# Institutionen för systemteknik
Department of Electrical Engineering

**Examensarbete**

# Driver training with look ahead

Examensarbete utfört i Fordonssystem
vid Tekniska högskolan i Linköping
av

**Robert Stribeck**

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Linköping 2010

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Förarträning med framförhållning
Driver training with look ahead

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**Sammanfattning**
Abstract

The ambition to lower fuel consumption has been a goal for the vehicle industry since many years. During the first oil crisis in the seventies this first came into light and it has become more relevant during the last years climate change debate. Fuel costs are also an issue. Reducing lifetime costs, in which fuel is 30 %, gives a competitive advantage to the vehicle producer. Over the years the drive train has been made efficient to the point where a reduction in fuel consumption due to improvements in the drive train is highly expensive to develop. The fact that the driver behavior is a big factor in the vehicle's fuel consumption has recently come into attention. This master thesis has been performed at Scania in Södertälje and presents a way to give the driver advice in advance of difficult road segments. The advice will help the driver drive in a fuel efficient manner. Focus is put on a specific case where the vehicle approaches a downhill and advice is given for the driver to let the vehicle coast up to the start of the downhill so that the vehicle can regain its speed in the downhill. The detection of the downhill is made with look-ahead technology where a GPS and a digital 3D road map makes the topography of the road segment ahead available.

**Nyckelord**
Keywords

Heavy vehicles, Automotive, Topography, Fuel consumption

# Abstract

The ambition to lower fuel consumption has been a goal for the vehicle industry since many years. During the first oil crisis in the seventies this first came into light and it has become more relevant during the last years climate change debate. Fuel costs are also an issue. Reducing lifetime costs, in which fuel is 30 %, gives a competitive advantage to the vehicle producer. Over the years the drive train has been made efficient to the point where a reduction in fuel consumption due to improvements in the drive train is highly expensive to develop. The fact that the driver behavior is a big factor in the vehicle's fuel consumption has recently come into attention. This master thesis has been performed at Scania in Södertälje and presents a way to give the driver advice in advance of difficult road segments. The advice will help the driver drive in a fuel efficient manner. Focus is put on a specific case where the vehicle approaches a downhill and advice is given for the driver to let the vehicle coast up to the start of the downhill so that the vehicle can regain its speed in the downhill. The detection of the downhill is made with look-ahead technology where a GPS and a digital 3D road map makes the topography of the road segment ahead available.



# Sammanfattning

Ambitionen att sänka bränsleförbrukningen har varit ett mål för fordonsindustrin sedan många år. Under oljekrisen på sjuttiotalet kom frågan i ljuset och sedan dess har frågan blivit viktigare under de senaste årens debatt om klimatförändringarna. Bränslekostnader är också ett problem. Att minska livscykelkostnaderna, där bränsle är 30 %, ger en konkurrensfördel för fordonstillverkaren. Under årens lopp har drivlinan har gjorts effektiv till den punkt där en minskning av bränsleförbrukningen till följd av förbättringar av drivlinan är mycket kostsam att utveckla. Det faktum att förarens beteende är en stor faktor i fordonets bränsleförbrukning har på senaste tiden fått ökad uppmärksamhet. Detta examensarbete har utförts på Scania i Södertälje och presenterar ett sätt att ge föraren tips inför svåra vägsegment. Tipsen kommer att hjälpa föraren att köra på ett bränsleeffektivt sätt. Fokus ligger på ett specifikt fall där fordonet närmar sig en nedförsbacke och tipsa föraren när han skall släppa på gasen inför nedförsbacken så att han inte behöver bromsa i nedförsbacken. Detektion av nedförsbackarna görs med look-ahead-teknologi där en GPS och en digital 3D-karta gör topografin av vägsegmentet framför fordonet tillgänglig.

# Acknowledgments

First of all I would like to thank Linus Bredberg and Jonny Andersson at Scania for bringing me in at Scania and giving me invaluable support with my thesis. My supervisor at Fordonssystem Erik Hellström has shown grate patience and knowledge when mentoring me trough this thesis. I owe my parents thanks for the support and inspiration when the failed exams piled up half way trough my education.

*Robert Stribeck*
Södertälje, 2010

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# Chapter 1

# Introduction

This Master's thesis project has been carried out at Scania CV AB in Södertälje at the Vehicle Management Controls group. Scania delivers trucks, buses, marine and industrial engines to several parts of the world. The company emphasizes the need for development to be able to present competitive products. All the research and development take place in Södertälje, Sweden.

## 1.1 Background

One of the largest cost in the life cycle of a commercial vehicle is fuel, which constitute up to 30% of total life cycle cost [5, 10]. Fuel consumption is also directly related to carbon dioxide emissions, carbon dioxide in the atmosphere is a major contributor to the increasing greenhouse effect that will raise earths temperature and cause major climate change, IPCC conclude in its forth report from 2007 that: "Warming of the climate system is unequivocal" [2]. Our modern society and global economy is heavily dependent on cheap and fast transportation which in its turn is mainly dependent on fossil fuels. To reach a sustainable development of the society and economy the dependence of fossil fuel must decrease. Many fleet operators recognize this and demand vehicles with less environmental impact. With fuel prices constantly increasing the advantage of reducing fuel consumption is evident in both environmental and economical aspects.

The efforts of making the driveline more efficient have been a continuous process for many years in the heavy vehicle industry. It has made the vehicles of today fuel efficient to the point where heavy investment in research and development is needed to achieve a slight improvement in fuel consumption. A major contribution to fuel efficiency and a great potential area of improvement is driver behavior.

Interactive driver training (IDT) is a Scania product that gives advice to the driver and grades his performance from an economic point of view. The advice IDT gives are based upon a more advanced algorithm and more input signals than the systems that have reached the market today. The aim of IDT is to help the driver to a more fuel efficient driving style. IDT uses information already available in the electrical networks and needs no additional sensors.

In the future additional information can be incorporated in the IDT's evaluation of the driver. An additional source of information could be the new and promising look ahead technology. The look ahead technology uses a detailed digital road map together with a GPS receiver to predict the attributes of the road ahead. Another application could be to use the information of the road ahead to present advice to the driver and advantages in driving behavior could be gained.

## 1.2 IDT

Interactive driver training (IDT) is a system that grades the driver from an economic point of view, whenever driving behavior is mentioned henceforth in this report it is meant from an economic point of view. The idea of the system is to use existing sensors and present scores and tips in the instrument cluster. The system will detect events after they occurred and give a score to each event using recorded information from the event. The driver is scored in different categories where hilltop behavior, vehicle wear, anticipation and gear choice are most relevant. Every detected event is scored on a scale from 0 to 10 where 10 is the best. The event scores are calculated into category mean scores. The main score is calculated from the category scores. IDT presents advice how to improve the most recent score to the driver together with the given score for the event in question. If the driver gets a high score an advice is unnecessary and an appreciative message is shown in the instrument cluster. This application will be an aid to the driver on the path to adapt a more economic drive style [7]. The driver is going to get an introduction to the IDT system when attending the Scania Driver Support sessions where an instructor helps the driver to achieve better economy with his vehicle.

## 1.3 Look-Ahead

Advanced driver assistance system (ADAS) is a broad concept containing a broad spectrum of technologies that are all aimed to assist the driver. The MAPS&ADAS project is a collaboration between vehicle manufacturers and digital map providers which aims to standardize the usage of digital maps among its members. ADAS Horizon is a concept within the MAPS&ADAS project that according to [8] is defined as:

*The usage of a digital map and the vehicle's position to predict the road geometry and track related attributes ahead of the vehicle.*

ADAS Horizon is referred to as look-ahead at Scania and will be so henceforth in this thesis. The most accepted way of determining the vehicle position and vehicle direction is to use GPS. Using the vehicle position and vehicle velocity together with the map it is possible to determine what road is being traveled and in what direction. Thereafter the system builds a one dimensional digital horizon where information about the road ahead is stored.

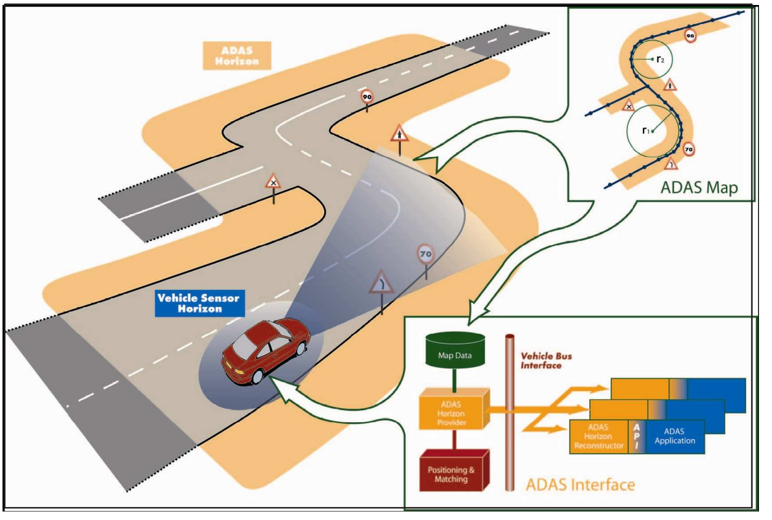


**Figure 1.1.** *The ADAS horizon concept. Note the possibilities represented in the figure, multiple path recognition, curve radius and traffic sign prediction, figure from [8].*

A common approach has been to divide the horizon into segments of about 20 meters, the horizon contains information about the length of the segment, distance to the segment and the average slope of the segment. The horizon can also include information about road curve, road bank, legal speed limit and other potential hazards. The horizon is continuously updated so that the horizon maintains its length.

## 1.4 Thesis Objective

The objective of this thesis have been to find synergies between two existing systems, IDT and look-ahead, particularly how the look-ahead information could be used in IDT. A strategy to implement an algorithm that detects and makes predictions about behavior in front of a downhill will be implemented. This algorithm presents information that can be given to the driver in an advice. A side track of this thesis has been to make a study of relevant literature and research concerning fuel consumption optimization, eco-driving, driver training and look-ahead. The concept of giving advice to the driver will be explored with regards to information density in form of advice frequency and advice detail. The feasibility of a product evolving from the ideas presented in this thesis is explored in the end concluding discussion.

# Chapter 2

# Related work

This chapter will give an overview of related research and publications, the chapter is divided into two main parts, one for articles concerning look-ahead and the other articles concerning IDT. The research field of look-ahead and driver training is vast. A strategy to narrow the search result was needed. A series of keywords was used to search the different databases, these keywords was used in different configurations and with different logical operators. Keywords: fuel consumption optimization, look-ahead, eco-driving, driver training, ADAS horizon, driver quality, driver behavior. The databases used were mainly SAE Digital Library and IEEE Xplore and about twenty articles of interest were studied.

## 2.1 Look-ahead

Over the last couple of years there has been an intense increase of look-ahead related research mostly due to the availability of cheap and accurate GPS receivers and increasing detail of digital maps. Look-ahead can also be seen as the natural development of the on board navigation system since it uses the same sources of information, GPS and a digital map. The most obvious use of the look-ahead horizon is to build a look-ahead cruise controller.

### 2.1.1 A switching controller using road curve

In [6] a control strategy utilizing information about road curve together with the slope of the road ahead is described. Alam discusses both the Pontryagin's minimum principle (PMP) and the linear quadratic regulator (LQR) methods to solve the optimal control problem throughly. He concludes that implementing such optimal controller is out of scope of his thesis. Alam also suggests a switching controller with switching rules based on analytical and engineering experience that handles speed limitations due to curvature and speed choice due to slope in different controllers. The suggested speed would be sent to the cruise controller which would actuate the suggested speed from the two controllers so it would form a look ahead cruise controller (lacc). The two controllers both uses the same input signals, road speed, road grade and curvature. The switching controller is tested and found to consume 4.8 % less fuel and be 1.5 % slower then an experienced driver instructed to maintain the legal speed limits and drive as intuitively as possible. The controller also reduced brake wear by 16 %, tests were carried out on road 225 between Södertälje and Nynäshamn.

### 2.1.2 A controller using dynamic programming

An approach using dynamic programming is described in [10] where Hellström repeatedly solves the optimization problem of what velocity trajectory to use over the horizon. The controller was tested in field on the highway between Södertälje and Norrköping. The average speed of the look ahead controller was set to speeds between 84 - 86 km/h and was compared with an ordinary cruise controller set to the same speed. The fuel consumption was lowered by 3.53 % on average while trip time remained constant. Due to the look ahead controller's ability to increase speed before up hills and thereby avoid unnecessary gear changes the number of gear changes was reduced by 42 %.

#### DPtool

DPtool is the Matlab based application developed by Hellström to calculate optimal speed trajectories over a horizon. The number of horizon segments is unlimited and their length can be chosen to an arbitrary length. The discrete longitudinal vehicle model used by DPtool is implemented in Simulink and is similar to the model described in Chapter 3.

#### Cost function

The cost function in [10] considers time use, fuel use, speed change and gear shift, each has a weight factor connected to it. The relation between time use and fuel use is the most important since that will determine the average speed of the controller. A steady state case on a flat road is introduced to determine the trade-off between time and fuel for different set speeds.

$$J = M + \beta T \tag{2.1}$$

## 2.2 IDT

The driver behavior research from an economic perspective has been energized lately due to the increasing environmental debate and insight that the driver behavior has substantial influence on the fuel efficiency.

### 2.2.1 A study on driver advice in real conditions

In [14], a study including a thousand trucks in Japan, equipped with simple systems for driver training is presented. The study shows that the fuel consumption of a heavy truck mostly traveling on highways can be lowered by up to 3% if the driver is given advice how to improve driving behavior to reduce fuel consumption. The advice focuses mainly on reducing heavy acceleration, maintaining economic speed and to avoid unnecessary idling. The advice in the study came from simple systems that only use the vehicle velocity as input signal and process it to present advice to the driver interactively. A reference measurement over 5 months were conducted November 2004 to March 2005 and a measurement with the drivers using the advice systems were conducted from November 2005 to March 2006. A total of 1048 heavy duty vehicles was included in the study, 280 vehicles was excluded from the study since they were forced to drive with snow chains from late 2005 to early 2006 due to an unprecedented harsh winter. Of the 768 remaining heavy duty vehicles 26 % were highway going, these 200 heavy trucks improve their fuel economy by about 3 %. The remaining trucks, mainly used for local transportation, showed an improvement rate of 9 %.

### 2.2.2 A study of an electronic system for driving advice

Haraldson and Nilsson [9] describes a method to develop an interface for driver training. Two aspects of this extensive thesis are described below, the interviews made with truck drivers and the extensive literature study.

#### Interviews

In the effort to understand how a driver training system will be received by different types of drivers a series of interviews were conducted with drivers of different kind. The interviewees were confronted with different types of presentation models, for instance four different models of mean fuel consumption. The answerers where then analyzed to find opinions and attitudes of the drivers. In this context a fleet of heavy vehicles is a number of vehicles operated by the same owner but driven by separate drivers.

- Compare the drivers current fuel consumption with the drivers mean fuel consumption.
- Compare the drivers current fuel consumption with a set goal for mean fuel consumption.
- Compare the drivers mean fuel consumption with the mean fuel consumption of the rest of the fleet.
- Compare the drivers mean fuel consumption with the mean fuel consumption of individual drivers in the same fleet.

They were also asked more general questions such as how they best take in information from text, pictures, voice, vibrations or sounds.

Using Janhagers Use Profile [12], which allows generalized types to be created from a mass of interviewees, three types of drivers were distinguished from the drivers interviewed.

- Competing Thomas works for a fleet operator who is working on saving fuel. He has been sent to a course and has great knowledge about what affects fuel consumption. The fleet operator encourages Thomas to compete with the other drivers in the fleet in order to improve his own fuel consumption.
- Economical Eric own his own vehicle and therefore pays for his own fuel. Eric would be glad to reduce costs and therefore tries to reduce speed in order to reduce costs, but it is hard since the delivery times must be kept. He would like to take a course in echo driving but has nether the time or money.
- Conservative Kent drives the way he always did. He thinks it is too late for him to change driving behavior and sees the fuel consumption as the fleet operators problem not his. Conservative Kent does not have any bonus system which considers his fuel consumption.

One conclusion from the interview series was that there is a wide range of opinions among the drivers as seen in the three driver types above. This spread comes largely from different types of employment and age. Trust was an important factor among the interviewees, many doubted that a fair system was possible to achieve, many interviewees said that they did not trust the systems they used. Another interesting problem was that some interviewees expressed that their competence was questioned when given advice.

The interface should educate, change habits and motivate drivers of different ages and different employment types.

**Litterature**

There is extensive literature available concerning the cognitive ergonomics of a car driver. The similarities in surrounding environment or the traffic situation is the same for a heavy truck driver as for a car driver and therefore the cognitive ergonomics are considered in this thesis to be the same for a car driver as for a truck driver. Although the environments are similar the authors recognize that they still differ some, for example car drivers and truck drivers use their vehicles for different periods of time, a truck driver drives longer time and have a bigger risk of experiencing fatigue or boredom.

A model of the human information process according to [15] is presented and explained in [9]. Stimuli, mostly visual impressions, affects the perception which in its turn cooperates with the memory to make a choice of response which in its turn needs to be executed. The attention recurses are divided between the perception, choice of response and the execution. Different individuals have different amount of attention recourses at different awareness levels but they are always limited [9].

The awareness level affects the amount of attention recourses available, more awareness gives more attention up to the point of stress where attention recourses declines. On the other end of the awareness scale the amount of attention is reduced when the driver falls into boredom and fatigue.

Driver distraction is considered to be a central cause of traffic incidents and is essential in the forming of a system that can be considered as a distraction.

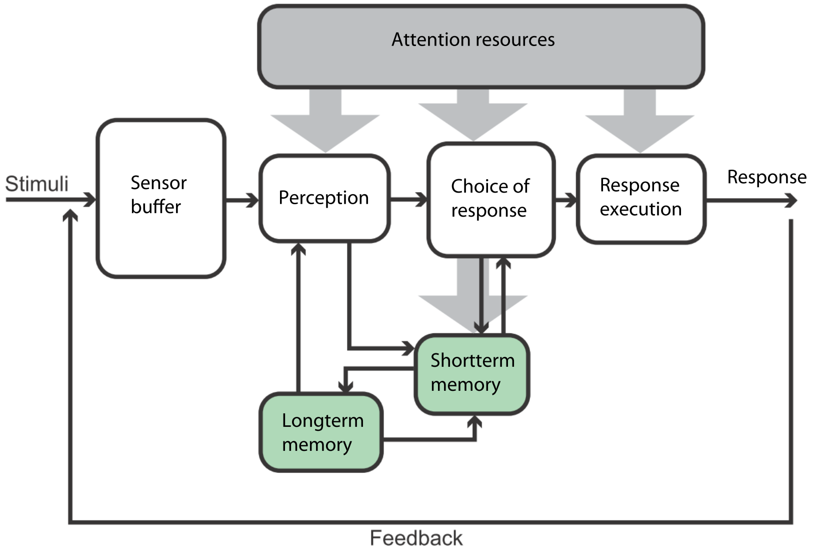


**Figure 2.1.** *The information process as described by Wickens and Hollands in [9]. Note that the attention recourses are divided between perception, choice or response and response execution.*

Haraldson and Nilsson [9] concludes that the term distraction does not have a recognized definition but literature agrees that a distraction is a task that takes away attention from the primary task. The primary task in this case is to drive the vehicle in a safe and in some cases economical manner. Many countries have legislated against talking on mobile phones to reduce the risks of traffic incidents by reducing the secondary tasks while driving [1].

## 2.3 Message apprehension discussion

How much information can the driver take in from the messages is a central question. It can be divided into two parts, the message frequency and the message resolution or the level of detail in the sent information. Different types of drivers will have different ability to take in the information presented. There is also a limit of how much of the driver training systems information is relevant. To get the biggest impact on driver behavior the intensity of the message must match the ability and ambition of the driver. The message intensity also presents a safety concern, how much attention is the message allowed to take away from driving the vehicle? The most reasonable way to handle this problem must be to let the driver set the frequency and resolution of his system. During the Scania Driver Support sessions when the driver is attending a course, these two parameters could be set by the teacher in consensus with the driver to match the drivers ambition. A safety feature can be to detect intense situations such as city driving or accelerating on to a highway and keep the system from displaying messages in those situations.

# Chapter 3

# Vehicle modeling

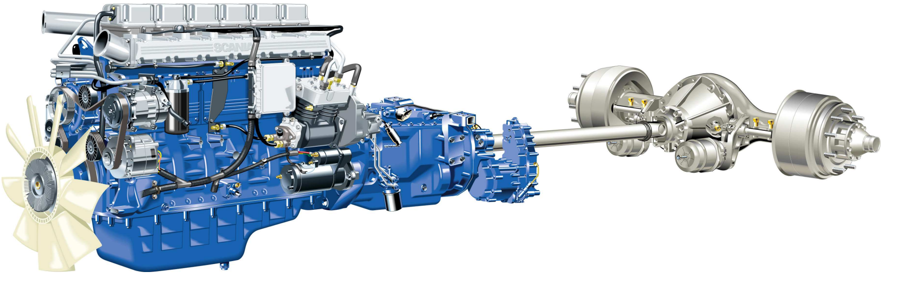

**Figure 3.1.** *Scania 12 litre driveline.*

In this chapter a longitudinal vehicle model will be described. The different parts of the powertrain will be modeled separately using basic physical principles and commonly used relations. The engine will be modeled giving drag torque.The main components of a heavy duty vehicle powertrain are the engine, clutch, gear box, propeller shaft, final drive, drive shafts and wheels. These will be described in this chapter together with mathematical models.

## 3.1 Driveline modeling

### 3.1.1 Engine modeling

An internal combustion engine transforms air and fuel into power and emissions, the model will describe a diesel engine. Diesel engines have for a long time been the only engine used for heavy trucks, and they still will be in the near future [13]. The main part of the power produced by the fuel will be lost as heat in the exhausts and cooling system and a certain part of the useful power output will be lost in form of mechanical friction which will add to the heat losses and finally pumping work. The power produced at the crankshaft will drive auxiliary systems

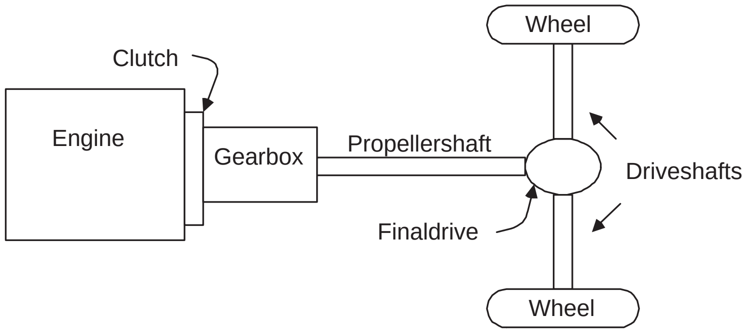


**Figure 3.2.** *The main parts of a heavy duty powertrain, as described by the model in this chapter.*

such as cooling fans and the alternator. The torque output of the engine after auxiliary losses will be modeled as a function of fueling and rotational speed:

$$T_e = f_e(\omega_e, u_f) \tag{3.1}$$

where $T_e$ is obtained empirically through engine mapping of an engine without auxiliary systems. The engine does not have its auxiliary components in the test cell so the engine map obtained from the test does not include auxiliary systems. The torque demand from the auxiliary systems are estimated based upon their maximum demand. The output torque at the flywheel will be the auxiliary and the mapped torque put together. The longitudinal vehicle model described in this chapter only considers the engine giving drag torque, when the fueling is set to zero, $u_f = 0$. At idling speeds the idle controller will set $u_f > 0$ to prevent the engine from stalling.

The rotational speed of the engine will be modeled using the generalized Newton's second law of motion and the torque equilibrium between torque produced by the engine and the torque transferred to the clutch.

$$J_e\dot{\omega}_e = T_e - T_c \tag{3.2}$$

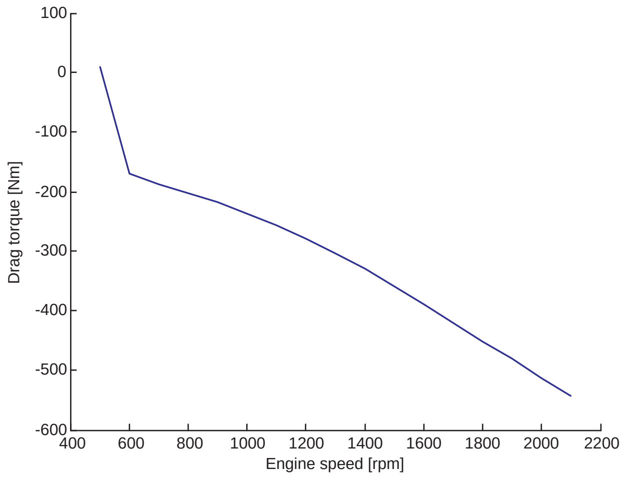


**Figure 3.3.** *Drag torque at the flywheel as a function of engine speed. Note that the drag torque is zero at the idling speed (about 500 rpm) and that is when fuel is injected to prevent the engine from stalling.*

### 3.1.2 Clutch, gearbox and final drive

The clutch consists of a disc pressed to the flywheel of the engine, the gradual increase of friction between friction disc and flywheel when the clutch is released ensures a smooth build up of torque limiting vehicle wear and increasing comfort. For the model presented in this thesis the clutch will be considered as rigid and the gear shifts to be instantaneous and thus always engaged.

$$\begin{array}{rcl} \omega_e & = & \omega_c \\ T_e & = & T_c \end{array} \tag{3.3}$$

The gearbox transmits the torque from the clutch to the propeller shaft with different conversion ratios, $i_g$, using different combinations of cog wheels (gears). This ratio changes with the different gears selected by the driver or the gearbox controller. The final drive also has a conversion ratio, $i_f$, changing the rotational speed of the propeller shaft to the drive shaft. The transmission ratio of the final drive and the gearbox will be lumped together giving a single transmission ratio $i_f i_g = i$. The in-going and out-going rotational speeds will be referred to as $\omega_e$ and $\omega_w$ respectively, they will relate to each other according to eq. (3.4) where $T_e$ is the engine torque and $T_d$ is the torque at the drive shaft:

$$\begin{array}{rcl} \omega_e & = & i\omega_w \\ T_d & = & iT_e \end{array} \tag{3.4}$$

Let $J_w$ denote the inertia of the wheels and the inertias of the gearbox, propeller shaft, final drive and drive shafts. $r_w$ will denote the wheel radius. The generalized Newtons second law in its rotational form for the wheel can, using the notation above, be written as seen in eq. 3.5. Note that the model only considers the engine giving drag torque and is there fore negative.

$$J_w\dot{\omega}_w = -iT_e - T_f - F_w r_w \tag{3.5}$$

where $T_f$ is the internal friction of the entire driveline including clutch, gear box, propeller shaft, final drive and drive shafts. Gear box, propeller shaft and final drive are considered to rotate at the same speed. The friction is introduced as a torque modeled with a simple static efficiency:

$$T_f = iT_e(\frac{1}{\eta} - 1) \tag{3.6}$$

Combining eq. (3.5) and eq. (3.6) two terms can be canceled out giving an equation where only $\dot{\omega}_w$ is unknown:

$$J_w\dot{\omega}_w = -iT_e - iT_e(\frac{1}{\eta} - 1) - F_w r_w = -iT_e - \frac{iT_e}{\eta} + iT_e = -\frac{iT_e}{\eta} - F_w r_w \tag{3.7}$$

## 3.2 Resistance forces

Resistance forces are the forces acting on the vehicle in the opposite direction of the traveled direction, they are resisting the vehicle to go forward. Great measures are taken by the vehicle manufacturers to minimize these forces but in the case of a heavy truck there are some parameters that gives high resistance forces that are considered to be set. These are cross sectional area $A$ and mass $m$. These parameters are closely connected with the ability to carry load which is the main task for most heavy vehicles, therefore it is desirable to keep these parameters as big as legally possible.

### 3.2.1 Rolling resistance

The rolling resistance can be modeled as proportional against the normal force between the wheel and the ground, the rolling resistance coefficient is denoted by $c_r$. The normal force, $f_r$, to the ground is dependent on road slope, $\alpha$:

$$F_{r1} = c_r mg\cos(\alpha) \tag{3.8}$$

Trigonometric functions are preferably not used in the final algorithm due to the limited computing capabilities of the electronic control unit (ECU). A simplified model is introduced using the familiar simplification $\cos x \approx 1$ for small x. For normal slopes ($\pm 0.1$ radians) that can be encountered on highways the error using the simplification above will be small.

$$F_r = c_r mg \tag{3.9}$$

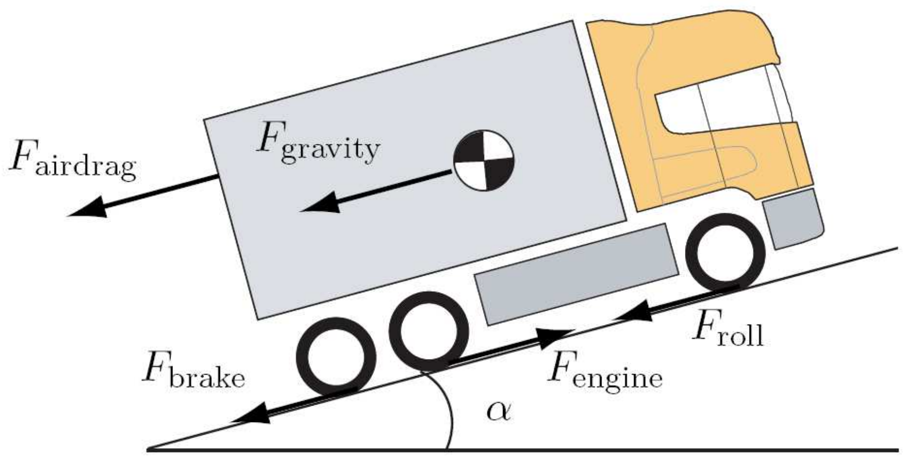


**Figure 3.4.** *The longitudinal forces inflicted on a heavy duty vehicle in motion.*

### 3.2.2 Gravitational forces

The longitudinal factor of the gravitational force for a vehicle traveling a road with the slope $\alpha$ [rad] is modeled as seen in (3.10).

$$F_{g1} = mg\sin(\alpha) \tag{3.10}$$

The unit of $\alpha$ when presented in the digital map is percent vertical rise per unit traveled distance it is also known as gradient. This have to be rescaled to radians using the standard formula:

$$\alpha_{rad} = \arctan\frac{\alpha_{grad}}{100} \tag{3.11}$$

Again a trigonometric function is not desired and the common simplification $\sin x \approx x$ can be done since slope will remain comparably small.

$$F_g = mg\alpha \tag{3.12}$$

### 3.2.3 Air drag

The aerodynamic resistance is, according to [16], modeled as eq. (3.13) where $c_w$ denotes the coefficient of aerodynamic resistance and $A_a$ the cross sectional area of the vehicle perpendicular to the travel direction.

$$F_a = \frac{1}{2}\rho_a A_a c_w v^2 \tag{3.13}$$

The aerodynamic resistance consists of two main parts, the pressure drag and the skin friction. The pressure drag is generated by the air being pushed in front of the vehicle and produces a pressure difference between the front and the rear of the vehicle. Skin friction arises when the outer layer of the body is dragged trough the air. A longer vehicle with a given front area will therefore have a higher $c_w$ value than a short vehicle with the same front area. Even for long vehicles the pressure drag is considerably larger than the skin friction, the latter making out only about 10% of the total air resistance. The above mentioned model includes both of these components, [16].

## 3.3 Model equations

Using the equations above the powertrain model will not consider any flexibilities or backlash, neither will it consider that wheel speed differs in curves. All these are considered to have a small impact on the longitudinal movement of the heavy duty vehicle [6], [10].

The combined longitudinal resistance forces from equations; (3.9), (3.12) and (3.13) gives the resistance force at the wheel $F_w$.

$$-F_w = \frac{1}{2}\rho_a A_a c_w v^2 + mg\frac{\alpha}{100} + c_r mg + m\dot{v} \tag{3.14}$$

The final model can be written in one model, based upon (3.2), (3.7), (3.6) and (3.14).

$$\dot{\omega}_w = \frac{-\frac{iT_e}{\eta} - F_w r_w}{J_w + mr_w^2 + \frac{i^2 J_e}{\eta}} \tag{3.15}$$

# Chapter 4

# Downhill detection and advice algorithm

One of many cases where look ahead information can be of use is when the vehicle is approaching a downhill. The accurate time to step off the accelerator can be hard to estimate for a driver, especially if the road is unknown.

The algorithm for detecting a downhill slope and calculating its fuel cut off point will be described here. The algorithm is made up of three main parts; the horizon buildup, the detection part and the calculation part. These parts are implemented in different blocks in the simulink model shown in Figure 4.1.

## 4.1 Horizon buildup

The Horizon buildup block receives map data from the external digital map as depicted in Figure 5.3. The data is sent in segments containing information about segment length and average slope in the segment. The digital map can send up to three segments per second depending on current horizon length and desired horizon length.

## 4.2 Detection

The detection block detects segments of the horizon where the vehicle will accelerate due to road grade with the engine dragging. The critical road grade will be where the vehicle will accelerate without fuel being fed to the engine but with the engine still coupled to the powertrain. The current critical road grade $\alpha_{crit}$ is calculated using the models described in Chapter 3 for a vehicle in steady state, i.e. the acceleration is zero. In the algorithm the calculated critical road grade is only dependent on velocity and vehicle mass. The actual critical road grade is also dependent on disturbances such as the wind conditions, that is disregarded for simplicity.

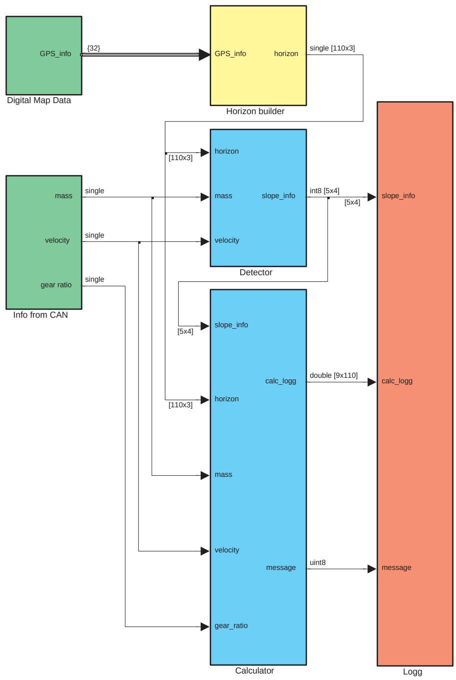


**Figure 4.1.** *The algorithm implemented in Matlab* SIMULINK *with its three main blocks in the middle. The dimensions in the brackets under the arrows represents the dimensions of the variable, the data type of the variable is also typed out on the arrows. GPS_info variable is a struct (its arrow is thicker then the others). The upper of the two blocks to the left reads data from the digital map. The lower of the left blocks reads data from the red CAN-bus. The block to the right is logging information from the Detector and the Calculator.*

$$\frac{F_r(m) + F_a(v) + T_w(v)r_w}{mg} = \alpha_{crit} \tag{4.1}$$

The criteria for a downhill is specified as follows: A segment of the horizon is a downhill if four out of five surrounding segments have a steeper downhill than the critical road grade. It can also be expressed as:

$$downhill_p = \begin{cases} 1 \quad if & \sum_{k=-2}^{k=2} f_{p-k} \geq 4 \\ 0 \quad if & else \end{cases} \tag{4.2}$$

Where $f$ is the criterion expressed in Equation (4.3) and $p$ is the position in the horizon. The subscript describes in which position of the horizon the value is valid.

$$f_p = \begin{cases} 1 & if \quad \alpha_p \leq \alpha_{crit} \\ 0 & if \quad \alpha_p > \alpha_{crit} \end{cases} \tag{4.3}$$

A matrix is created named *slope_info* that will pass information to the calculation block. A possibility to use less memory would have been to let the $slope\_info$ matrix have a variable length depending on the number of downhills detected in the horizon. The embedded matlab function does not allow dynamic variable dimensions so the length of the matrix is set to five, it is unlikely that more then five coherent slopes, according to the definition above, will occur in the proposed horizon length of two kilometers. The matrix contains informations about the following:

- The length of the downhill in meters.
- The start segment of the downhill in the horizon.
- The end segment of the downhill in the horizon.
- The altitude change of the downhill.

The initial ambition was to implement the algorithm in a ECU so the need to optimize memory use is apparent. Therefore the data type for the matrix needs to be as memory efficient as possible. The 8 bit unsigned integer (uint8) data type is extensively used in the algorithm to minimize memory use. Since the altitude change takes negative values it is not convenient to use it here. The 8 bit signed integer (int8) data type is chosen, it allows integer values from -128 to 127. The altitude change is calculated from two 32 bit single-precision floating point (single) data types it has got an accuracy limited by the accuracy of the data in the digital map. To keep some of the accuracy in the altitude change value it is scaled down so the altitude is expressed in decimeter [4].

If a downhill ends just before a new one is starting or the downhill flattens out in the middle so that it is categorized in two different downhills it is favorable to consider these as one single downhill. The vehicle will not have time to decelerate to the second downhill if it starts to close to the first downhills end. It might come to a situation where the vehicle reaches too high speed in the end of the second downhill and it needs to reduce speed by means of the brakes. If two downhills ends and starts within a specific distance and the altitude difference between the end point of the first downhill and the start of the second downhill is below a certain value the slopes are merged into one.

## 4.3 Calculation

The main task of the calculation block is to determine the fuel cut off point by calculating the velocity trajectory over the horizon. To do so it utilizes the vehicle model described in Chapter 3, the digital horizon created by the Horizon buildup described in Section 4.1 and the matrix sent by the detection block.

### 4.3.1 Euler solver

To solve the ordinary differential equation (ODE) of the longitudinal motion over the horizon a first order Euler estimation is used. The Euler method is used to solve many real life simulations with satisfying accuracy. Here follows an example:

---

Introducing Euler's solving method in its time based form;

$$a_{k+1} = a_k + \dot{a}\Delta t$$

where $a$ is a state that has a time derivate $\dot{a}$ and is solved over time in steps of $\Delta t$.

Consider a known ordinary differential equation $\ddot{x} = f(\dot{x})$, where x is the longitudinal position. Solving the velocity as function of x, $\dot{x} = f(x)$, the time derived $\ddot{x}$ needs to be expressed as the spatially derived velocity $\frac{d\dot{x}}{dx}$ using the chain rule;

$$\ddot{x} = \frac{d\dot{x}}{dt} = \frac{d\dot{x}}{dx}\frac{dx}{dt} = \frac{d\dot{x}}{dx}\dot{x}$$

when solved for the spatially derived velocity, using the notation above; $\frac{d\dot{x}}{dx} = \frac{\ddot{x}}{\dot{x}}$. Changing Euler's method to spatially based and using the velocity $\dot{x}$ as the state gives;

$$\dot{x}_{k+1} = \dot{x}_k + \frac{\ddot{x}}{\dot{x}}\Delta s$$

where $\Delta s$ is the spatial step length. The current state is calculated using the previous state plus the state change rate multiplied with the step length. The spatial step length determines the accuracy of the solution where small step lengths gives better accuracy.

If the known differential equation is set to $\ddot{x} = -\xi\dot{x}^2$ and the initial state is set to $\dot{x} = 80km/h$ the solution can be seen in Figure 4.3.1.

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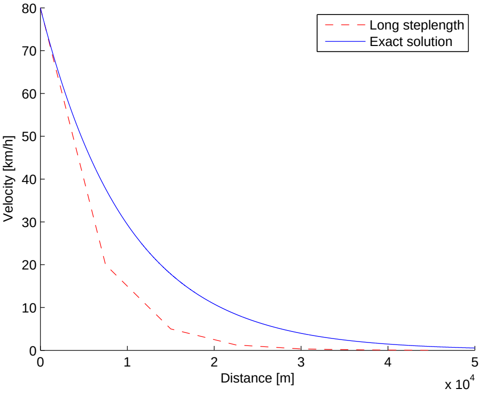


**Figure 4.2.** *An example of an Euler ODE solver, the dashed line, a low resolution estimation ($\Delta s$ = 7500 m) and the full line is the solution.*

The Euler estimation of the algorithm is going to solve the velocity backwards in a spatially sampled environment. Since it is solved backwards we need to subtract the difference calculated by the derivative and the time step.

$$v_k = v_{k+1} - \frac{dv}{ds}_{k+1} \Delta s_{k+1} \tag{4.4}$$

The acceleration gained from Newtons second law is time based $\frac{dv}{dt}$ and the acceleration needed for the Euler solver is spatially based $\frac{dv}{ds}$. So we need to change from time sampled to spatially sampled. Using the chain rule we can go from time derivative to spatially derivate.

$$\frac{dv}{dt} = \frac{dv}{ds}\frac{ds}{dt} = \frac{dv}{ds}v \Leftrightarrow \frac{dv}{ds} = \frac{\frac{dv}{dt}}{v} \tag{4.5}$$

Combining eq. (4.4) and eq. (4.5) gives the equation used in the algorithm:

$$v_k = v_{k+1} - \frac{\frac{dv}{dt}_{k+1}}{v} \Delta s_{k+1} \tag{4.6}$$

### 4.3.2 Criterion

The starting point will be set to the end of the slope at the vehicle's current speed. The initial conditions are taken from the position of the end of the nearest downhill from the matrix produced by the detection block and the current velocity from the red CAN bus. It will then calculate the speed trajectory backwards over the horizon to until either of the following three stop conditions are met.

- The speed reaches below the low set speed. Then a new Euler loop is started where the start point of the downhill is the start point of the solution and the speed will be set to the low set speed.
- The speed reaches the vehicle's current speed. This point will be the fuel cut off point if the downhill is not steep or long enough for the vehicle to recover its speed from the low set speed.
- The horizon ends, meaning that if the throttle is let go at that moment the speed at the end of the downhill will be at least the current speed of the vehicle.

The figures below depicts the three different stop conditions the curve in the upper graph is the road profile of the horizon, the stars represents their start and end of the downhill detected by the detection block. The upper straight line in the lower graph represents the current speed, the lower straight line represent the low set speed. The curved line represent the velocity trajectory calculated by the calculation block.

The following three graphs describes the three cases presented above. The curve in the upper graph is the road profile of the horizon, the stars represents their start and end of the downhill detected by the detection block. The upper straight line in the lower graph represents the current speed, the lower straight line represent the low set speed. The curved line represent the velocity trajectory calculated by the calculation block. After the text "Message" the time to fuel cut off is displayed.

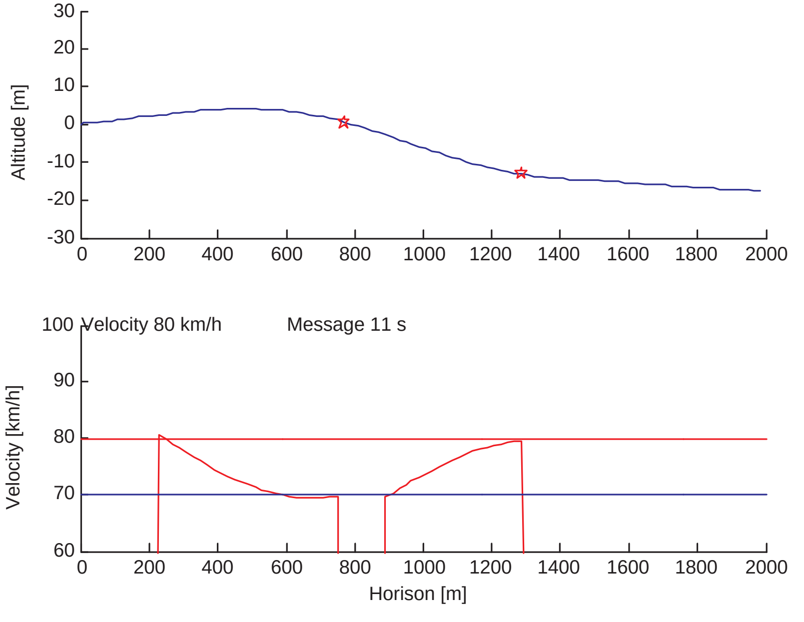


**Figure 4.3.** *Note the gap in the calculated speed trajectory, the speed reached the low set speed in the calculation and it is restarted at the start of the slope. This trajectory will let the truck reach the low set speed at the beginning of the slope and the truck will accelerate to over the current speed in the downhill.*

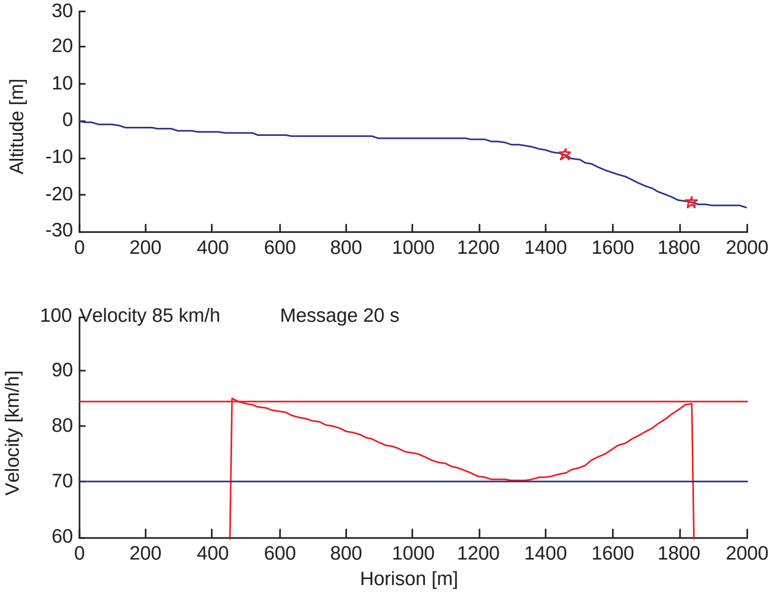


**Figure 4.4.** *The downhill is just long enough for the truck to regain its current speed if it is slowed down to the low set speed.*

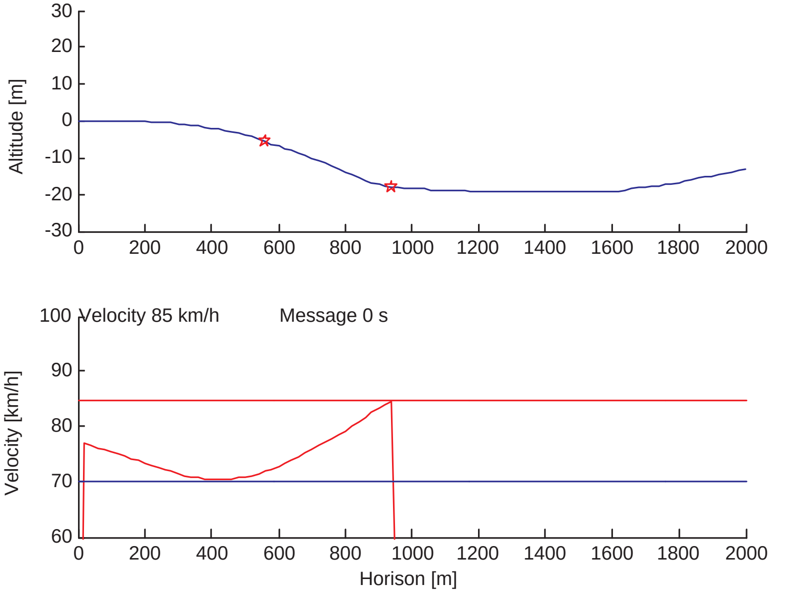


**Figure 4.5.** *The downhill is close enough for the driver to let go of the throttle now and still have more speed then the current speed.*

# Chapter 5

# Implementation

## 5.1 Laboratory environment

This chapter will describe the test environment and the set up of the tests. The test environment is the heavy truck and its electrical system together with the computer used for logging the CAN traffic. It also consists of the GPS receiver and the digital map stored in a separate ECU. The computer will have two different softwares active one to log the CAN traffic and the other to trigger and synchronize the GPS data to the digital map data.

### 5.1.1 CAN

To be able to see how internal vehicle data can be used in the algorithm, an understanding of the communication protocol is needed. To further understand the possibilities with the electronics a short study of the architecture of the electronics of the Scania vehicles of today is made. An early ambition of the project was to implement the final algorithm in a existing Rapid Prototyping System (RPS). Due to complications concerning the code building software real time workshop these plans had to be canceled.

Controller-area network (CAN) is a protocol for internal digital vehicle communication, the standard was introduced in the late eighties by Bosch Electric and has reach a widespread use in the automotive and aerospace industry [3]. It enables the manufacturer to use a single network for a wide range of applications and functions instead of having individual wiring between each ECU that needs to communicate with other ECUs. CAN incorporates serial digital communication, a solution that emphasizes on delivery security rather than bandwidth. CAN networks can be specified with different bandwidths up to 1 Mbps, faster transfer is made possible at the expense of delivery security. Information sent over a CAN network is divided into distinct packages or messages. The standard used by Scania is the J1939 where the messages are made up out of the following seven segments:

- Start of frame is essentially a logic one to indicate start of message and end of network idling to all other nodes.
- The arbitration field contains the 29 bit extended message identifier and the priority of the message.
- Control field specifies the length of the data field, usually 8 byte.
- Data field contains the actual data of the message.
- CRC field Cyclic Redundancy Check is a number calculated using a function that depends on Start of frame, Arbitration field, Control field and Data field. It is then possible to ensure that the information sent in the fields mentioned above is right by calculating the CRC-number in the receiving controller and compare it to the CRC-number sent in the message. This is similar to the last digit in a Swedish personal number.
- When a message is received by a station, the station sends the message back on the network with altered information in the ACK field as an acknowledgment of its delivery.
- End of frame: Every message is delimited by an array of seven logical ones.

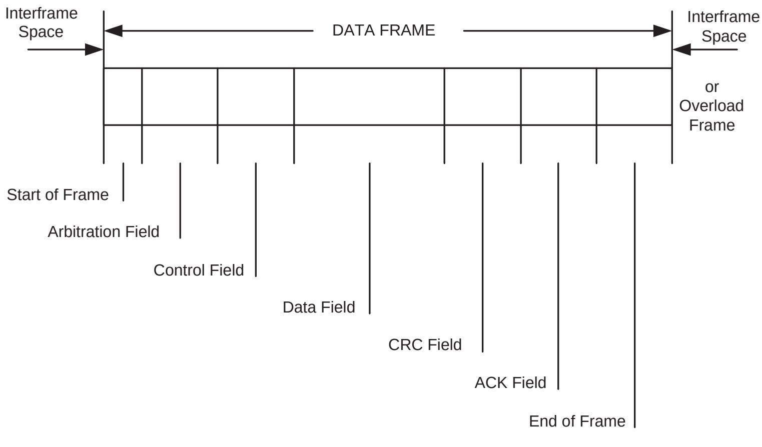


**Figure 5.1.** *The structure of a CAN message.*

Most functions in Scanias products are connected to the electrical system and most of the new functionality is made possible due to development in the electrical system. The information distributed in a modern vehicle is too much for just one CAN bus, the traffic is usually transmitted with a number of CAN buses. Another possible solution is to only use the CAN bus for operational critic information and other, faster, networks for less sensitive information. Other types of network can be flexray, IP networks or bluetooth for wireless applications. Scania uses three main CAN busses for distributing information in the vehicle. Each bus handles information with different sensitivity. The ECUs controlling the most sensitive functions are connected to the red CAN-bus, that is ECUs handling functions critical for security and operability such as engine and brake management. The yellow bus connects ECUs handling functions with legal demands, here we can find the instrument cluster and the control unit that takes care of the lights. Finally, the green bus handles information for less critical systems such as the radio and automatic cruise control. To make the system less sensitive to a network failure the information can only be passed between the different networks trough the coordinator ECU. To be able to read fault codes and maintain the electrical system a diagnostic bus is located on the green bus. The coordinator passes traffic to the other busses enabling the diagnostic tool to reach the ECUs on other busses. A standardized connection to the trailer where mostly brake information is passed is managed by the brake management system. If the truck needs to be fitted with a hydraulic crane or other specialized equipment this will be fitted by a body builder. In order to make it easy for body builders to access the electric system there is a body builder connection.

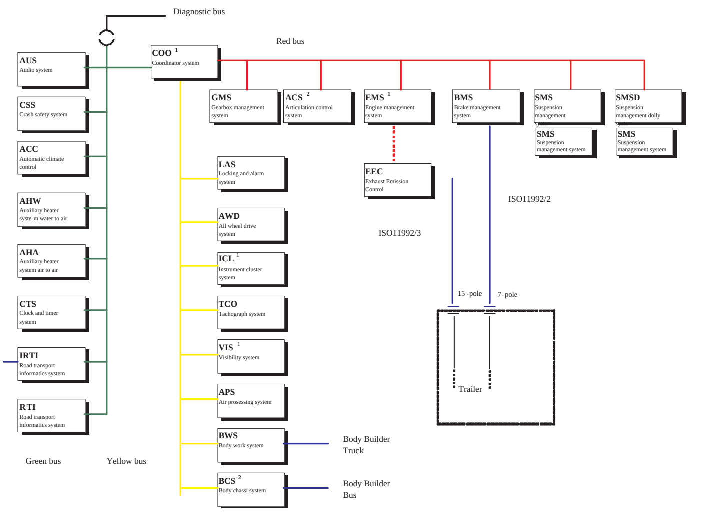


**Figure 5.2.** *The ECU architecture of a Scania vehicle. The three busses are clearly separated to reduce the risk of network failure on all three busses but are all connected to the coordinator. Depending on the specification of the truck the number of ECUs change but the coordinator is always present.*

### 5.1.2 Vehicle

To be able to simulate the algorithm in the computer and later in the RPS, the traffic on the CAN busses needs to be recorded during a test run with a truck. The truck used for this test were "Montana" with a loaded trailer to increase vehicle weight, see Figure 5.4. Early versions of the algorithm was implemented in the

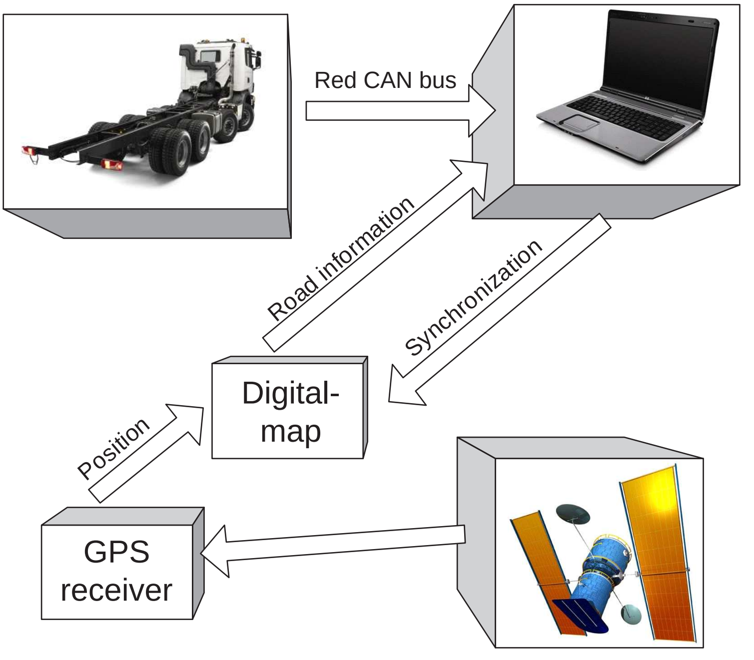


**Figure 5.3.** *Architecture of the test. The GPS receiver feeds its position to the digital map unit. The digital map unit sends road information to the PC and the PC sends back how long the horizon is at the present and what road information is needed. The PC listens to the red CAN bus to get information from the vehicle.*

RPS unit and tested with recorded CAN traffic in a bench simulation. This test and its results is described in Chapter 6.

### 5.1.3 Horizonviewer

Horizonviewer is a program that communicates with the digital map unit, who in its turn communicates with the GPS receiver. The software is running on a laptop during the tests and communicate with the digital map using the CAN J1939 protocol. The computer needs a vehicle communication interface (VCI2) adapter to send and receive messages over the CAN network.

## 5.2 IDT, hilltop behavior

To get the IDT score that the different drive strategies would give, the strategy is evaluated by the real IDT application in Matlab Simulink. The different values and environmental conditions are made available to the application and it gives grades back as it would when it is running in the ECU in the truck.


**Figure 5.4.** *Laboration vehicle "Montana" and trailer at the test track after completed testing. Length: 21m. Weight: 36 tonnes.*

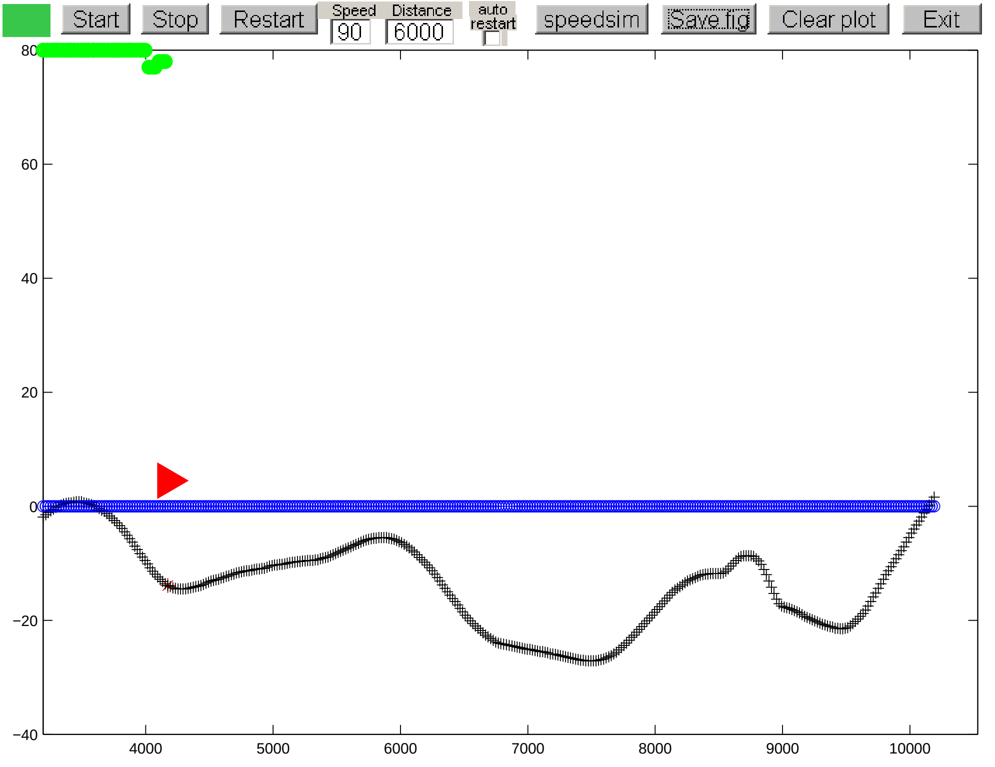


**Figure 5.5.** *Screen dump of the program Horizonviewer. The arrow represents the position of the heavy truck. The black crosses represent the start and stop positions of the segments. The horizon length is set to 6000 meter in the screen dump, in the algorithm a horizon length of 2000 meter is utilized.*

# Chapter 6

# Result

The result of the test carried out on the E4 northbound between the Hölö- and the Järna junctions is described in this chapter. The test stretch was chosen for its short and steep downhill ideal for IDT hill grade, and its vicinity to Södertälje. The test considers the algorithm described in Chapter 4.

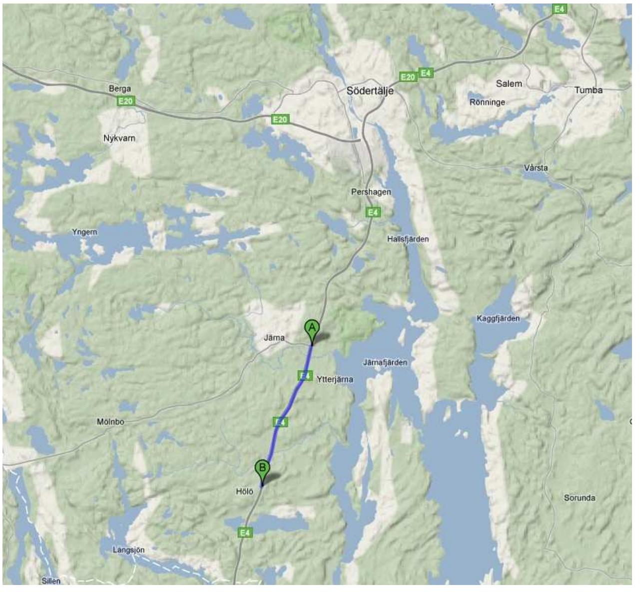


**Figure 6.1.** *The road between Hölö and Järna*

The slope offers a special challenge to the driver since the road has got a minor downhill slope in front of the main downhill. This puts the fuel cut off point further back and is harder to estimate for the driver.

## 6.1 Verification of the algorithm

To test the algorithm without implementing it in the onboard ECUs the fuel cut off point was found empirically. By stepping off the accelerator at slightly different points and the same speed over and over again a spot was found where the vehicle takes the same speed trajectory as suggested by the algorithm.

The speed trajectory of the test was plotted together with the speed trajectory of the algorithm to verify the accuracy of the model in the algorithm, see Figure 6.2.

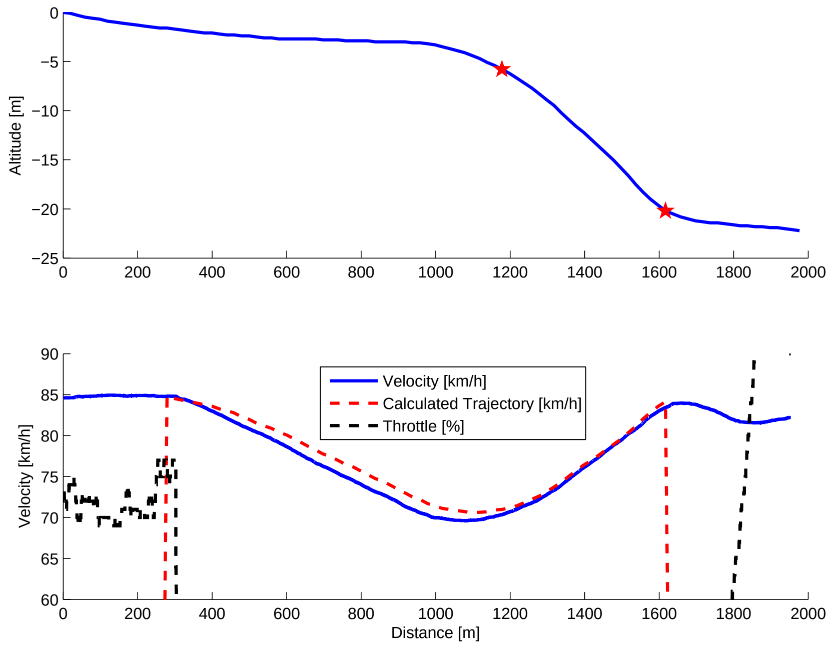


**Figure 6.2.** *The trajectories of the actual test and the suggested trajectories from the algorithm. The algorithms suggested fuel cut off point is 30 meter or 1.3 seconds in front of the test fuel cut off point. Estimation from the detection block is slightly off suggesting* $\alpha_{crit}$ *being too big, the error can also come from the low resolution of the road slope in the digital map.*

The trajectories are similar enough to make the assumption that the algorithm is able to resemble the vehicles longitudinal motion. The deceleration part does not have the same inclination and the lowest speed of the calculation only reaches 70.6 km/h while the lowest speed in the test was 69.6 km/h. The algorithm suggests a fuel cut off point 1.3 seconds earlier, that would give an even lower lowest speed than was reached in the test. The errors are still rather small and can be affected by disturbances such as wind, changed friction conditions or a faulty mass estimation. The trajectories are similar enough for the calculation to be considered as useful.

## 6.2 Optimized trajectory

To have a reference to the algorithms strategy it is compared with the trajectory suggested by DPtool described in section 2.1.2. Comparison will be in aspects of fuel, time and driveability. To generate a relevant speed profile DPtool must be set with the accurate parameters of which the LC set speed is the most important. The LC set speed is determining the trade off between fuel and time penalty or $\beta$ as seen in eq. 2.1.

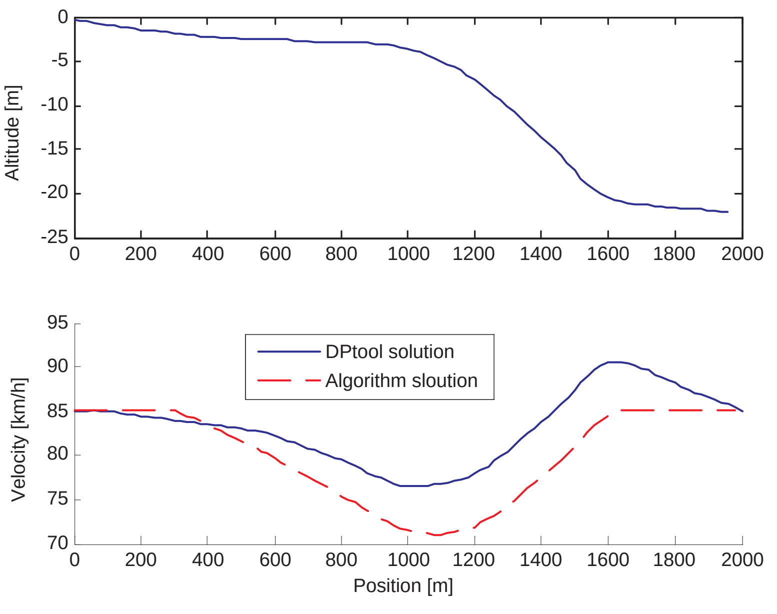


**Figure 6.3.** *The trajectories of the DPtool solution and the solution of the algorithm over the same downhill described above. Note that the dynamic programming solution is faster than the solution proposed by the algorithm, 87.6 seconds and 90.4 seconds respectively.*

The trajectory of DPtool is a faster strategy then the trajectory suggested by the algorithm. The DPtool trajectory travels the horizon in 87.6 seconds and the trajectory suggested by the algorithm would travel the horizon in 90.4 seconds. The DPtool solution never completely steps off the accelerator, it is suggesting a small amount of torque throughout the horizon. The possibilities to optimize a trajectory is greater if you have the possibility to set the accelerator pedal position gradually rather then the on off signal given by the algorithm. If a new algorithm using dynamic programming would be introduced, the speed trajectory of the

DP solution could be used to give advice to the driver. The problem is that the trajectory suggested by DPtool uses the full spectrum of the engine torque i.g. the accelerator is for example to be depressed to 34%, this is hard to achieve for the driver. If the DPalgorithm would penalize the use of the accelerator pedal places on the horizon could be identified where the pedal could be released.

To go further a dynamic programming algorithm could be set up to only allow the pedal to be fully depressed, fully released or used to maintain speed. An algorithm like this could have three simple advice to the driver:

- Full throttle.
- No throttle.
- Maintain speed.

Another approach would be to present the required speed shortly into the future from the optimized trajectory. Such system would use the optimized trajectory and have the driver itself as actuator. The problem would be the amount of attention required from the driver if a message is shown at a frequency so that the vehicle velocity would follow the trajectory.

## 6.3 IDT grade

The two different trajectories, seen in Figures 6.4 and 6.5, completes the stretch in different times, the DPtool solution is faster. Since IDT does not take travel time into consideration the faster strategies does will not be rewarded by IDT. IDT will consider the fuel spent for using a faster trajectory and set a lower grade on the DPtool trajectory. To compare these two a comparison between fuel and time must lay as a foundation, such a comparison is different from case to case and is hard to estimate.

## 6.4 Disturbances

One of the disturbances that will affect the longitudinal movement of a heavy truck is wind. It is the magnitude of the aerodynamic resistance force in relation to vehicle mass that will tell how sensitive the heavy vehicle is to wind. The interesting thing is to see how the fuel cut off point is moved when wind is taken into consideration. Since wind is not measured or modeled it is considered a disturbance and will not be considered in the model in the algorithm.

To see how the fuel cut off point is affected by wind conditions a constant wind speed $v_{wind}$ is implemented in the aerodynamic resistance model of the calculation block in the algorithm. The trajectories of the two wind conditions and the no wind case are calculated over an identical horizon using the modified calculation block, see Figure 6.6 and 6.7.

The ambient air velocity or wind will affect the relative wind of the vehicle depending on its amplitude and direction. The relative wind of the vehicle is the

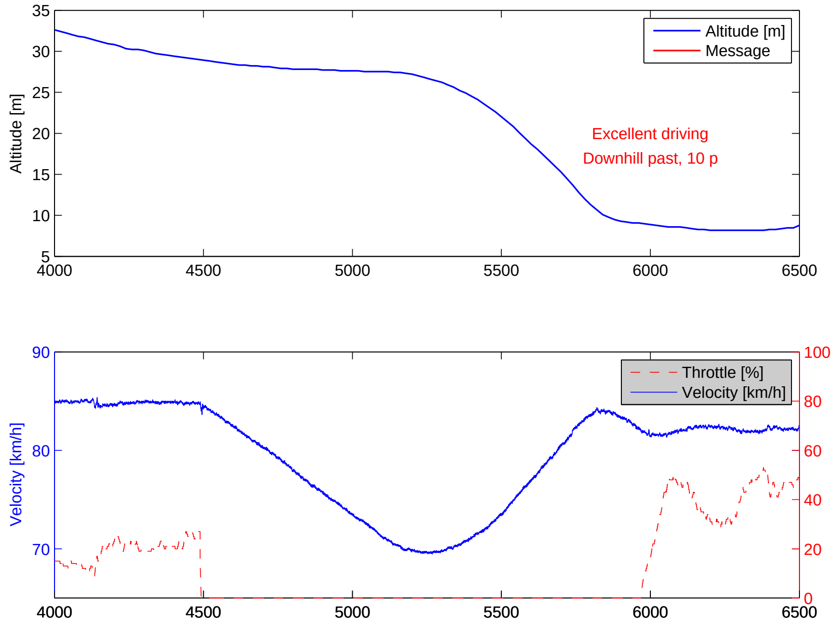


**Figure 6.4.** *The IDT evaluation of the test run. The test run has the same speed trajectory as the algorithm making the evaluation an indirect evaluation of the algorithm. Since the throttle is fully released during the slowdown and the following downhill the IDT system grades it higher.*

sum of the ambient air velocity and the velocity of the vehicle. If we consider the two cases of pure head wind and pure tailwind, the wind speed will simply be added or subtracted from the vehicle speed, as seen below.

$$F_a = \frac{1}{2}\rho_a A_a c_w (v + v_{wind})^2 \tag{6.1}$$

Two wind conditions were simulated: headwind 6.5 m/s and tailwind 6.5 m/s. 6.5 m/s is a 4 on the the Beaufort scale and is occurring 25 % of the time on Swedish roads at 2 meters above the road surface [11] p. 423. It must of course be considered that the wind is not always exact headwind or tailwind, most of the time the wind will come from an angle, the aim of the test is to show the extremes.

The difference between no wind and headwind is 16 seconds meaning that the driver is supposed to release the accelerator 16 seconds later in the case of headwind. In the case of tailwind the driver should have let go of the accelerator before the current position, see Figure 6.6.

To further understand the influence of wind another slope profile is analyzed with the same wind speeds, see Figure 6.7. In this case the considered downhill

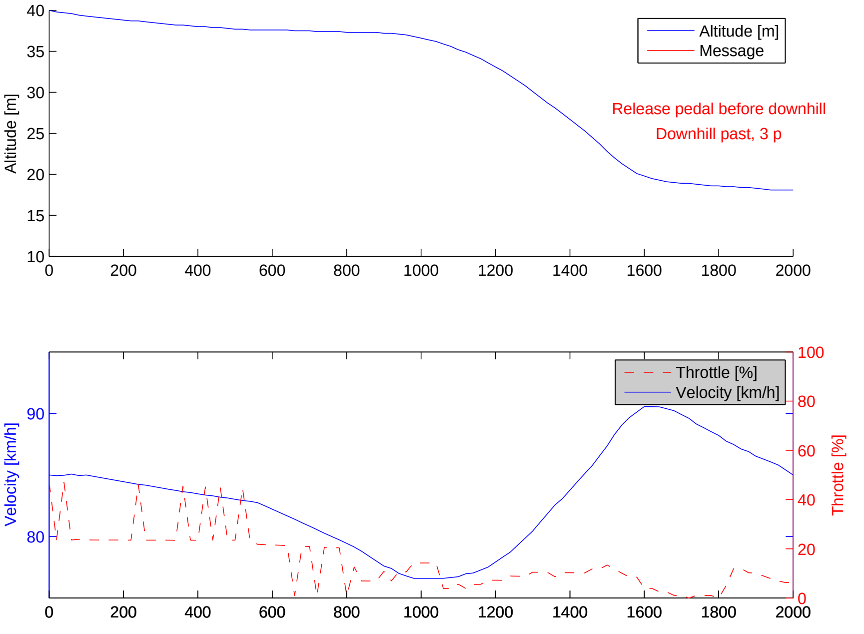


**Figure 6.5.** *The IDT evaluation of the speed trajectory suggested by DPtool. The throttle is not released fully during the slowdown so the IDT system grades it lower, it expects a full release of the throttle.*

has a uphill in front of it, a typical hill. This road profile presents less challenge to the driver since the distance from the fuel cut off point to the beginning of the downhill is shorter. Therefore it is not as interesting in the aspect of giving advice to the driver since, if he is reasonable experienced, it is easier for the driver to estimate the fuel cut of point it is closer to the downhill.

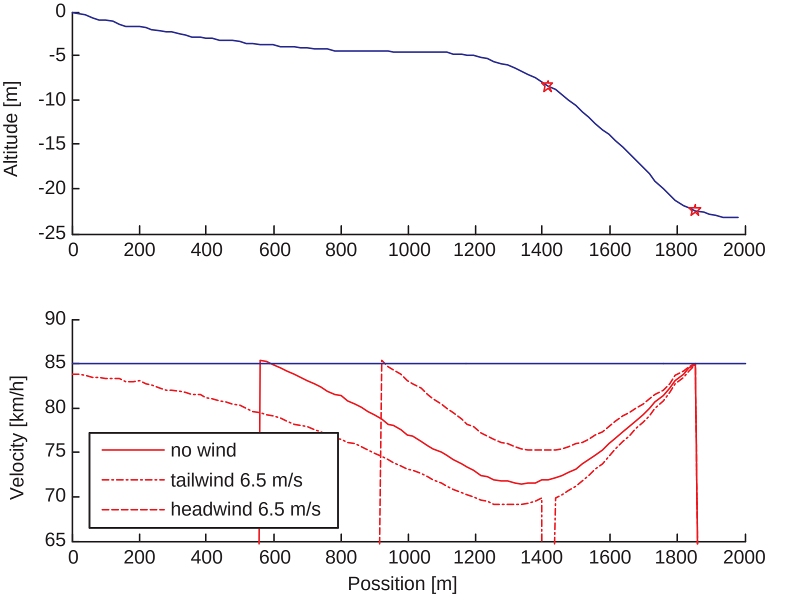


**Figure 6.6.** *Different calculated speed trajectories with different ambient wind conditions. The downhill detection will not be affected by the wind, meaning that* $\alpha_{crit}$ *and the detected downhill will be identical for all three trajectories. Note that acceleration is taking place before the detected downhill in the tailwind case and that the vehicle is retarding in the detected downhill in the headwind case. The difference in fuel cut off time between the no wind case and the headwind case is 610 m or 16 seconds traveling at 85 km/h, a considerable difference.*

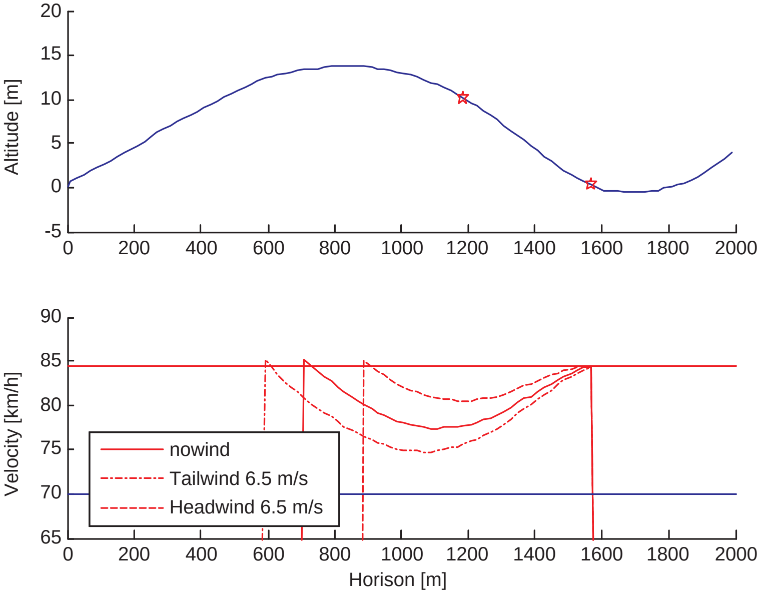


**Figure 6.7.** *Different speed trajectories with different ambient wind conditions calculated over a crest. The difference in time for the headwind and tailwind cases to the no wind case are 13 and -7 seconds respectively. Note that the downhill is not steep or long enough to regain initial speed from more than 77 km/h in the no wind case.*

# Chapter 7

# Conclusions

Interaction between vehicle and driver has traditionally been rather simple; the driver gives input to the vehicle by throttle position and steering angle and the vehicle responds by accelerating and turning. Later different types of indicators started to appear, such as the oil pressure lamp and coolant temperature, to give feedback to the driver to avoid a breakdown. Recently gauges showing the instant fuel consumption have been on the market. They give interesting information but do not provide the long perspective needed to evaluate the driver's performance. A fuel consumption gauge also gives too crude information making it hard to distinguish poor driver performance from external conditions, for example heavy load.

More capable onboard electronics and a increased desire to improve fuel consumption has paved way for driver training systems helping drivers to develop their abilities. The advice system suggested in this thesis could help a driver to improve their driving, but there are problems. As figure 6.6 suggests, the impact of disturbances such as wind will make the advice suggested in this thesis inaccurate or even irrelevant during certain conditions. If the algorithm calculates the fuel cut off point to 16 seconds too early as seen in figure 6.6, the relevance of the message sent to the driver is rather random. The driver may lose faith in the message, causing it to be disregarded and considered as an annoyance.

Setting up a parameter adjustment system could be a solution, a system that evaluates conditions from the last downhill passed and adjust parameters to compensate for different conditions. The problem with such a system is that the time between two downhills might be considerable and conditions might have changed, it is always hard to estimate surrounding conditions.

Having speed trajectories that the truck can follow in a closed loop system has proven successful in other cases but it always involves automatic speed control. In this concept the driver controls the speed, so if there would be a speed trajectory presented for the driver to follow the driver could be considered to be part of a closed-loop system. Such a system would increase robustness to disturbances such as the ones described above. A message to the driver could state: "Reduce speed to xx km/h over the next xxx meters". The distance will thereafter reduce until the point is reached, it would be up to the driver to reach the desired speed by reducing throttle long before or releasing it completely just before.

# Bibliography


[1] Driving abroad. http://www.aboutdrivingabroad.co.uk.

[2] Ipcc fourth assessment report: Climate change 2007. http://www.ipcc.ch.

[3] Can specification, 1991. http://www.semiconductors.bosch.de/pdf/can2spec.pdf.

[4] Matlab documentation, 2008.

[5] Assad Al Alam. Test report, IDT kröntagning, 2009.

[6] Assad Al Alam. Optimally fuel efficient speed adaptation. Master's thesis, Royal Institute of Technology, 2008.

[7] Jonny Andersson. Technical Product Data, Interactive Driver Training, 2008.

[8] Vincent Blervaque, Klaus Mezger, Leo Beuk, and Jan Loewenau. Standardised interface between advanced driver assistance systems and digital maps for safer, smarter and cleaner transport. 2007. SAE 2007-01-1106.

[9] Kajsa Haraldsson and Emma Nilsson. Gränssnitt för interaktiv förarträning. att få förare att välja ett bränslesnålt körsätt. Master's thesis, Chalmers Institute of Technology, 2007.

[10] Erik Hellström. Look-ahead control of heavy trucks utilizing road topography. 2007. Licentiate thesis, Linköping University.

[11] Wolf-Heinrich et. al Hucho. *Aerodynamics of Road Vehicles*. Society of Automotive Engineers, International, fourth edition edition, 1998.

[12] Jenny Janhager. *User Consideration in Early Stages of´ Product Development : Theories and Methods*. Royal Institute of Technology, Stockholm, 2005. ISBN 0-321-04711-7.

[13] Lars Nielsen and Lars Eriksson. *Vehicular System*. Linköpings Universitet, 2007.

[14] Yutaka Takada, Shigeru Ueki, Akira Saito, Naoya Sawazu, and Yayoi Nagatomi. *Improvement of Fuel Economy by Eco-Driving with Devices for Freight Vehicles in Real Traffic Conditions*. Society of Automotive Engineers, International, 1 edition, 2007. SAE 2007-01-1323.

[15] C. D. Wickens and J. G. Hollands. *Engineering Psychology and Human Performance (3rd ed.)*. Upper Saddle River, NJ: Prentice Hall., 2000. ISBN 0-321-04711-7.

[16] J. Y. Wong. *Theory of Ground Vehicles*. John Wiley Sons, New York, 3 edition, 2001.