h	

4.2 Reference Simulations

Two reference simulations are made for each of the two reference stretches. One simulation with Ecoroll without preview information and one simulation with all preview-based fuel-saving functions activated using perfect preview information. In this case the perfect preview information is the same data as the road data used within VSim+ for the stretches Landvetter-Borås and Borås-Landvetter. The result from the simulation with Ecoroll active shows the best possible fuel economy possible to obtain in a production truck from Volvo today. The simulations where perfect preview information are used for control of the predictive functions are to be seen as the ideal cases, which gives a benchmark of how much fuel it is possible to save by use of preview-based fuel-saving functions.

The results obtained from these simulations will serve as a reference when comparing to simulations in which measured inclination data from a truck is used as preview information.

In the simulation plots below, the Zeropedal curve only shows whether Zeropedal is active or not. Zeropedal is active when it has the value 16 and not active when it has the value 15. The gear curve shows when Ecoroll is active by shifting down to gear zero, i.e. neutral.

4.2.1 Landvetter-Borås Reference Simulation

Road 40 between Landvetter and Borås in Sweden is the first reference road. The altitude curve is shown in Figure 2.

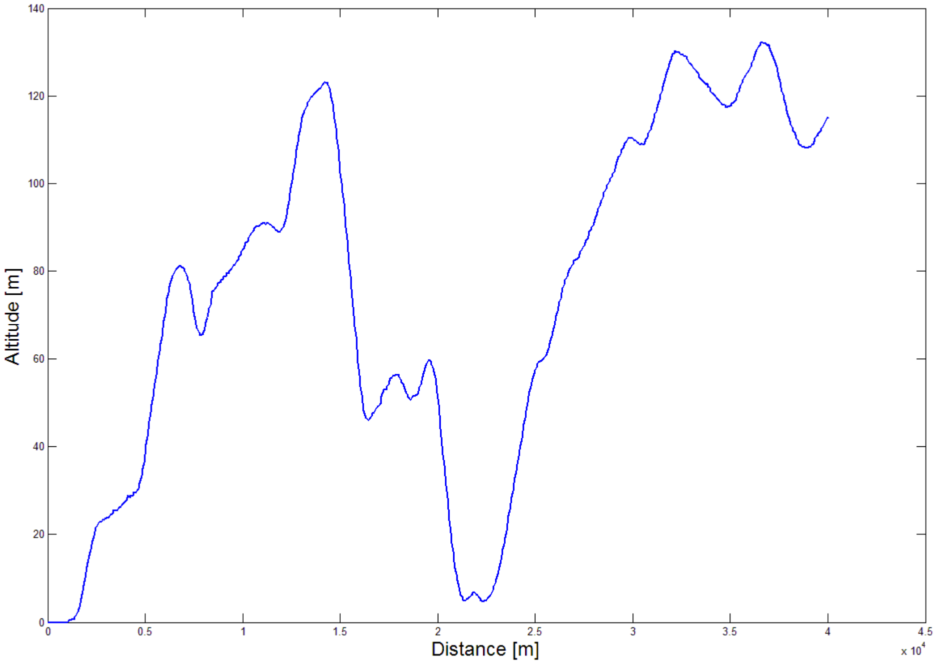

Figure 2. The altitude curve for road 40 from Landvetter to Borås.

In Figure 3 and Table 2, the simulation results for the simulation with only Ecoroll active are presented. In the figure the average speed of the truck and when Zeropedal and Ecoroll are active is presented.

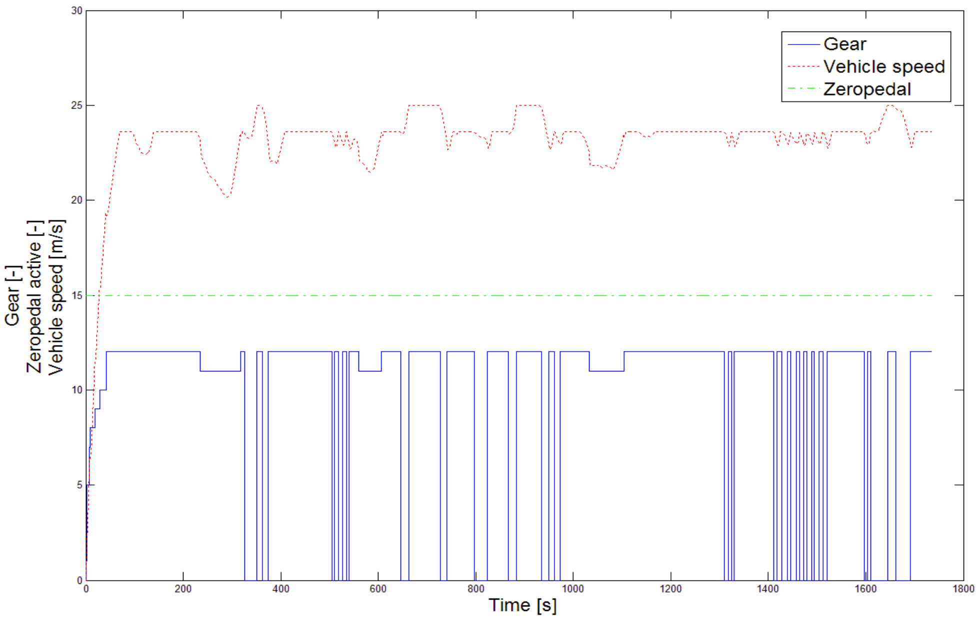

Figure 3. The figure shows vehicle speed, Zeropedal behaviour and gear selection with Ecoroll and no preview information activated between Landvetter and Borås. In this figure Zeropedal is inactive, Ecoroll is active at gear zero, i.e. neutral.

The simulation results where all preview-based fuel-saving functions are active are presented in Figure 4 and Table 2. In the figure the average speed of the truck and when Zeropedal and Ecoroll are active is presented.

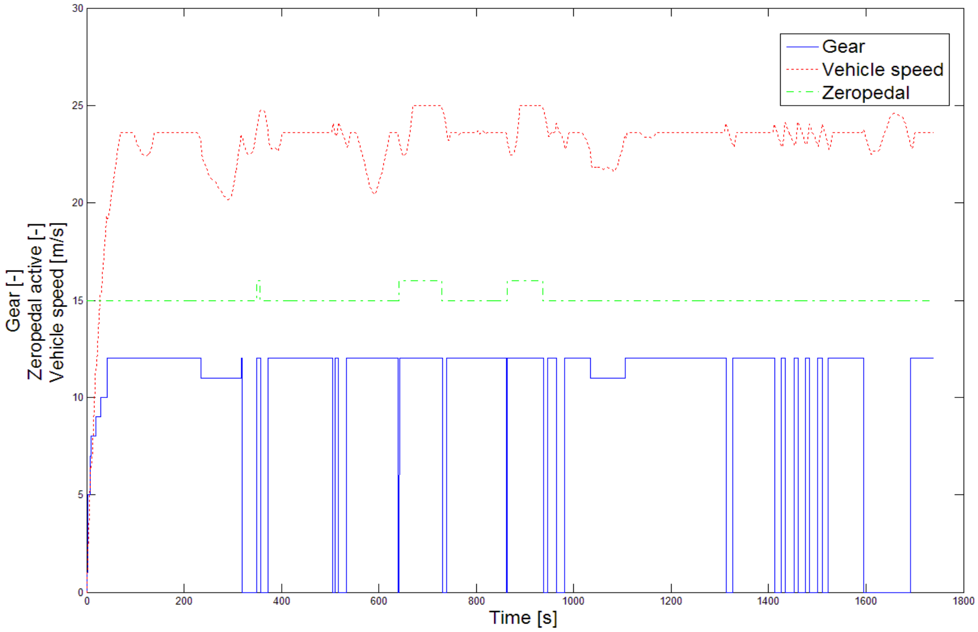

Figure 4. The figure shows vehicle speed, Zeropedal behaviour and gear selection with preview-based-fuel–saving-functions activated with perfect preview information between Landvetter and Borås. Zeropedal is active at value 16 and inactive at 15 and Ecoroll is active at gear zero, i.e. neutral.

Table 2. The simulation results from VSim+ for the road from Landvetter to Borås for the reference simulations.

Reference Simulations Landvetter to Borås	Fuel_{avg} (l/10 km)	v_{avg} (km/h)	Downshifts (-)	Zeropedal Active			Ecoroll Active		
				t_{active} (sec)	Times (-)	% of t_{tot}	t_{active} (sec)	Times (-)	% of t_{tot}
Ecoroll	5.0125	83.0831	3	0	0	0	310	23	17.8
All preview-based fuel-saving functions active with prefect preview	4.947	82.9342	2	169	3	9.73	293	16	16.9

4.2.2 Borås-Landvetter Reference Simulation

Road 40 between Borås and Landvetter in Sweden is the second reference road. The altitude curve for this road is shown in Figure 5.

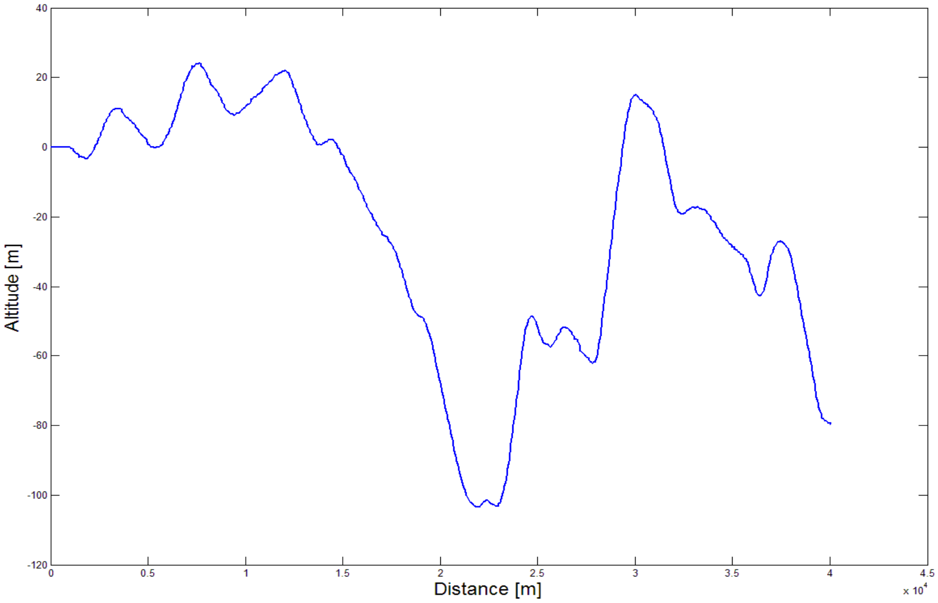

Figure 5. The altitude curve for road 40 Borås to Landvetter.

In Figure 6 and Table 3, the simulation results for the simulation with only Ecoroll active is presented. In the figure the average speed of the truck and when Zeropedal and Ecoroll are active is presented.

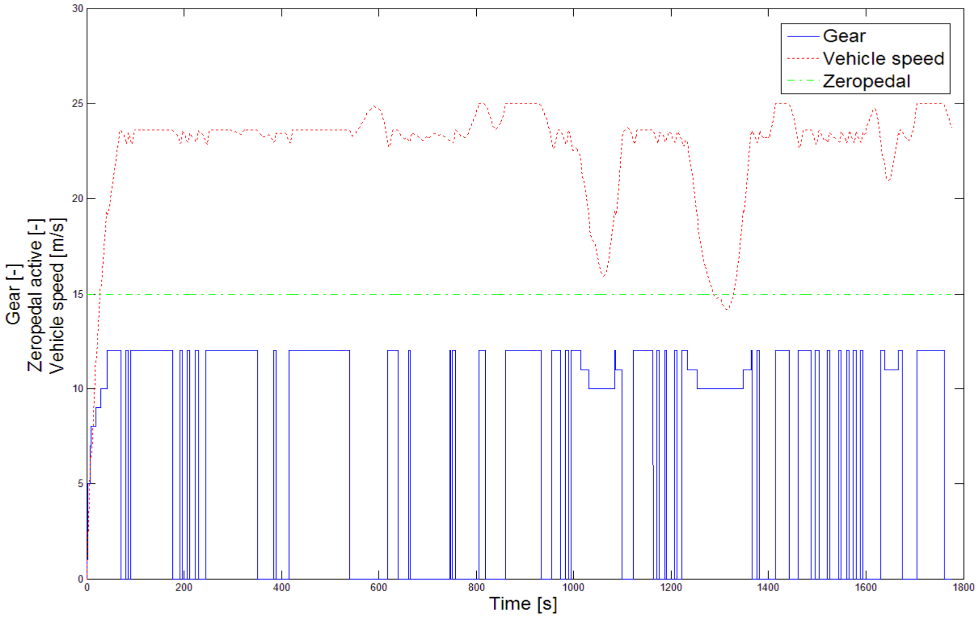

Figure 6. The figure shows vehicle speed, Zeropedal behaviour and gear selection with Ecoroll and no preview information activated between Borås and Landvetter. Zeropedal is inactive, Ecoroll is active at gear zero, i.e. neutral.

The simulation results where all preview-based fuel-saving functions are active are presented in Figure 7 and Table 1. In the figure the average speed of the truck and when Zeropedal and Ecoroll are active is presented.

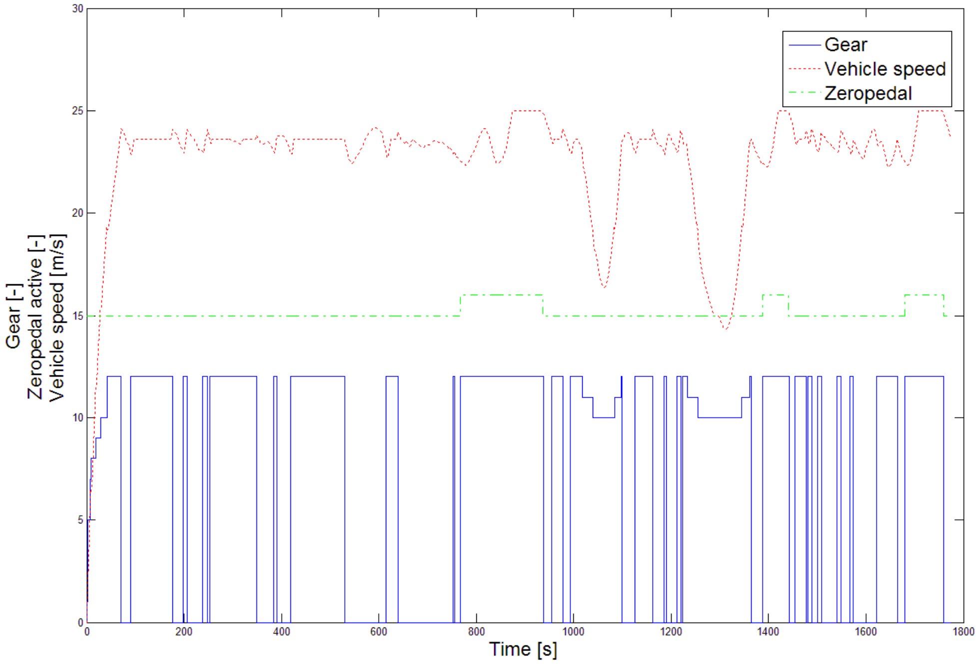

Figure 7. The figure shows vehicle speed, Zeropedal behaviour and gear selection with preview-based fuel-saving-functions activated with perfect preview information between Borås and Landvetter. Zeropedal is active at value 16 and inactive at 15 and Ecoroll is active at gear zero, i.e. neutral.

Table 3. The simulation results from VSim+ for the road from Borås to Landvetter for the reference simulations.

Reference Simulations Borås to Landvetter	$Fuel_{avg}$ (l/10 km)	v_{avg} (km/h)	Downshifts (-)	Zeropedal Active			Ecoroll Active		
				t_{active} (sec)	Times (-)	% of t_{tot}	t_{active} (sec)	Times (-)	% of t_{tot}
Ecoroll	3.4283	81.3431	6	0	0	0	717	34	40.4
All preview-based fuel-saving functions active with prefect preview	3.3696	81.3682	4	304	3	17.2	633	24	35.7

4.2.3 Average Speed Corrected Fuel-Consumption for the Reference Simulations

The simulation results should be corrected for differences in average speed, since this will influence the average fuel consumption. This is done by use of,

$$\Delta Fuel_{corr} = \Delta Fuel - k_{corr} \cdot \Delta v \qquad (8)$$

Where ΔFuel is the difference in fuel-consumption and k_{corr} is a fuel correction factor individual for each road. The values for road 40 are presented in Table 4. [1]

Table 4. The fuel correction factors needed to compensate for lower average speed [1].

Road	Fuel correction factor, k_{corr} [10^{-10}·m·h]
Landvetter – Borås	0.7
Borås – Landvetter	0.94

The fuel consumption results from the reference simulations corrected for differences in average speed are presented in Table 5. The results show that the preview-based fuel-saving functions save between 1.18 and 1.74 percent of fuel compared with Ecoroll.

Table 5. The speed compensated fuel evaluation results for the reference simulations.

Road and Functions activated	v_{avg} (km/h)	Fuel_{avg} (l/10 km)	Δv [%]	ΔFuel [%]	$\Delta Fuel_{corr}$ [%]
Landvetter to Borås with Ecoroll	83.0831	5.0125	0	0	0
Landvetter to Borås with preview-based fuel-saving functions active with perfect preview	82.9342	4.947	-0.18	-1.31	-1.18
Borås to Landvetter with Ecoroll	81.3431	3.4283	0	0	0
Borås to Landvetter with preview-based fuel-saving functions active with perfect preview	81.3682	3.3696	0.03	-1.71	-1.74

5 Positioning of the Truck

To be able to use the preview-based fuel-saving functions, an accurate positioning of the truck is needed and since no GPS is available, correlation was used. The function that enables this positioning is presented in this chapter. It is also evaluated with simulations in chapter 8 to guarantee its function.

5.1 Position-Finding Function

As explained in section 3.2, Pearson correlation is used to calculate the position of the truck relative a previously driven route, here called a reference route. To make this possible, the truck stores inclination information from driven roads in a memory. When the truck drives the same route the next time, the aim is that the truck should identify its position on this route.

The main design criterion for the position finding function is that it should always find a match if a match exists. This can be achieved by dividing the function into two parts:

- The initial search, where all reference routes are searched in order to find the position.
- The correlation check, where the correlation between the current drive and the chosen reference route is checked. This is done in order to know whether the reference route is still correct or not.

The initial search creates a vector of a predefined number of elements before the correlation calculation begins. When the predefined vector length for the current drive is reached, the correlation calculation begins. The correlation calculation between the current drive vector and the stored reference vector are then conducted on all positions of all stored reference route vectors, containing inclination information. This search function always searches for the highest correlation coefficient and saves which reference route and the position on that reference route, i.e. the position of the truck. This is done so that the reference route and position on it with the highest correlation value can be sent to the correlation check function.

The correlation check function controls that the desired level of correlation is maintained throughout the whole drive. If this is not the case, the correlation check function is left and a new initial search is made. The flow chart in Figure 8 describes the flows and states of the position finding function.

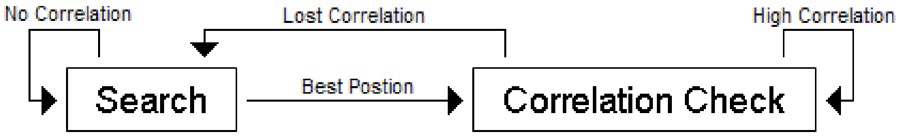

Figure 8. A flowchart describing the two main states of the position-finding function.

5.2 Simulation with the Position-Finding Function

The simulations performed with the position-finding function were done to determine when it is possible to know that the right position is found. The simulations on the position-finding function were performed using MATLAB and all the inclination data used were from real measurements from a truck. If the positioning works in MATLAB, then it is assumed that it will work in a real truck, since the simulations are carried out using on board measured sensor data.

The position-finding function is evaluated by comparing a current drive, the inclination data collected when driving, with the reference routes. If the position-finding function locates the position correctly, a variable that shows the correct positioning is increased. If the position is wrong, a variable indicating wrong positioning is increased. This is done for all current drives.

The current drives used when evaluating the position-finding function are of the length 10 to 50 samples, i.e. approximately 50 m segments, in order to evaluate how long stretch that is needed for an accurate positioning. The current drives are created from drives from Kållered to Onsala and from Onsala to Kållered. From these drives, between 1085 and 1285 different current drives were created depending on the sample length of the current drive. So the position-finding function has been tested with 1285 different current drives for the cases where the current drive has a length of 10 samples and with 1085 for the cases where it has a length of 50 samples.

The used references are drives from Kållered to Onsala, Onsala to Kållered, Landvetter to Borås, Borås to Landvetter, Lerum to Alingsås and Alingsås to Lerum. Landvetter to Borås and Borås to Landvetter are divided into three reference routes, so the total number of reference routes becomes eleven.

The results obtained from these simulations shows the certainty with which the positioning function can find the position of the truck, depending on the current drive sample length.

6 Results for the Confidence Interval Calculations on the Inclination Signal

To get a system that uses the inclination signal both for positioning and as preview information, a noise level evaluation of the inclination signal is needed. This noise level evaluation is done using the equations in section 3.1, which gives the confidence interval for the inclination signal.

The inclination information that is used for the confidence interval calculations were measured in a real truck on road E6/E20 between Kållered and Onsala and back. This inclination information is low-pass filtered by calculating the mean value over 50 m segments. The length of 50 m is based on the resolution of the e-Horizon used in "Preview-Information-based Transmission Functions for Improved Fuel Economy in Heavy Trucks". [1]

The stretch E6/E20 between Onsala and Kållered was measured three times while the Kållered to Onsala stretch was measured twice. These measurements where made the second of September 2008 for this thesis work. The mean variance and the standard deviation for the inclination signal are presented in Table 6. The standard deviation that will be chosen as the confidence interval for the inclination signal are the worst of the two. In this case, this is for the Onsala to Kållered stretch, which has a value of ~0.09 percent.

Table 6. The mean variance and the standard deviation confidence interval for the inclination signal.

	Kållered to Onsala	Onsala to Kållered
$\bar{s}^2$	0.0014	0.0078
s	0.0378	0.0883

This means that the inclination signal will be given by

$$\Theta(t) = \hat{\Theta} \pm 0.09 \tag{9}$$

The measurements that these calculations were performed on are presented in Appendix A.

7 Results for the Fuel-Consumption Simulations using Collected Inclination Data as Preview Information

The fuel consumption results presented here are from simulations made in VSim+ on the roads Landvetter to Borås and Borås to Landvetter. The purpose of the simulations is to test whether it is possible to use the inclination signal as preview information and still save fuel, compared with Ecoroll.

The preview altitude information sent to VSim+ is based on CAN-data, measured in a real truck. The CAN-signals used are the inclination signal and the vehicle speed signal. From these, it is possible to calculate an altitude curve. The reason for using the vehicle speed signal instead of the distance signal is that the vehicle speed signal has higher resolution.

7.1 Simulations for Road 40 between Landvetter and Borås

The VSim+ simulation results for the stretch from Landvetter to Borås and Borås to Landvetter with measured inclination data as preview information are presented in this chapter. These simulation results are also compared with the reference simulation results, i.e. the ones carried out with Ecoroll and the ones with perfect preview information. This is done to see how the measured inclination signal affects the fuel consumption and the activation of the preview-based fuel-saving functions.

7.1.1 Altitude Curve between Landvetter and Borås

The reference altitude curve, from VSim+, and the two altitude curves calculated using information from the inclination and vehicle speed signals between Landvetter and Borås are presented in Figure 9. The three curves have a similar appearance, which indicates that the inclination signal is fairly accurate. However, as can be seen in Figure 9, there is a difference between the reference altitude and the altitude calculated from the inclination signal that increases with the distance. This is due to the integration made when calculating the altitude curves. This integrating error will affect the simulation results, but, as will be seen later, this effect will not be significant.

The difference between the two calculated curves is most significant the first half of the stretch Landvetter-Borås. This is due to that they are not identically calibrated, see section 2.2. This difference in the inclination signals can be seen in Figure 18, in Appendix B.

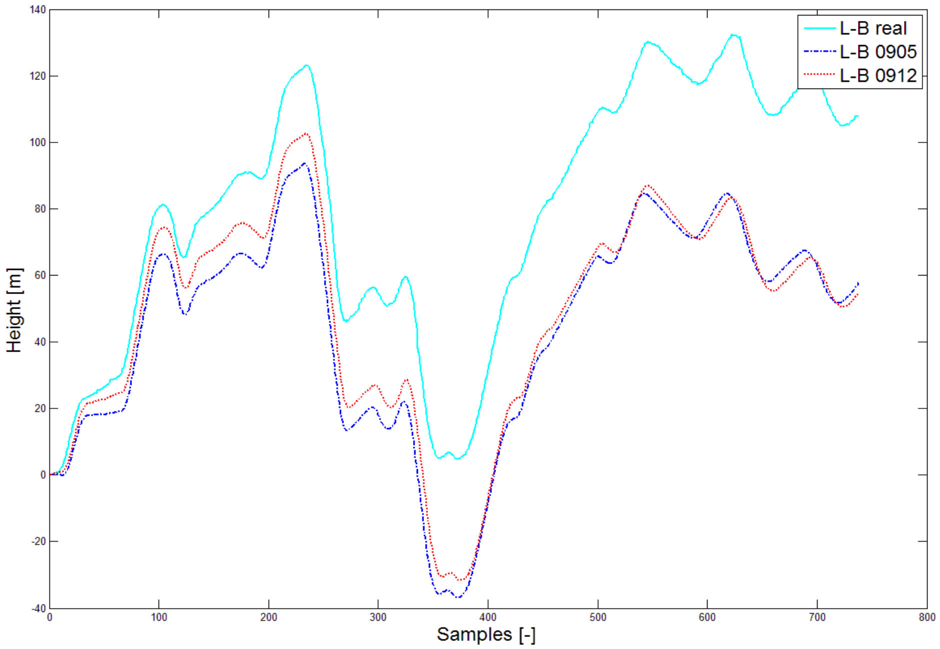

Figure 9. The altitude curves for Landvetter-Borås. The cyan curve is the reference from VSim+, the magenta and blue are the calculated curves based on the inclination signal.

7.1.2 Simulation results for Landvetter to Borås

In Figure 10 and Table 7, the simulation results using preview information from the L-B 0905 drive is presented and in Figure 11 and Table 8, the results from the L-B 0912 drive are presented.

As can be seen in Figures Figure 10 and Figure 11, the results are similar for the two simulations. The main difference is that in the L-B 0905 simulation, Zeropedal is active during a shorter period of time than the L-B 0912 simulation. However, in the L-B 0905 simulation Ecoroll is active during a longer period of time than in the L-B 0912 simulation.

When the two simulations are compared with the reference simulation with perfect preview information, the main difference for the simulations is that the simulations that use altitude information based on the inclination signal have resulted in a longer, and additional, Zeropedal activation. This behaviour can be seen in Figure 4, Figure 10 and Figure 11 at about 330 seconds of simulation. Notable is also that the Ecoroll time is shorter for both the simulations in which the calculated altitude curves were used. This indicates that the truck chooses to Zeropedal instead of Ecoroll with the calculated altitude as preview information.

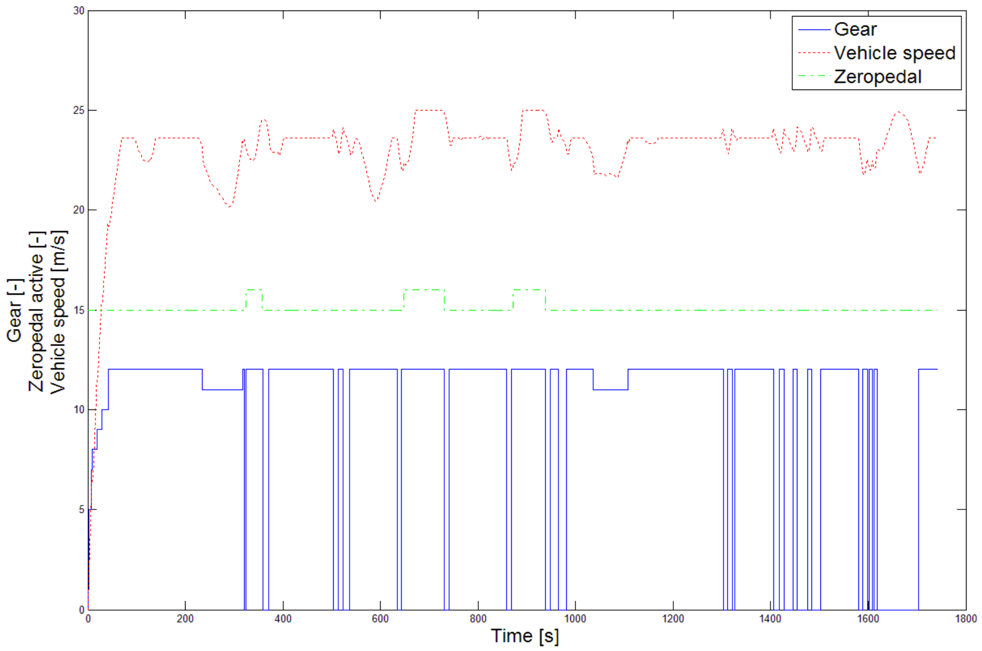

Figure 10. The figure shows vehicle speed, Zeropedal activation and gear selection with preview-based fuel-saving functions activated and the calculated altitude curve based on drive 0905 between Landvetter and Borås as preview information.

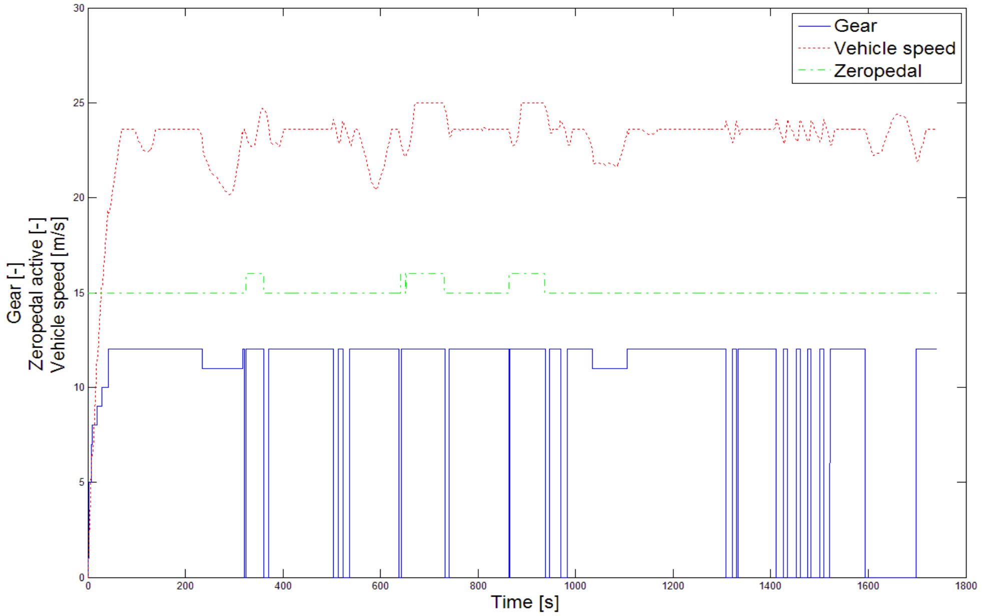

Figure 11. The figure shows vehicle speed, Zeropedal activation and gear selection with preview-based fuel-saving functions activated and the calculated altitude curve based on drive 0912 between Landvetter and Borås as preview information.

Table 7 The simulation results from VSim+ for the road from Landvetter to Borås with the calculated altitude curves based on the inclination signal as preview.

Fuel simulations Landvetter to Borås	Fuel_{avg} (l/10 km)	v_{avg} (km/h)	Downshifts (-)	Zeropedal Active			Ecoroll Active		
				t_{active} (sec)	Times (-)	% of t_{tot}	t_{active} (sec)	Times (-)	% of t_{tot}
Landvetter to Borås with 0905 altitude curve as preview	4.9477	82.7972	2	182	3	10.4	283	19	16.2
Landvetter to Borås with 0912 altitude curve as preview	4.9531	82.8466	2	197	4	11.3	276	17	15.8

In Table 8, all fuel-consumption simulation results for Landvetter to Borås are presented. The factor $\Delta Fuel_{corr}$ is the speed compensated fuel saving for the two simulations, with the calculated altitude curve compared with the reference simulation, i.e. the Ecoroll. The best result is obtained with all preview-based fuel-saving functions active using perfect preview information, as expected.

Table 8. The speed corrected fuel consumption results for the reference simulations and the simulations with calculated altitude as preview information for the road from Landvetter to Borås.

Road and Functions activated	v_{avg} (km/h)	Fuel_{avg} (l/10 km)	Δv [%]	ΔFuel [%]	$\Delta Fuel_{corr}$ [%]
Landvetter to Borås with Ecoroll	83.0831	5.0125	0	0	0
Landvetter to Borås with preview-based fuel-saving functions active with perfect preview	82.9342	4.947	-0.18	-1.31	-1.18
Landvetter to Borås with preview-based fuel-saving functions active with 0905 height curve as preview	82.7972	4.9477	-0.34	-1.29	-1.05
Landvetter to Borås with preview-based fuel-saving functions active with 0912 height curve as preview	82.8466	4.9531	-0.28	-1.19	-0.99

7.1.3 Altitude Curve between Borås and Landvetter

The altitude curves for Borås to Landvetter are presented in Figure 12. The characteristics of the two calculated altitude curves are similar to the reference altitude curve. All crests are at the same positions and the relative altitude between different points are almost the same.

The difference between the inclination signal based calculated altitude curves is large, this is due to differences in the inclination signal. For the B-L 0912, the inclination signal has an offset for almost the entire stretch and that gives the higher altitude curve, this can be seen in Figure 19 in Appendix B. For the measurements B-L 0905 and the two L-B, the calculated altitude is lower than the real altitude, which indicates that the B-L 0905 drive may be more correct than the B-L 0912 drive. As will be seen later this difference will affect the simulation results.

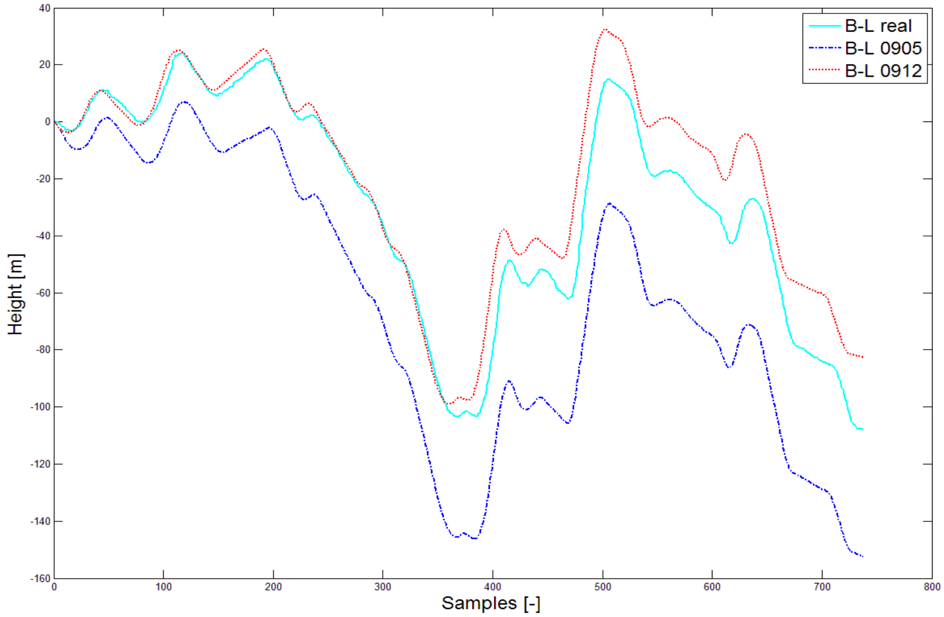

Figure 12. The altitude curves for Borås-Landvetter. The cyan curve is the reference from VSim+, the magenta and blue are the calculated curves based in the inclination signal.

7.1.4 Simulation Results for Borås to Landvetter

The simulation results for B-L 0905 and B-L 0912 are presented in Figure 13, Figure 14 and in Table 9. The main difference between the two is that in the simulation with the B-L 0912 altitude curve as preview information, both Zeropedal and Ecoroll is used less than in the simulation with the B-L 0905 altitude curve.

The results for the simulation with B-L 0905 as preview information is similar to the results of the reference simulation with perfect preview information. The largest difference between the two simulations is that Zeropedal is active at around 530 seconds when the B-L 0905 drive is used as preview information. The Zeropedal behaviour in the simulation with the B-L 0912 drive as preview information is similar to the simulation with perfect preview information. The main difference is that in the simulation with B-L 0912 engaged and disengaged Zeropedal more often than in the simulation with perfect preview information. The other difference for the B-L 0912 simulation is the shift behaviour, one more down shift and one less up shift is made.

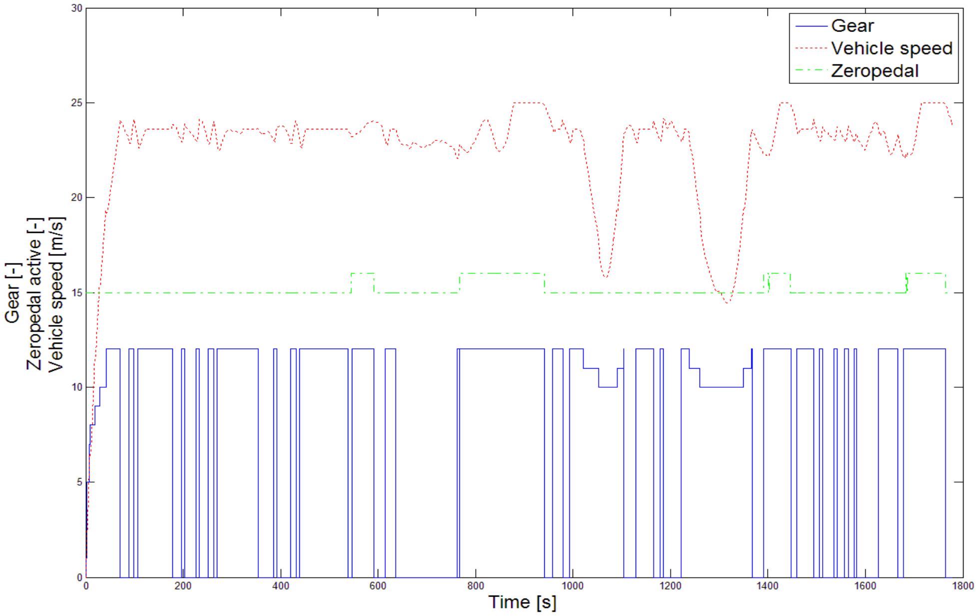

Figure 13. The figure shows vehicle speed, Zeropedal activation and gear selection with preview-based fuel-saving functions activated and the calculated altitude curve based on drive 0905 between Borås and Landvetter as preview information.

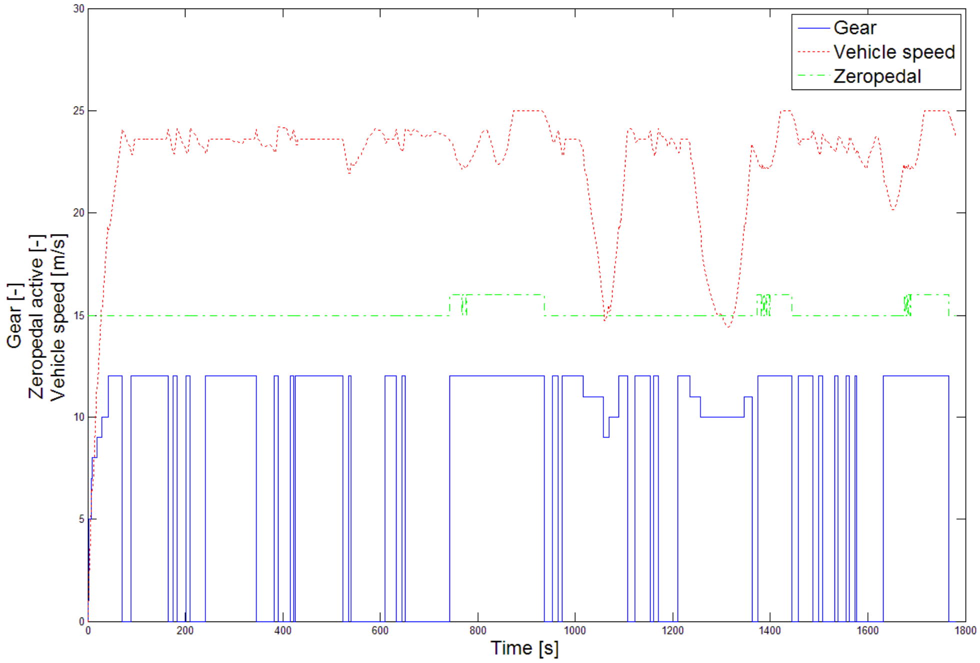

Figure 14. The figure shows vehicle speed, Zeropedal activation and gear selection with preview-based fuel-saving functions activated and the calculated altitude curve based on drive 0912 between Borås and Landvetter as preview information.

Table 9. The simulation results from VSim+ for the road from Borås to Landvetter with the calculated altitude curves based on the inclination signal as preview.

Fuel simulations Borås to Landvetter	$Fuel_{avg}$ (l/10 km)	v_{avg} (km/h)	Downshifts (-)	Zeropedal Active			Ecoroll Active		
				t_{active} (sec)	Times (-)	% of t_{tot}	t_{active} (sec)	Times (-)	% of t_{tot}
Borås to Landvetter with 0905 altitude curve as preview	3.3738	81.1209	4	353	6	19.8	591	27	33.2
Borås to Landvetter with 0912 altitude curve as preview	3.372	81.0375	4	338	12	19	571	24	32.1

In Table 10, all fuel consumption simulation results for Borås to Landvetter are presented. The factor $\Delta Fuel_{corr}$ is the speed compensated fuel saving for the two simulations with the calculated altitude curve compared with the reference simulation, i.e. the Ecoroll. Again the best result is obtained with all preview-based fuel-saving functions active using perfect preview information, as expected.

Table 10. The speed corrected fuel consumption results for the reference simulations and the simulations with calculated altitude as preview information for the road from Borås to Landvetter.

Road and Functions activated	v_{avg} (km/h)	Fuel_{avg} (l/10 km)	Δv [%]	ΔFuel [%]	$\Delta Fuel_{corr}$ [%]
Borås to Landvetter with Ecoroll	81.3431	3.4283	0	0	0
Borås to Landvetter with preview-based fuel-saving functions active with perfect preview	81.3682	3.3696	0.03	-1.71	-1.74
Borås to Landvetter with preview-based fuel-saving functions active with 0905 height curve as preview	81.1209	3.3738	-0.27	-1.59	-1.33
Borås to Landvetter with preview-based fuel-saving functions active with 0912 height curve as preview	81.0375	3.372	-0.38	-1.64	-1.29

8 Results for the Position-Finding Function

This chapter presents the results for the simulations made in MATLAB on the developed position-finding function.

To find the position of the truck with a 100 percent certainty, the current drive length has to be at least 38 samples, which corresponds to a distance of approximately 1.9 km. In Figure 15, the result from the positioning evaluation is shown.

If a lower certainty can be accepted, a shorter current drive length can be used. When having a sample length of 30 samples, i.e. 1.5 km, the localization certainty is 99.2 percent, at 20 samples, i.e. 1 km, it is 85.8 percent and at 10 samples, i.e. 500 m, it is 58 percent.

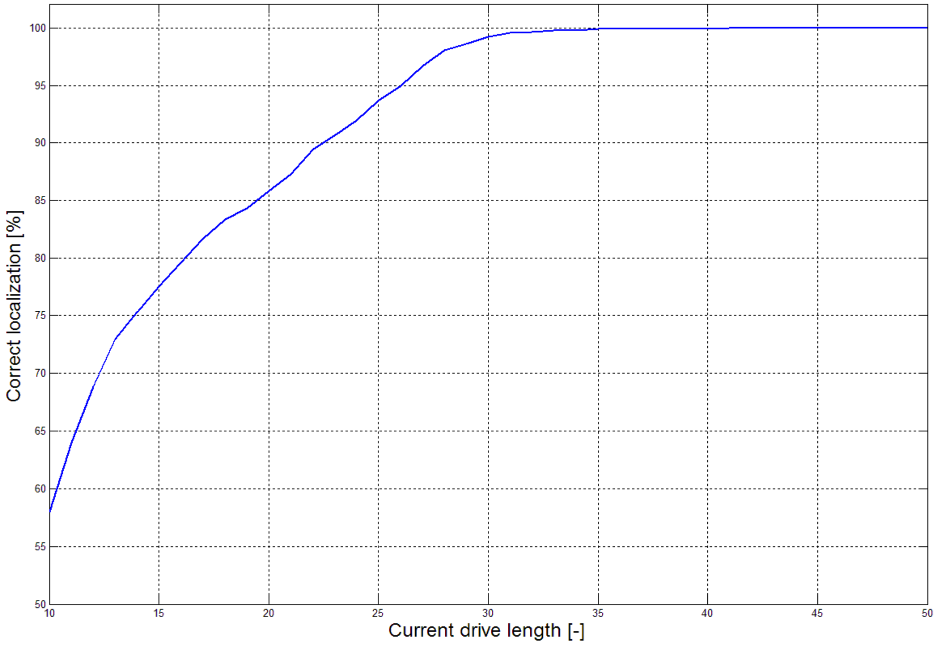

Figure 15. The likelihood of the position-finding function to find the position of the truck for different current drive sample lengths.

9 Discussion of the Results and Methods

This chapter contains the analyses on the results obtained in chapter 6, 7, 8 and a discussion of how these were attained and if something could have been done differently.

9.1 Discussion of the Inclination Signal Results

The inclination signals’ confidence interval of ±0.09 percent is lower than the resolution of the signal, which is 0.2 percent. This shows that the noise level of the inclination signal is low, which is a requirement for the intended application.

A low noise level of the inclination signal will make the positioning of the truck easier. This means that the inclination signal will give almost the same value every time the truck travels a specific road.

On the drives from Landvetter to Borås and Borås to Landvetter, calibrations of the inclination signal have occurred as described in section 2.2, see Appendix B. These calibrations may affect the noise level of the inclination signal on the test vehicles used in this thesis work. However, this calibration would not be a problem in a real truck, since the software in the TECU is not changed and a new calibration is only carried out after a software change.

One missing part in the evaluation of the inclination signal is to compare it to the real inclination of the roads from Landvetter to Borås and Borås to Landvetter. This has not been possible to carry out within the scope of this thesis work because no such data is available. However, the low noise level of the inclination signal could indicate that the inclination signal value is close to the real inclination value of the road.

9.2 Discussion of Fuel Simulation Results

The simulation results show that it is possible to save approximately 1.0 percent of fuel from Landvetter to Borås and around 1.3 percent of fuel from Borås to Landvetter. This is a significant improvement on the fuel consumption and shows the potential of using the inclination signal as preview information for the preview-based fuel-saving functions.

As seen in Figure 12, the difference between the two inclination signal based altitude curves is large but does not affect the fuel consumption in any significant way. The reason for this is that the relative altitude between crests and valleys are almost the same for the two, and it is on these relative altitudes the time-estimation calculations for the preview-based fuel-saving functions are made.

In all simulations carried out using a calculated altitude, it can be seen that the Zeropedal function has to be examined further. This is evident since it is used more often and is engaged and disengaged excessively. The engaging and disengaging is due to the poorer accuracy of the preview information, which results in that the time-estimation miscalculates the time Zeropedal should be active. The Zeropedal function criteria for engaging and disengaging must be made more robust to avoid the observed behaviour.

The inaccuracy of the measured preview information is both due to that it has been transformed twice and to the calibration offset. The measured inclination signal is transformed into altitude when used as input in VSim+. When the simulation is run in VSim+ the altitude curve is converted into inclination again. This means that the integrated error shown in the calculated altitude curves will affect the inclination signal. The unnecessary transformations was tried to be avoided by feeding the CAN-inclination signal directly to VSim+. However this was not possible since the modifications needed in the VSim+-model to do this were substantial.

This transformation of the inclination signal is not made in the real implementation in the truck. The truck uses the inclination signal directly. This would imply that somewhat higher fuel-savings could be achieved in a real truck.

9.3 Discussion of the Position-Finding Function Results

The position-finding function require approximately 1.9 km to localize the truck on the reference inclination data in the simulations.

A truck that this system would be suitable for travels large distances on highways on a daily basis. The truck can be assumed to be driven eight hours a day and of these hours, approximately 6 are on highway. If the average speed on the highway is assumed to be 75 km/h, the truck would cover approximately 450 km a day.

With the above assumptions, i.e. a truck travels 450 km a day, the 1.9 km needed to locate the truck only represent approximately 0.4 percent of the total distance driven on a day. After a lunch break a relocation is needed, so the total localization distance would represent 0.8 percent of the daily drive.

Even though the simulations are made using real measurements from a truck, the results are based on simulations. In a real truck, the localization distance may need to be longer. To determine this, testing on road in a real truck is necessary. However, as long as the localization succeeds to locate the truck, fuel will be saved, so the length of the localization distance is not critical.

9.4 Discussion about Methods used within this Thesis Work

The calculated confidence interval is based on the calculations from section 3.1. To calculate the confidence interval, assumptions had to be made; these assumptions are Equations (1), (2), (4) and (5). These assumptions were required to attain a realistic confidence interval that coincides with the visual impression of the inclination signal measurements. An alternative way to solve this would be to make more measurement drives. Then take the worst case confidence interval and set as the confidence interval for the inclination signal. To get a more thorough examination of the inclination signal a test with different truck types with various weights would also be interesting to perform, this in order to see whether this would influence the inclination signal.

The main limitation for the correlation method is when the road has a constant angle, since in that case, $x_i - \bar{x}$ would always be zero. For the position-finding function, this is an unacceptable threshold value and therefore not computable. However in reality, this will never be a problem since there is only a very small likelihood to drive on a road with constant angle.

The fuel-simulations performed in VSim+ are based on altitude curves. If the simulations would have been based on inclination instead, the obtained results would have been more realistic. However this is not possible since no accurate road inclination information can be obtained for the simulation.

10 Implementation of the Position-Finding Function in the TECU

When implementing the position-finding function in a real truck, many parts have to be considered. For example, information can only be obtained from the CAN-bus and the TECU software needs excessive changes. How the TECU software is changed and how the position-finding function is integrated into this new TECU software is presented in this chapter. Also the results from testing of the position-finding function in a real TECU are presented.

10.1 Changes in the TECU Software

In order to give the position-finding function enough calculation power, some drastic changes of the software running in the TECU has to be made. In this case, all ordinary calculations in TECU 2 are moved to TECU 1, which gives a utilization rate of 85 percent in TECU 1. TECU 2 is released from its ordinary assignment, making it possible to run only the position-finding function in TECU 2. The interchange of information between TECU 1 and TECU 2 has also been changed; in this modified version, TECU 2 is unable to send information to TECU 1. This makes it impossible for the position-finding function, which is run in TECU 2, to save information to the external flash memory mounted on the TECU. This also implies that self learning, as the TECU software is configured at this point, is impossible to implement. If the self-learning functionality where to be implemented, the TECU 2 would have to be able to send information to TECU1 in order to be able to reach the external flash memory.

10.2 Position-Finding Function for the TECU

The position-finding function is implemented in C code using Ascet. The function is built up using three classes; the statistics class calculates the Pearson correlation, the getRef class contains all the references and the mainFinding class is the main class in which the position-finding function is implemented according to Figure 8.

When implementing the function in a control unit, the requirements of the function is a bit different from the ones when the function is implemented in for example MATLAB. First of all, the memory usage has to be smaller, since only approximately 1 Mb of flash memory and approximately 50 Kb of RAM is available in the TECU. This can be compared with a PC, which has several gigabytes of RAM. For storing reference routes, 4 bytes of memory are needed for every approximately 50 meter segment, in other words, every kilometre requires approximately 80 bytes of memory. The processor in the control unit has a clock frequency of 132 MHz. This forces the programmer to minimize the code in order to be able to perform the calculations. [8]

10.3 Test in the TECU

The test performed in the TECU is to see whether it is possible to implement the position-finding function in the TECU and if so, to see how long the execution time is. This execution time is important to know when deciding the deadlines within the real-time functionality for the processor.

The test equipment are a TECU test-card and a PC with ATI Vision 3.5, which is used to monitor the TECU test-card. The TECU test-card is programmed with the position-finding function, one reference with a length of 900 samples, i.e. 45 km, and one current drive. The current drive is preloaded since no data collection to create a current drive is possible within this test. The test consists of a 38 samples long current drive, i.e. the 1.9 km needed to locate the truck according to the simulations, to see how long execution time the position-finding function requires.

The result from this test is that the position-finding function execution time for a reference with the length of 45 km is 140ms. This shows that it is possible to implement the position-finding function in TECU 2.

11 Future work

This thesis work has mainly focused on simulations for evaluation of the inclination signal, the position-finding function and evaluation of whether fuel saving is possible with the inclination signal as preview information. This means that the main future work that has to be performed is the implementation of the system in a truck.

One interesting approach for further development is a system that uses the inclination signal in combination with a GPS. This means that instead of using correlation to find the location of the truck on a reference horizon, the GPS value is used. This solution would decrease the storing space needed, since it only requires memory to save stretches where the preview-based fuel-saving functions are used.

11.1 Implementing the System in a Truck

The thesis work “Preview-Information-based Transmission Functions for Improved Fuel Economy in Heavy Trucks” studied the effect of preview-based fuel-saving functions with perfect preview information in a simulation environment. Their conclusion was that large fuel savings thanks to preview-information-based fuel-saving functions is probably possible to obtain in a real truck.

This thesis work has examined whether it is possible to use the inclination signal as preview information and as a positioning tool. The simulations indicate that predictive transmission functions that uses the inclination signal as preview information can save fuel. The simulations have also showed that positioning of the truck is possible within a reasonable distance driven.

The next step should be to combine these two thesis works and implement it in a real truck. The implementation purposes are both to test whether the preview-based fuel-saving functions really save as much fuel as the simulations indicate and also to try the position-finding function.

To make this possible, a major change has to be made in the TECU software, since data saving at the moment is not possible. Further, the preview-based fuel-saving functions, the self-learning and the position-finding function should be implemented in the TECU software.

Within this implementation, a “smarter” saving of the inclination signal should be implemented, i.e. one should only save the position where the preview-based fuel-saving functions are used. This would make it possible to store even more driven roads into the memory and thereby make the system more versatile. However this data shrinking may affect the precision and speed of the position-finding function since it gets less information for the correlation.

11.2 Inclination Signal in Combination with a GPS

If a GPS-system was available, this would continually store inclination data and evaluate whether the truck could have behaved differently, for example used Crestroll. If the truck could have behaved differently, a start GPS-position where the truck should have started the fuel-saving function for optimal fuel savings is stored. Also the GPS-position where the truck should have stopped using the fuel-saving function, what operations it should have done and the inclination information would be stored.

The start and stop GPS-position can be made individual for each truck, since the weight of the vehicle is known. If the weight always is the same, the start and stop constraints can be set so that the information requires as little memory as possible. However, if the weight varies a lot for the truck, start and stop GPS-positions are set for the lightest case, since it is able, for example, to perform Ecoroll for a longer period of time than the heaviest case.

Other signals may also be saved and considered in this case in order to get a better picture of other surrounding factors. For example, heavy headwind or snowy roads may affect when various preview-based fuel-saving functions should be engaged or disengaged.

12 Conclusions

The inclination signal calculated from the I-shift inclination signal has a noise level that is low enough for using it for predictive control of Ecoroll, Crestroll and Zeropedal, as shown in section 6. The accuracy of the inclination signal is presumably high, since the characteristics of the altitude curves based on the inclination signal are very similar to the references from VSim+.

In the simulations for fuel consumption analysis, fuel savings of 1 % for the stretch Landvetter-Borås and 1.3 percent for the same stretch in the opposite direction where found.

The position-finding function managed to position the truck with 100% certainty without a GPS on a road distance of approximately 1.9 km.

It is possible to implement the position-finding function in TECU 2 and it takes 140 ms to loop through a 45 km reference with a current drive of 1.9 km.

13 References

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Appendix A

Figure 16 shows three drives between Onsala and Kållered and Figure 17 shows two drives between Kållered and Onsala. All confidence calculations are made on these curves.

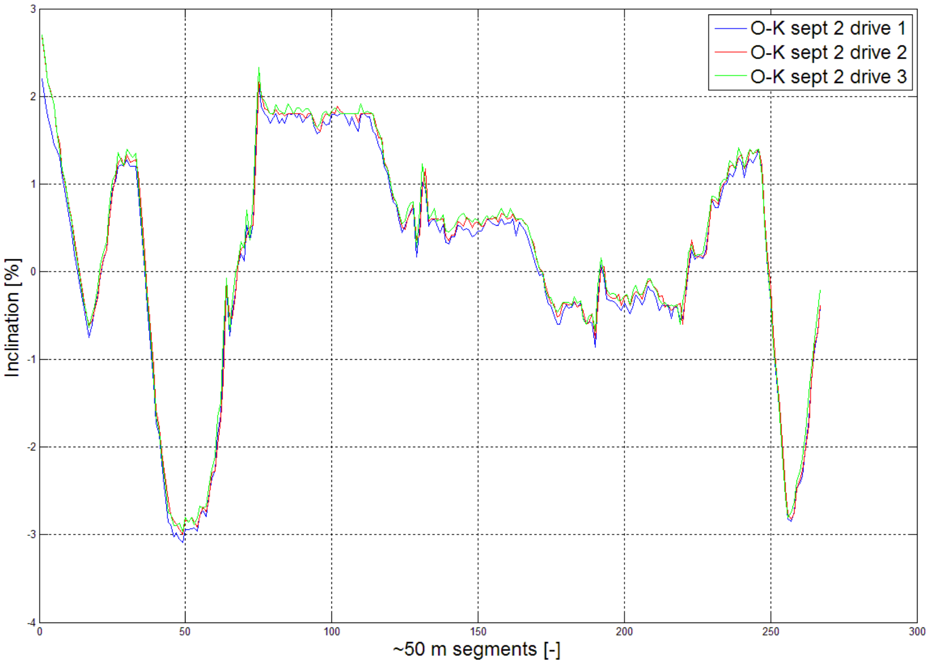

Figure 16. The inclination signal for the road from Onsala to Kållered.

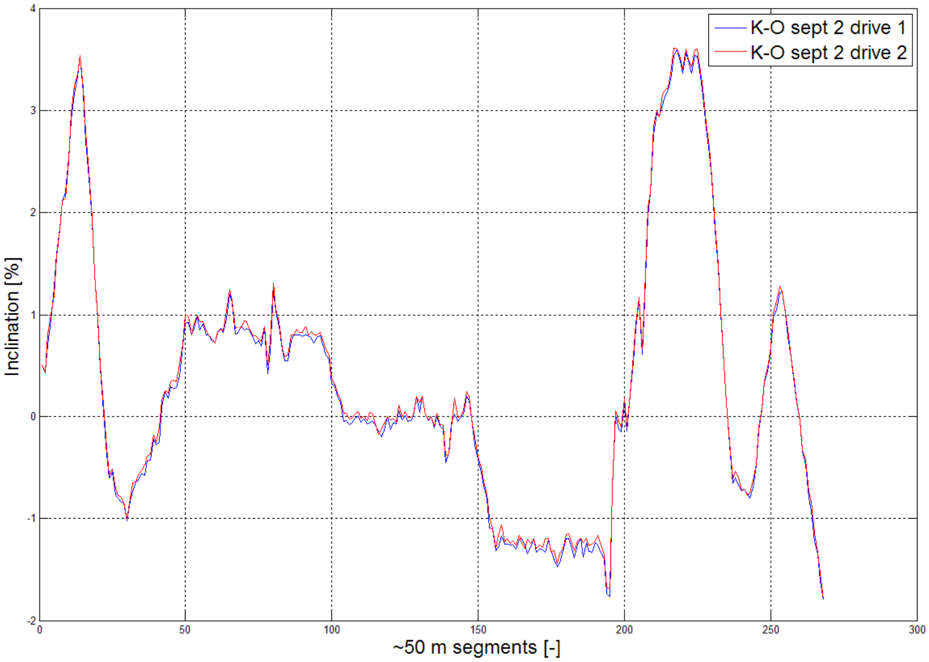

Figure 17. The inclination signal for the road from Kållered to Onsala.

Appendix B

The calibration occurs around the 150:th ~50m segment between Landvetter and Borås and around the 650:th ~50m segment between Borås and Landvetter. This can be seen in Figure 18 and Figure 19.

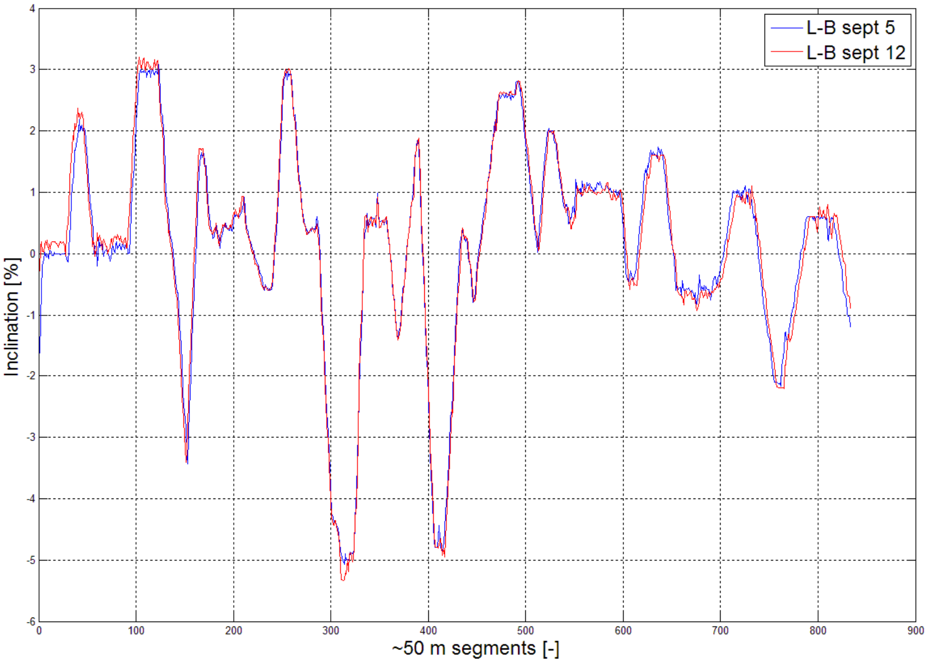

Figure 18. The inclination signal for the road from Landvetter to Borås.

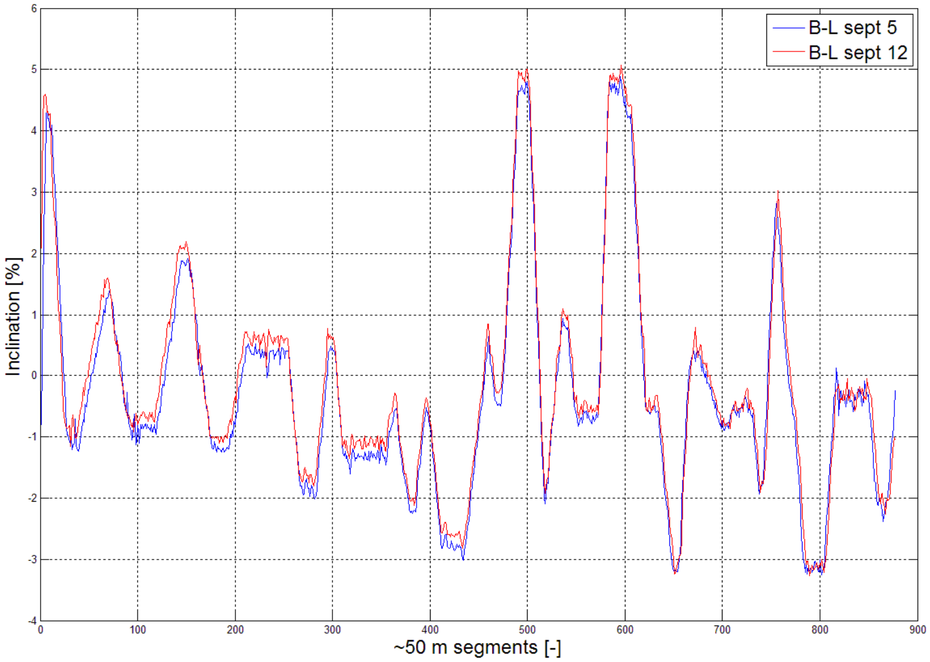

Figure 19. The inclination signal for the road from Borås to Landvetter.