Institutionen för systemteknik
Department of Electrical Engineering

Examensarbete

Adaptive cruise control utilizing Look-Ahead information

Examensarbete utfört i Fordonssystem
vid Tekniska högskolan i Linköping
av

Johanna Rost

LITH-ISY-EX--09/4251--SE

Linköping 2009

Linköpings universitet
TEKNISKA HÖGSKOLAN

Department of Electrical Engineering
Linköpings universitet
SE-581 83 Linköping, Sweden

Linköpings tekniska högskola
Linköpings universitet
581 83 Linköping

Adaptive cruise control utilizing Look-Ahead information

Examensarbete utfört i Fordonssystem
vid Tekniska högskolan i Linköping
av

Johanna Rost

LITH-ISY-EX--09/4251--SE

Handledare: **Erik Hellström**
ISY, Linköpings universitet
Assad Al Alam
Scania CV AB

Examinator: **Lars Nielsen**
ISY, Linköpings universitet

Linköping, 9 June, 2009

Avdelning, Institution
Division, Department

Division of Vehicular Systems
Department of Electrical Engineering
Linköpings universitet
SE-581 83 Linköping, Sweden

Datum
Date

2009-06-09

Språk
Language

☐ Svenska/Swedish
☒ Engelska/English
☐ ____________

Rapporttyp
Report category

☐ Licentiatavhandling
☒ Examensarbete
☐ C-uppsats
☐ D-uppsats
☐ Övrig rapport
☐ ____________

URL för elektronisk version

http://www.vehicular.isy.liu.se

ISBN
—

ISRN
LITH-ISY-EX--09/4251--SE

Serietitel och serienummer
Title of series, numbering

ISSN
—

Titel
Title

Adaptiv farthållning med användande av Look-Ahead information

Adaptive cruise control utilizing Look-Ahead information

Författare
Author

Johanna Rost

Sammanfattning
Abstract

In this master thesis the possibilities of combining an adaptive cruise control with information about the road ahead has been studied. The focus has been to investigate the possibility to save fuel by using information about road topology, Look-Ahead. An adaptive cruise control, AiCC, is used when there are preceding vehicles and when the driver in addition to choosing a desired travel speed for the vehicle also chooses a desired time gap that is to be kept to preceding vehicles travelling slower than the own vehicle.

Using information about the road ahead and information of preceding vehicles a controller with the function to adapt the speed to the preceding vehicle, target, and at the same time reduce the fuel usage has been constructed. The controller considers the topography on the road and the distance to the target to be able to reduce the utilization of the brakes in steep downhills and to reduce fuel by slowing down before the downhill and then gain speed due to the gravitational force. The controller uses the assumption that the target travels with constant velocity at all time.

The work has included simulations with two different test roads, one in Sweden with shorter and not so steep downhills. The other road is placed in Germany and has long and steep downhills. In the simulations three various time gaps, 1, 2 and 3 seconds, has been used and three different weights of the preceding vehicle, 20, 40 and 50 tonnes. The vehicle with the controller using adaptive cruise control and Look-Ahead has a weight of 40 tonnes.

The results shows that fuel can be saved, using information about the road ahead in combination with an adaptive cruise control. The best result is obtained when the road contains steep and long downills, where the vehicle will gain speed due to the gravitational force. For the long and steep downhills the result is best when the target weight is 40 and 50 tonnes. When the downhills are smaller and not so steep the best result is obtained when the target weight is 20 tonnes. For these downhills the assumption that the target travels at constant speed makes the vehicle reduce the speed too much before the downhill, not considering that a heavier vehicle will accelerate in the downhill as well.

The time gaps that gives the best result is time gap 1 second. This is due to that the aerodynamic force acting upon the vehicle is reduced when there is a preceding vehicle at a not too far distance. The smaller the distance to the preceding vehicle the more the aerodynamic force is reduced.

Nyckelord
Keywords

Adaptive cruise control,Look-Ahead

Abstract

In this master thesis the possibilities of combining an adaptive cruise control with information about the road ahead has been studied. The focus has been to investigate the possibility to save fuel by using information about road topology, Look-Ahead. An adaptive cruise control, AiCC, is used when there are preceding vehicles and when the driver in addition to choosing a desired travel speed for the vehicle also chooses a desired time gap that is to be kept to preceding vehicles travelling slower than the own vehicle.

Using information about the road ahead and information of preceding vehicles a controller with the function to adapt the speed to the preceding vehicle, target, and at the same time reduce the fuel usage has been constructed. The controller considers the topography on the road and the distance to the target to be able to reduce the utilization of the brakes in steep downhills and to reduce fuel by slowing down before the downhill and then gain speed due to the gravitational force. The controller uses the assumption that the target travels with constant velocity at all time.

The work has included simulations with two different test roads, one in Sweden with shorter and not so steep downhills. The other road is placed in Germany and has long and steep downhills. In the simulations three various time gaps, 1, 2 and 3 seconds, has been used and three different weights of the preceding vehicle, 20, 40 and 50 tonnes. The vehicle with the controller using adaptive cruise control and Look-Ahead has a weight of 40 tonnes.

The results shows that fuel can be saved, using information about the road ahead in combination with an adaptive cruise control. The best result is obtained when the road contains steep and long downills, where the vehicle will gain speed due to the gravitational force. For the long and steep downhills the result is best when the target weight is 40 and 50 tonnes. When the downhills are smaller and not so steep the best result is obtained when the target weight is 20 tonnes. For these downhills the assumption that the target travels at constant speed makes the vehicle reduce the speed too much before the downhill, not considering that a heavier vehicle will accelerate in the downhill as well.

The time gaps that gives the best result is time gap 1 second. This is due to that the aerodynamic force acting upon the vehicle is reduced when there is a preceding vehicle at a not too far distance. The smaller the distance to the preceding vehicle the more the aerodynamic force is reduced.

Acknowledgments

I have enjoyed the time I have spent doing this master thesis work. It has been both fun and inspiring to be able to use some of the things it took me 4 years to learn at the university. There are many people who have been a great help to me during this thesis work, thank you!

Some special thanks to some special people.

Thanks to all the persons at REVM for making me feel welcome and making my time at your group the best. A special thanks to my supervisor Assad for his inputs and all his inspiration.

Thanks to Erik Hellström and Lars Nielsen for the valuable time and inputs you gave during our meetings. A special thanks to Erik for all the help with the report.

Thanks to all my friends.

A special thanks and all my love; to my mother for all her help with the report and for reading it to me out loud; to my father for all the dinners, laundry and for driving me where ever I want; to my sister for nothing and everything.

At last I want to thank Daniel for all his support and help, for listening to my endless discussion about my thesis work, for knowing when I am sad and for always making me feel loved.

Contents

Chapter 1

Background

Software in vehicles today have become more advanced and complex, increasing safety, comfort for the driver and improving the performance of the vehicle. For a heavy duty vehicle, fuel costs are one of the most significant costs in its lifecycle. That is why one major field of research is on how to reduce the fuel usage for heavy duty vehicles.

One way of saving fuel is to get information about the road ahead and then make control decisions based on the gathered information. The system is called Look-Ahead at Scania CV AB. Before implementing such a system, the possibilities and limitations in collaborating with other systems have to be explored. The function of an adaptive cruise controller in addition to the regular cruise controller already exists in Scania trucks today. Scania CV AB wants to investigate if Look-Ahead data can be used to improve the function of the adaptive cruise control (AiCC).

1.1 Adaptive cruise control

The adaptive cruise control (AiCC) has two main functions; to keep constant speed or keep a constant time gap to a preceding vehicle. The driver chooses a desired speed for the vehicle to travel at and also a desired time gap that he wishes to keep to other vehicles. When encountering a preceding vehicle the AiCC adapts the speed and adjusts the distance so that the time gap to the target agree with the time gap decided by the driver. In Figure 1.1 the main function of an adaptive cruise control can be seen. The AiCC is a comfort system which is developed to make the usage of a cruise controller possible even on trafficked roads.

The AiCC vehicle is equipped with radar which provides the AiCC vehicle with information about the distance and the relative velocity to the target vehicle, or target. The radar has a rather small angle and only vehicles that are in the radar's field of vision can be detected. The radar can detect up to four different vehicles at the same time, two in the right lane in front of the AiCC-vehicle and two in the left lane. Because of the narrow field of vision the target may be lost in sharp curves. Target simulation is used when this happens. Only the vehicles driving in the same direction as the AiCC vehicle will be detected, not oncoming vehicles or stationary objects.

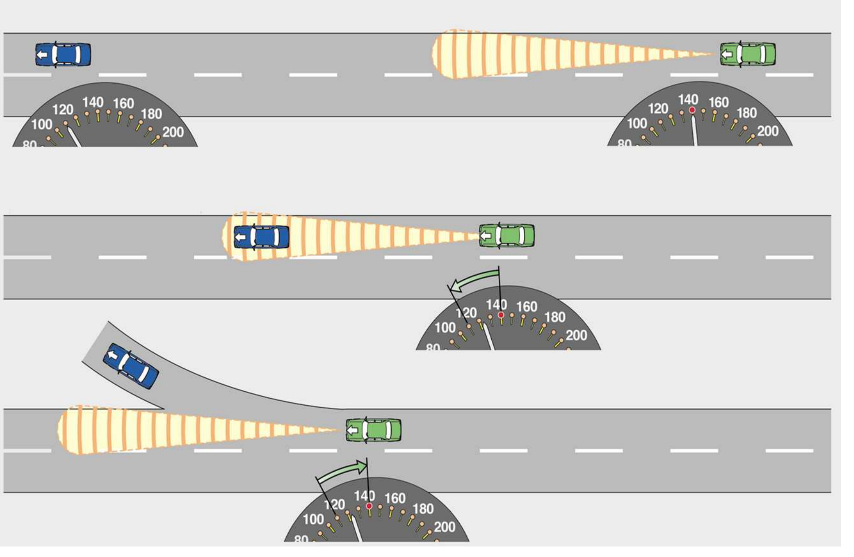

Figure 1.1. The function of an adaptive cruise control.

The adaptive cruise controller at Scania has five time gap settings which the driver can choose between, 1, 1.5, 2, 2.5 and 3 seconds. Where time gap 1 corresponds to 1 second, time gap 2 corresponds to 1.5 seconds, etc. The desired time gap is denoted by τ, the AiCC transforms the time gap to a distance which depends on the target speed. The distance to the target is denoted by d and is measured in meters. The vehicle velocity is denoted by v and the target velocity is denoted by v_t. The relative velocity is $v_{rel} = v_t - v$. The desired distance to the target when the time gap is τ is denoted by d_τ and is given by $d_\tau = \tau v_t$.

When adapting to a target the relative speed is the most significant control parameter. To obtain a smooth controller the distance to the target is allowed to vary within an interval around the desired distance. Unlike a regular cruise controller the AiCC can use the brakes to adjust the distance when the target is coming to close. The brakes are only used when the relative speed becomes negative, i.e. the AiCC vehicle is travelling at a higher speed than the target.

1.2 Look-Ahead

Look-Ahead is a system that uses digital maps and GPS positioning. The maps contain information about properties of the road and the GPS is used to get the position of the vehicle. The information in the maps can be topography, speed limits and curvatures etc. One of the opportunities is to use the information to decide a velocity trajectory which can be used for fuel savings.

1.2.1 Related work

How to use GPS positioning and digital maps to foresee the properties of the road ahead has been studied in many different ways. In [1] the curvatures, topography and speed limits are used to find an optimal velocity trajectory in curves and when changes in speed limits occur. Here an optimal control problem is solved using dynamic programming.

In [2] information about the topography is used to find an optimal control strategy with the goal to minimize the travelling time and the fuel consumption. Also here the problem is solved using dynamic programming.

1.3 Combination of AiCC and Look-Ahead

The technology to use knowledge of the road ahead of the vehicle is something that soon will be reality in heavy duty vehicles on the roads. Since a regular cruise controller does not consider the surrounding traffic the Look-Ahead controllers will not work when there is a preceding vehicle. Examining the possibilities to improve the performance of an AiCC is then an interesting matter. This will make a Look-Ahead controller work even on more trafficked roads and can also improve the functionality of the adaptive cruise controller. Today the AiCC is mainly a function with the purpose to increase the comfort for the driver.

Road data of interest for the AiCC is for example; topography, curvature, speed limits and information about exits. There are two different purposes of using Look-Ahead data in the AiCC. One is to examine the possibility to save fuel by adapting the speed to the target but also after road properties. The other purpose is to improve the system so it becomes more natural for the driver. With information about curvature the system knows when a curve, with a radius small enough for the radar to lose the target, is approaching. The system can also approximate when the target is supposed to be found again. This can improve the target simulations that occur when a target is lost due to a sharp curve or improve the handling of turn-offs.

In this thesis the focus will be on examining if the fuel usage can be reduced using a combined AiCC/Look-Ahead (AiCC/LA). An AiCC/LA that can be shown to have potential to improve the fuel consumption can be more attractive for buyers.

1.3.1 Premise

It is assumed that the vehicle has a preceding vehicle at all times during the simulations. The driver will also decide the route that shall be travelled so data can be obtained from the digital maps. The information of topography and position is assumed to be accurate and provided to the vehicle at all times.

1.3.2 Restrictions

During the development of the AiCC/LA it is assumed that the target travels with a cruise controller and can maintain constant velocity at all times. The case when there is more than one target will not be considered. The purpose of the work is to develop a model of the system. This model will not be implemented in a truck, only simulations will be performed.

1.3.3 Implementation

To be able to give a velocity reference the AiCC/LA needs information about the target provided by the radar, it also needs information about the current time gap and the cruise set speed for the cruise controller. It is assumed that information about the current road is available and that the vehicle position is provided by a GPS signal.

Chapter 2

Vehicle model

The powertrain is an important part when modelling the dynamics of a vehicle. It consists of the engine, clutch, transmission, shafts and wheels. To get a complete model the external longitudinal forces acting on the vehicle are added to the model of the powertrain.

2.1 Powertrain

The powertrain can be modelled in various ways depending on the application of the model. In this work the model is used to simulate the longitudinal velocity of the vehicle. A general modelling of the powertrain can be found in [3]. In Figure 2.1 the parts included in the model are shown.

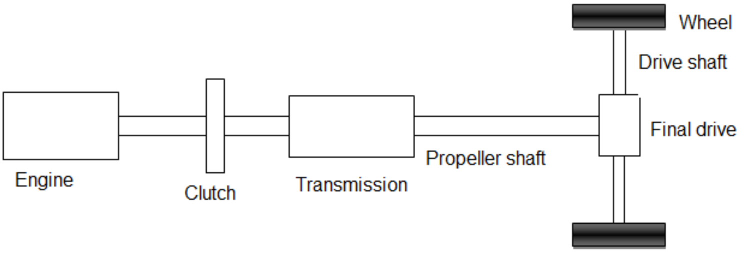

Figure 2.1. Powertrain

Engine: The output torque from the engine is characterized by the driving torque, M_e, which is produced during the combustion of fuel in the engine and the external load from the clutch, M_c. Newton's second law of motion gives the following model:

$$J_e \dot{\omega}_e = M_e - M_c \tag{2.1}$$

where J_e is the mass moment of inertia of the engine and ω_e is the engine speed.

Clutch: The clutch consists of a clutch disk connecting the flywheel of the engine and the transmission's input shaft. This kind of clutch is often used when the vehicle is equipped with a manual transmission. The clutch is assumed to be stiff, which gives the following equations:

$$M_t = M_c \tag{2.2}$$

$$\omega_t = \omega_c \tag{2.3}$$

where M_t is the output torque and ω_t is the output angular speed of the transmission.

Transmission: A transmission has a set of gears, each with a conversion ratio i_t and an efficiency η_t. This gives the following relation between the input and output torque of the transmission:

$$M_p = i_t \eta_t M_t \tag{2.4}$$

$$i_t \omega_p = \omega_e \tag{2.5}$$

where M_p is the output torque and ω_p is the output angular speed of the propeller shaft.

Propeller shaft: The propeller shaft connects the transmission's output shaft with the final drive. No friction is assumed and the propeller shaft is assumed to be stiff which gives the following equations:

$$M_p = M_f \tag{2.6}$$

$$\omega_p = \omega_f \tag{2.7}$$

where M_f is the output torque and ω_f is the angular speed of the final drive.

Final Drive: The final drive is characterized by a conversion ratio i_f and an efficiency η_f in the same way as for the transmission. Neglecting the inertia the following relation for the input and output torque holds:

$$M_d = i_f \eta_f M_f \tag{2.8}$$

$$i_f \omega_d = \omega_f \tag{2.9}$$

where M_d is the output torque and ω_d is the angular speed of the drive shafts.

Drive Shafts: The drive shafts connect the wheels to the final drive. The drive shafts are modelled as one shaft because it is assumed that the wheel speed is the same for both wheels. The drive shafts are assumed to be stiff and generate the following equations:

$$M_w = M_d \tag{2.10}$$
$$\omega_w = \omega_d \tag{2.11}$$

where M_w is the output torque and ω_w is the angular speed of the wheels.

Wheels: Assuming no slip, the connection between the wheels and the road can be described as:

$$J_w \dot{\omega}_w = M_w - M_b - r_w F_w \tag{2.12}$$
$$v = r_w \omega_w = \frac{r_w \omega_e}{i_t i_f} \tag{2.13}$$

where J_w is the mass momentum of inertia of the wheels, F_w is the resulting force at the wheels, r_w is the wheel radius and v is the vehicle velocity. The wheel friction is neglected, $M_b = 0$.

2.2 Longitudinal forces

Figure 2.2 shows the longitudinal forces acting on a heavy duty vehicle. F_{brake} is neglected in this model because the brakes are not supposed to be used by the system and then not needed in the model.

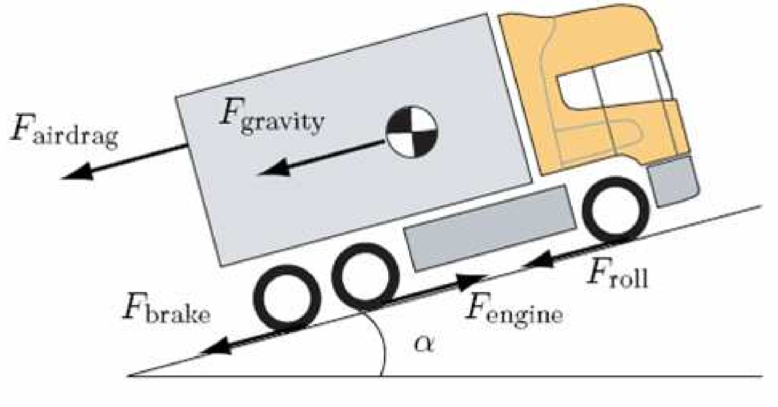

Figure 2.2. The longitudinal forces acting on a heavy vehicle.

Newton's second law of motion gives the equation:

$$m\dot{v} = F_{engine} - F_{air}(v,d) - F_{roll}(\alpha) - F_{gravity}(\alpha) \tag{2.14}$$

Where $F_{engine} = F_w$ in the model of the powertrain, d is the distance to the target, α is the road slope and v is the vehicle velocity.

The aerodynamic force is given by:

$$F_{air} = \frac{1}{2}\rho_{air} c_D(d) A_f v^2 \tag{2.15}$$

where ρ_{air} is the density of air, A_f is the cross-sectional area of the vehicle and $c_D(d)$ is the aerodynamic drag constant. The rolling resistance is given by:

$$F_{roll} = c_r mg\cos\alpha \tag{2.16}$$

where c_r is the rolling resistance coefficient, m is the vehicle mass, α is the road slope and g is the gravitational constant. The resistance due to gravity is the longitudinal component of the gravitational force and is given by:

$$F_{gravity} = mg\sin\alpha \tag{2.17}$$

Together with the model of the engine the equations can be written as

$$\dot{v} = \frac{1}{\frac{J_w}{r_w^2} + m + \frac{i_t^2 i_f^2 \eta_t \eta_f J_e}{r_w^2}}\left(\frac{i_t i_f \eta_t \eta_f}{r_w} M_e - \frac{1}{2} c_D(d)\rho A_f v^2 - c_r mg\cos\alpha - mg\sin\alpha\right) \tag{2.18}$$

Eq. (2.18) is time dependent, since the digital maps are based on position it is convenient if the equation depends on the position instead of time. Making the assumption:

$$\frac{1}{\frac{J_w}{r_w^2} + m + \frac{i_t^2 i_f^2 \eta_t \eta_f J_e}{r_w^2}} \approx \frac{1}{m} \tag{2.19}$$

the following transformation can be made to make Eq. (2.18) become position dependent:

$$\frac{dv}{dt} = \frac{dv}{ds}\frac{ds}{dt} = \frac{dv}{ds}v \Rightarrow \frac{dv}{ds} = \frac{1}{vm}(F_{engine} - F_{air} - F_{roll} - F_{gravity}) \tag{2.20}$$

Since the data from the map and the GPS is sampled it is convenient if Eq. (2.20) is discretized. This is done by using a first order Euler approximation, Eq. (2.20) can then be rewritten as:

$$v_k = v_{k-1} + \Delta a_{k-1}\Delta s \tag{2.21}$$

where Δs is the length of the segment and Δa_{k-1} is given by:

$$\Delta a_{k-1} = \frac{1}{m}\left(\frac{M_{e,k-1} i_t i_f \eta_t \eta_f}{r_w v_{k-1}} - \frac{1}{2}\rho_{air} c_D A_f v_{k-1} - \frac{c_r mg}{v_{k-1}} - mg\frac{\sin\alpha_k}{v_{k-1}}\right) \tag{2.22}$$

Where v_k is the velocity the truck will have at the end of segment k and v_{k-1} is the velocity the truck will have at the beginning of segment k.

2.2.1 Reduction of air resistance

The air resistance is one of the most significant forces acting upon a heavy duty vehicle. By reducing the air resistance a large amount of fuel can be saved. A heavy duty vehicle has the shape of a blunt body. Behind a blunt body in motion a wake is formed where the air is moving turbulent with the mean velocity in the same direction as the vehicle. The closer the air is to the vehicle the closer is the air velocity to the vehicle velocity. When driving behind another heavy duty vehicle the aerodynamic force, F_{air}, is reduced according to [5]. The later vehicle does not confront stationary air but air moving at the same direction as the vehicle. This reduces the resistance from the air. The reduction of the air resistance depends on the distance to the target. When the distance is small the reduction is large and the opposite when the distance is large.

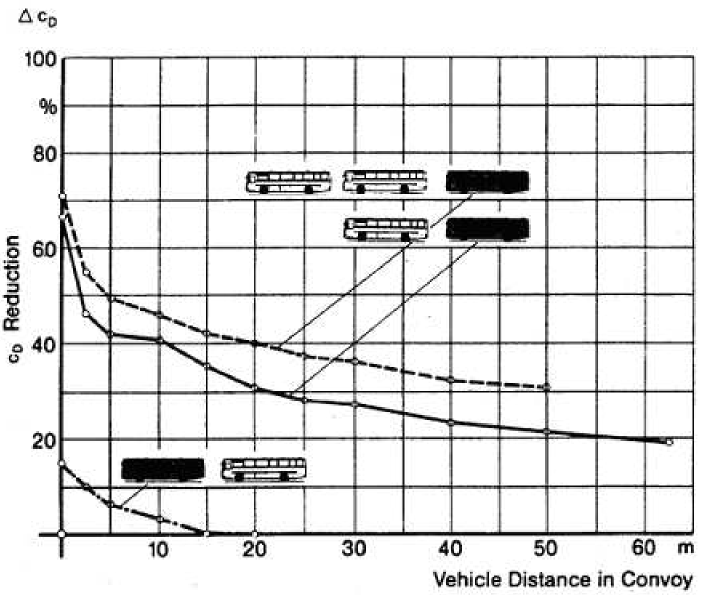

Figure 2.3. Reduction of c_D depending on the distance to the target,[5].

The distance to the preceding vehicle mainly decides how much the air resistance is reduced. If the vehicle is directly behind the target, c_D can be reduced with up to 70 %. In Figure 2.3 it can be seen how c_D depends on the distance to the preceding vehicle. As seen in Figure 2.3 a significant change in c_D can be observed even at distances up to 60 m.

Chapter 3

AiCC/Look-Ahead

By using the information in the digital map and the position of the vehicle, given by the GPS, a horizon can be built. Using the information in the horizon the AiCC/LA can find the sections on the road where the road properties make it favourable to not only base the reference velocity on the target but also on the properties of the road. Since the main function of the AiCC is to keep a constant distance to the target the distance must be a significant variable for the AiCC/LA. Estimating the changes in velocity and distance to the target over the horizon the AiCC/LA can isolate the segments where the control operations are to be executed.

Because the AiCC/LA will make a velocity trajectory over the entire horizon, some assumptions about how the target is behaving have to be made. The AiCC/LA operates parallel to the regular AiCC. The regular AiCC has a well developed function for adapting the speed to preceding vehicles and has also a security aspect which makes an AiCC vehicle brake if the distance to the target or the relative velocity becomes too small. The AiCC/LA will not give any brake requests; only a velocity reference will be given to the engine. However when the regular AiCC decides that braking is necessary the AiCC/LA function will not prevent the braking. The AiCC already has limits for when the brakes are supposed to be applied, considering the settings made by the driver and the safety aspects. There is no reason for the AiCC/LA to prevent the brake request or make its own.

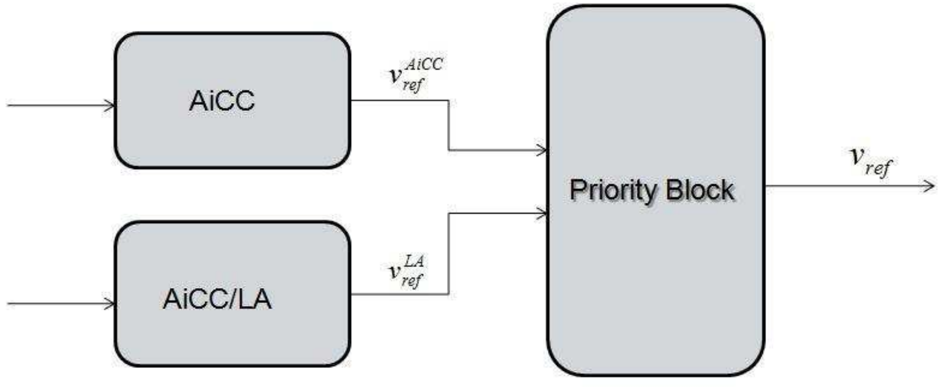

Figure 3.1. The main structure of the system.

The AiCC/LA and the regular AiCC uses two different methods to calculate the velocity reference. A strategy to decide which velocity reference that will get the higher priority and be sent to the engine is needed. In Figure 3.1 the basic function of the total system is shown. Note that the block prioritizing will only get velocities and no brake requests. As mentioned before the AiCC/LA will not give any brake requests or try to prevent the ones given by the AiCC.

3.1 Horizon

The data containing the map and all the information is divided into segments with a length, Δs, and a slope, α. The slope is the quotient of the difference in height and length of the each segment and is given in percent.

3.1.1 Segment classes

The road segments can be divided into different classes. The class of the segment depends on the influence that the gravitational force will have upon the vehicle. This means that a segment can have different classes for two different vehicles, because not only the slope is a factor also the mass of the vehicle and the capacity of the engine. For each class there is a corresponding threshold for the vehicle that is used to classify all the segments in the horizon.

To get the thresholds for the different classes Equation (2.18) is used. Making the assumption that $\dot{v} = 0$ during the segment the threshold slope is given by.

$$\alpha = \arcsin\left(\frac{F_{engine} - F_{roll} - F_{air}}{mg}\right) = \arcsin\left(\frac{\frac{i_t i_f \eta_t \eta_f}{r_w} M_e - mg - \frac{1}{2}\rho_{air} c_D A_f v^2}{mg}\right) \tag{3.1}$$

Where $\cos\alpha \approx 1$ has been assumed.

3.1.2 Creating the horizon

To create the horizon the digital map is divided into segments of length Δs and a mean slope is calculated for each segment. The segments are then assigned with a segment class. The slope of each segment is calculated using the altitude difference between the altitude in the beginning of the segment and the altitude in the end of the segment. Then the horizon is build by placing segments in the horizon so it obtains the desired length and while the vehicle is driving the passed segments are removed from the horizon and new segments are inserted to keep the length of the horizon.

3.2 Desired behaviour from the AiCC/LA

The desired behaviour for the AiCC/LA has to be decided, before the control strategy can be set. The typical behaviour of the Look-Ahead can be found by studying vehicles using Look-Ahead based control strategy. A combination of the typical behaviour for Look-Ahead and the behaviour for the adaptive cruise control will give the behaviour for the AiCC/LA.

3.2.1 Behaviour for a Look-Ahead controller

The study of controllers like the one in [2], with the main purpose to reduce fuel usage and trip time, a typical behaviour for a cruise controller using Look-Ahead data can be recognized. When approaching a steep hill the Look-Ahead controller will increase the velocity to avoid gear change and too low velocity. Before a downhill where the vehicle will accelerate due to gravity, the velocity is reduced to avoid unnecessary braking and make the vehicle able to accelerate due to gravity.

3.2.2 Behaviour for an adaptive cruise controller

The adaptive cruise controller wants to keep a constant distance to the target. The driver decides at which time gap he wishes to be from the target. The AiCC system then transforms the time gap to a distance which is to be kept to the target. The AiCC does not aim to follow at the exact desired distance, a certain variation is allowed. When making the control decisions the relative velocity is more significant than the distance. The velocity of the AiCC vehicle is desired to be the same as the velocity for the target; if the relative velocity is kept close to zero the variation in the distance will be small. For the AiCC the relative velocity is the most important control parameter.

3.2.3 Behaviour of a combinated AiCC and Look-Ahead

When combining the AiCC and the Look-Ahead not only fuel consumption is considered, the driver experience is also important and has to be made allowance for. The time gap set by the driver has to be respected even though the time gap to the target can be smaller without risking a collision. The adaptive cruise controller is used when the vehicle has caught up with a preceding vehicle. It can then be assumed that the speed the vehicle's regular cruise controller is set to is higher than the speed of the target. To lower the speed and let the distance to the target increase can be experienced as unnatural by the driver. Hence, the distance to the target cannot be allowed to get too large.

It has been mentioned earlier that the trip time is an important factor when designing a Look-Ahead controller. However for the AiCC the time is not a parameter that can be varied. It is the target who decides the total trip time. The main purpose of the AiCC/Look-Ahead is still to follow the preceding vehicle. Another limitation when driving behind another vehicle is that the speed cannot be increased without first being reduced. This makes the strategy to accelerate before an uphill to maintain the speed and avoid gear changes impossible to use because the driver would consider it unnatural.

Intuitively, when the vehicle is in a small uphill it is not favourable to accelerate in the cases when an uphill has made the velocity lower then desired. It is then better to keep the lower velocity until the small uphill is over and the road is level again, or even better if there is a downhill ahead where the vehicle can accelerate due to gravity. This is due to the fact that the gravitational force in Eq. (2.17) has a greater negative impact on the vehicle in an uphill than on level road. To accelerate in an uphill demands more fuel then accelerating on level road where the contribution from the gravitational force is small. One other strategy could be to maintain the lower velocity received in a steep uphill until the road is level. But then the distance to the target will increase and force the AiCC/LA vehicle to increase the speed over the target speed to be able to catch up with the target. This will then cost more fuel than just follow the target.

Below follows a list of the behaviour that is desired from the AiCC/LA.

- The distance to the target cannot be allowed to increase over a limit d_{max}, which depends on the time gap and the target velocity.

- The distance to the target may not be smaller than a distance d_{min} which depends on the time gap and the target velocity.

- The velocity, v, may not exceed v_{max} which depends on the set speed of the regular cruise controller.

- The relative velocity may not be so low that there is a risk for unnecessary brake use.

- When the horizon does not contain segments of interest for the AiCC/LA the AiCC should have higher priority and normal target following is to be applied.

- When there is a downhill that will make the vehicle accelerate and decrease the distance to the target below d_{min} the distance to the target shall be increased before the downhill and the vehicle speed should be decreased.

3.3 AiCC/LA control strategy

The AiCC is already designed to drive fuel efficient, braking is avoided for as long as possible and just by driving behind another vehicle the air resistance is reduced and fuel is saved. The brakes for a vehicle are most often used in downhills where the distance is hard to keep due to the acceleration caused by the slope. Because the vehicle travels at a lower velocity then desired due to the target, it is not the increased velocity in the downhill that is the cause to the brake use. The reason the brakes are applied is that the distance to the target becomes too small and the relative velocity becomes too low. If the distance to the target could be reduced before a downhill the braking could be delayed or be avoided completely. So to be able to reduce the brake wear the main focus for the AiCC/LA is to adjust the target distance before a steep downhill. The estimated distance can be received by the following equations.

3.3.1 Distance to the target

To be able to adjust the distance in the situations where the distance will become too small, the distance has to be predicted over the horizon.

$$d = d_0 + \int_{t_0}^{t_{final}} v_{rel}(t)dt \tag{3.2}$$

where d is the distance to the target, d_0 is the initial distance and v_{rel} is the relative velocity. This can be written in discrete form as:

$$d_k = d_{k-1} + v_{rel,k-1}\Delta t \tag{3.3}$$

where d_k is the distance to the target in the end of segment k, d_{k-1} is the distance in the beginning of segment k, $v_{rel,k-1} = v_t - v_{k-1}$ is the relative velocity and Δt is the time that passes during the segment.

Assuming that both the target and the AiCC/LA vehicle are travelling at constant speed at each segment the time that it takes to travel the segment, Δt can be given by

$$v_{k-1} = \frac{\Delta s}{\Delta t} \Rightarrow \Delta t = \frac{\Delta s}{v_{k-1}} \tag{3.4}$$

Using Eq. (3.4) in Eq. (3.3) it can be rewritten as

$$d_k = d_{k-1} + v_{rel,k-1}\frac{\Delta s}{v_{k-1}} \tag{3.5}$$

Since the assumption of constant velocity for the AiCC/LA vehicle leads to large faults in steep downhills and uphills, a more accurate estimation of the distance can be received by using the mean velocity for the vehicle over the segment.

$$v_{mean,k} = \frac{v_{k-1} + v_k}{2} \tag{3.6}$$

Where v_{k-1} is the vehicle velocity in the beginning of the segment and v_k is the velocity in the end of the segment. Also the relative velocity over the segment can be estimated using the mean value of the velocity for the AiCC/LA vehicle.

$$v_{rel,mean,k} = v_t - v_{mean,k} \tag{3.7}$$

Where v_{k-1} is the velocity in the beginning of the segment and v_k is the velocity in the end of the segment. Then this can be used in Eq. (3.3).

$$d_k = d_{k-1} + v_{rel,mean,k} \frac{\Delta s}{v_{mean,k}} \tag{3.8}$$

Using Eq. (3.8) the situations where the distance to the target is becoming too small can be identified. The distance is the factor which tells when the AiCC/LA shall go in and change the velocity of the AiCC/LA vehicle.

3.3.2 Control strategy

To be able to decide when the distance will become too small, the velocity at the end of each segment is estimated, using Eq. (2.21) where $M_e = M_{e,min}$. By using the initial velocity and the final velocity for each segment the change in distance over the segment is received using Eq. (3.8).

Figure 3.2 shows a flow chart for the process when a downhill is discovered during a road segment. When the current segment, segment i, belongs to the class downhill, D, the change in velocity and distance is examined. If the distance becomes too small the controller corrects the distance in previous segments. When the last segment of the horizon, i_{max}, is reached the velocity reference is sent to the priority block and the process starts from the beginning again.

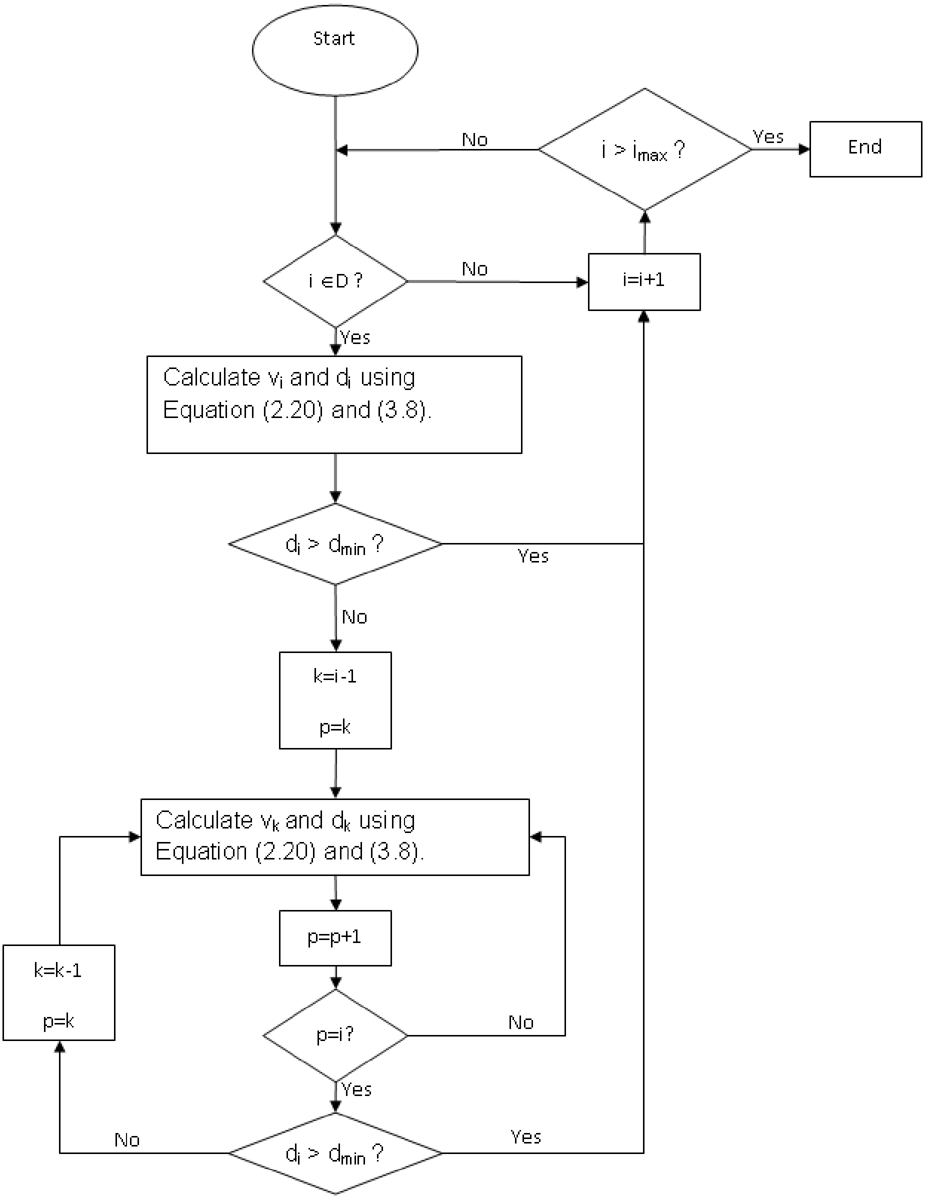

Figure 3.2. Flow chart over the process.

3.4 Priority block

The priority block shall decide which one of the AiCC/LA and AiCC that will have the highest priority and send the velocity reference to the engine. To be able to make the decision the priority block uses a range vs. range-rate diagram, see [4]. In Figure 3.3 the range vs. range-rate diagram for time gap 2 seconds, target velocity $80 km/h$ and a set speed for the AiCC/LA on $90 km/h$ is shown. As long as the velocity reference from the AiCC/LA lies inside of the shaded area it will have the highest priority.

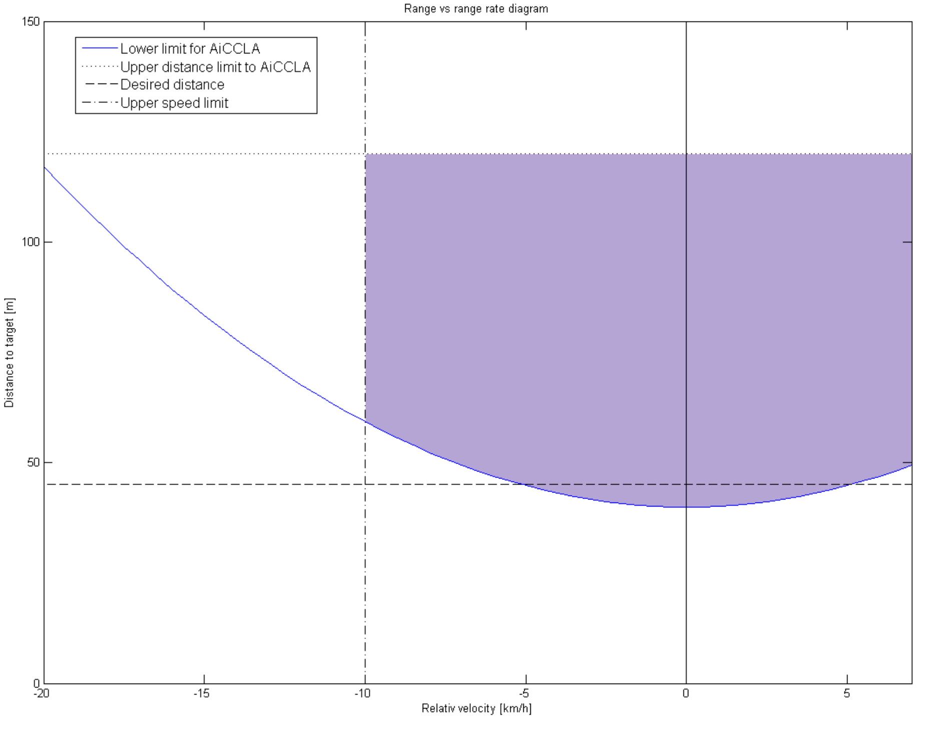

Figure 3.3. Range vs. range-rate diagram for time gap 2 seconds and target speed 80 km/h.

The lower limit in the range vs. range-rate diagram is constructed using the limitations for when the brakes is to be applied according to the AiCC. Because the AiCC/LA will not try to prevent the brake requests from the AiCC the speed request cannot make the relative speed pass the limit or allow the distance to become too small. The upper distance limit depends on the desired distance to the target. Every time gap has a corresponding maximum distance. If the driver has decided that he wants to hold a close distance to the target the upper limit is lower then when a longer distance is chosen. If the speed request from the AiCC/LA exceeds the requested speed from the regular cruise control, the cruise control will overtake control of the vehicle, since the upper speed limit set by the driver has to be respected. This is marked with the vertical limit at the left.

The dashed horizontal line in the middle of the range vs. range-rate diagram is showing the desired distance to the target with the current target speed and time gap setting. As can be seen there is not much space for the vehicle to increase the speed while being on the desired distance from the target.

When the AiCC/LA gets outside the allowed area in the range vs. range-rate diagram the regular AiCC will overtake control of the vehicle and a signal is sent to the AiCC/LA and makes it start over from the beginning not considering the previous velocity references. To make sure that the AiCC is controlling the vehicle on level road it will always have control when no steep uphill or no steep downhill are ahead of the vehicle.

The priority block also considers the case when the target has a large deceleration so the assumption of constant speed no longer is accurate. In this case the range vs. range-rate diagram is not enough so the AiCC will be in control as soon as the target acceleration is below a threshold.

The AiCC/LA doesn't give any brake requests so if the regular AiCC consider the target to be too close it will give a brake request and this does not pass through the priority block. This is because the brake request from the AiCC is only given when it is considered necessary for either safety reasons or of respect to the time gap decided by the driver.

Chapter 4

Results

The results from the simulations made with the combined AiCC/LA are presented in this chapter. The simulations are made on data from real roads, but no real test drive has been performed. They have been performed with two different roads, with time gap 1, 3 and 5 (1, 2 and 3 seconds), and with target weight 20, 40 and 50 tonnes. The AiCC/LA vehicle has the weight of 40 tonnes in all the simulations. Two roads have been used in the simulations, one road in Sweden between the cities Södertälje and Jönköping and one in Germany between the cities Koblenz and Trier.

The result shows that fuel can be saved with all time gaps and all target weights. But when the target weight is 40 or 50 tonnes fuel is not always saved.

The comparison in the figures is made with a vehicle using the regular AiCC on the same road and with the same target as the AiCC/LA-vehicle.

4.1 Truck properties in the simulations

The simulations are performed with a truck with a mass of 40 tonnes and a DC1210 engine with maximum engine torque of $1700Nm$. The target is the same kind of truck as the AiCC and AICC/LA vehicles; it is only the weight of the target is varied.

4.2 Road Södertälje-Jönköping

The road between Södertälje and Jönköping can be considered as a typical Swedish highway, the altitude and the slope of the road can be seen in Figure 4.1. The simulations on this road show that the performance of the combined AiCC/LA is mostly better than the performance with the regular AiCC. The road is in general level, which makes the fuel savings rather small. Since the combined AiCC/LA only operates when there are steep downhills the overall performance on a road with small altitude changes is not large. The results show that fuel usage is reduced for time gap 1 and 3 for all target weights. For time gap 5 the results are not the same, here the fuel usage is only reduced when the target weight is 20 tonnes. The reduction of fuel during the entire road lies between −0.09% and 0.09%.

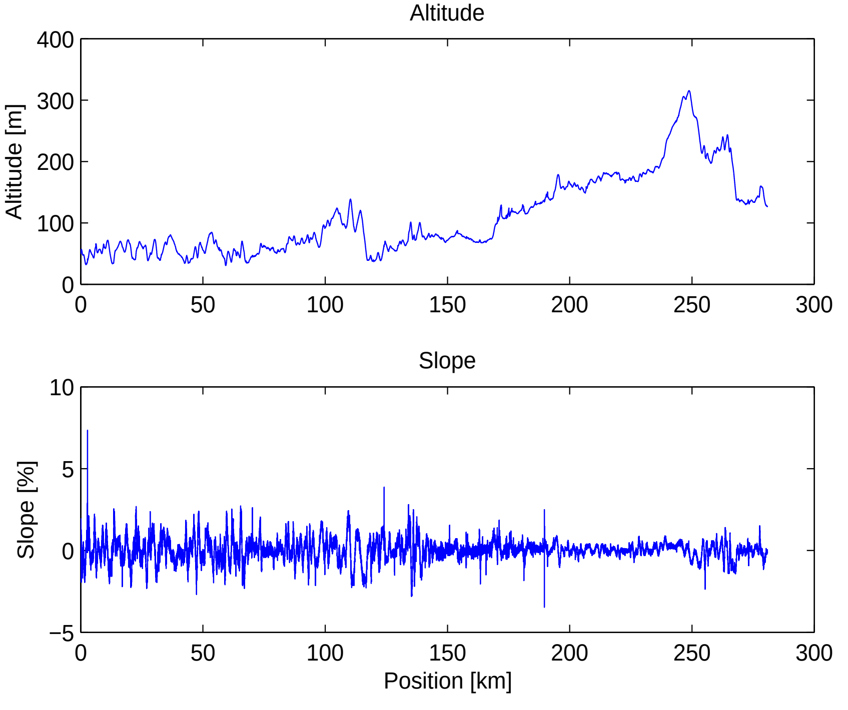

Figure 4.1. The road between Södertälje and Jönköping.

In Table 4.1 the total reduction in fuel usage for the road between Södertälje and Jönköping can be seen. The table shows the reduction in percent for the different time gaps and target weights. The table shows that for all the time gaps the best results occurs when the target weight is 20 tonnes. This is due to that the model uses the assumption that the target travels with constant velocity, and when the target is light it is not affected as much of the road slope and can therefore keep the velocity more constant compared to a target weight of 40 or 50 tonnes. When the target weight is 40 or 50 tonnes the regular AiCC does not need to use the brakes when the time gap is 3 seconds. Then the optimal behaviour is to just use the regular AiCC and follow the target.

Table 4.1. The total reduction of fuel for the different time gaps and target weights on the road between Södertälje and Jönköping.

Target weight	Time gap 1	Time gap 3	Time gap 5
20 tonnes	0.088%	0.077%	0.003%
40 tonnes	0.015%	0.038%	−0.094%
50 tonnes	0.009%	0.002%	−0.088%

In Table 4.2 the total amount of fuel consumed during the simulation can be seen. When comparing it to Table 4.1 it is clear that the least reduction from the first table is not corresponding to the least fuel consumption in litres during the entire road. The lowest fuel consumption is obtained when driving with time gap 1. This is due to that the distance is smallest for time gap 1 which leads to a greater reduction in air resistance, which then makes the total fuel consumption lower. Studying the influence of the target weight on the fuel consumption it can be seen that the best results are obtained for the target weights 20 and 40 tonnes.

Table 4.2. The total amount of fuel consumed for the different time gaps and target weights, measured in litres, for both the AiCC and the AiCC/LA.

Target weight	Time gap 1	Time gap 3	Time gap 5
AiCC			
20 tonnes	$67.72l$	$68.10l$	$70.80l$
40 tonnes	$66.70l$	$68.11l$	$70.70l$
50 tonnes	$67.36l$	$68.70l$	$71.66l$
AiCC/LA			
20 tonnes	$67.67l$	$68.05l$	$70.80l$
40 tonnes	$66.69l$	$68.09l$	$70.76l$
50 tonnes	$67.35l$	$68.70l$	$71.72l$

To better be able to evaluate the results from the simulations two road segments have been chosen for a closer look. The first segment, Segment 1, lies at a distance between $110km - 113.5km$ from Södertälje. The second segment, Segment 2, lies at a distance between $134.7km - 137.4km$ from Södertälje.

4.2.1 Segment 1

Time gap 3

In Figure 4.2, 4.3 and 4.4 the results from Segment 1 can be seen driving with time gap 3. The target weight is 20 tonnes in Figure 4.2, 40 tonnes in Figure 4.3 and 50 tonnes in Figure 4.4. The fuel reduction using the AiCC/LA over the segments is 1.58% when the target weight is 20 tonnes, 4.72% when the target weight is 40 tonnes and −1.37% when the target weight is 50 tonnes.

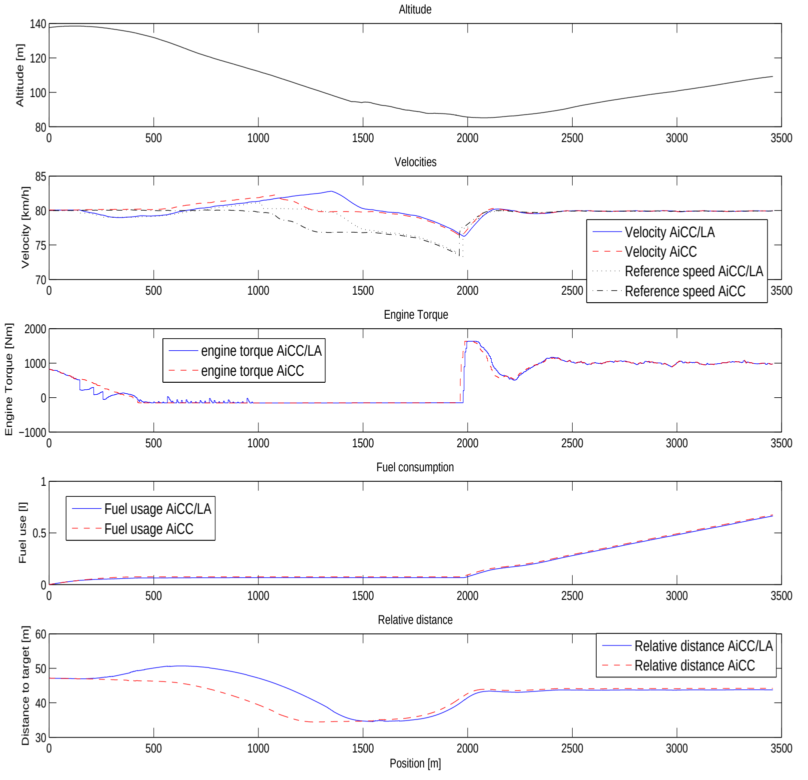

Figure 4.2. The result for Segment 1 with time gap 3 and target weight 20 tonnes.

When comparing the figures it is clear that regardless of the weight of the target the first part of the segment is similar. The speed is lowered at the same point and with the same amount. The difference starts after the downhill has begun. For the cases when the target weight is respectively 20 and 40 tonnes the speed is the same until the speed reference for the AiCC/LA vehicle is lowered to $80km/h$. Then when the end of the downhill is reached the velocity is reduced more for the AiCC/LA vehicle with a 20 tonnes target then the one with a 40 tonnes target. When entering the uphill which follows the downhill the AICC/LA vehicle with a 40 tonnes target has a higher speed and does not need as much engine torque as the AiCC/LA with a 20 tonnes target. This makes the fuel savings greater for the case when the target weight is 40 tonnes.

In the case when the target weight is 50 tonnes the fuel usage is greater with the AiCC/LA then with the regular AiCC. When the downhill ends the regular AiCC takes over the control because of the requirement that the AiCC shall be in control when no steep downhill is ahead of the vehicle in the horizon. As can be seen in Figure 4.4 the speed request in the end of the downhill is higher than the vehicle speed which makes the vehicle increase the speed and then consume more fuel.

When comparing the distance to the target over the segment for the different target weights it is clear that the heavier the target is the greater becomes the distance. It also takes longer time before the distance for the AiCC/LA vehicle becomes the same as the distance when only the regular AiCC was used. When the target weight is larger the assumption that the target will be able to maintain constant speed is inaccurate. This makes the distance become larger than predicted and also makes the speed required to get the right distance in the end of the downhill higher.

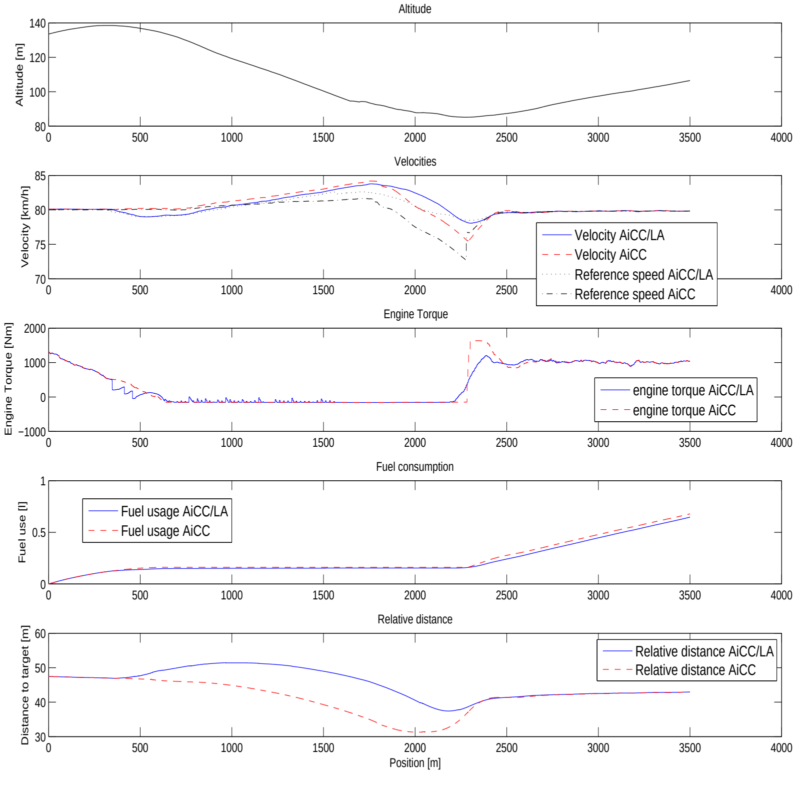

Figure 4.3. The result for Segment 1 with time gap 3 and target weight 40 tonnes.

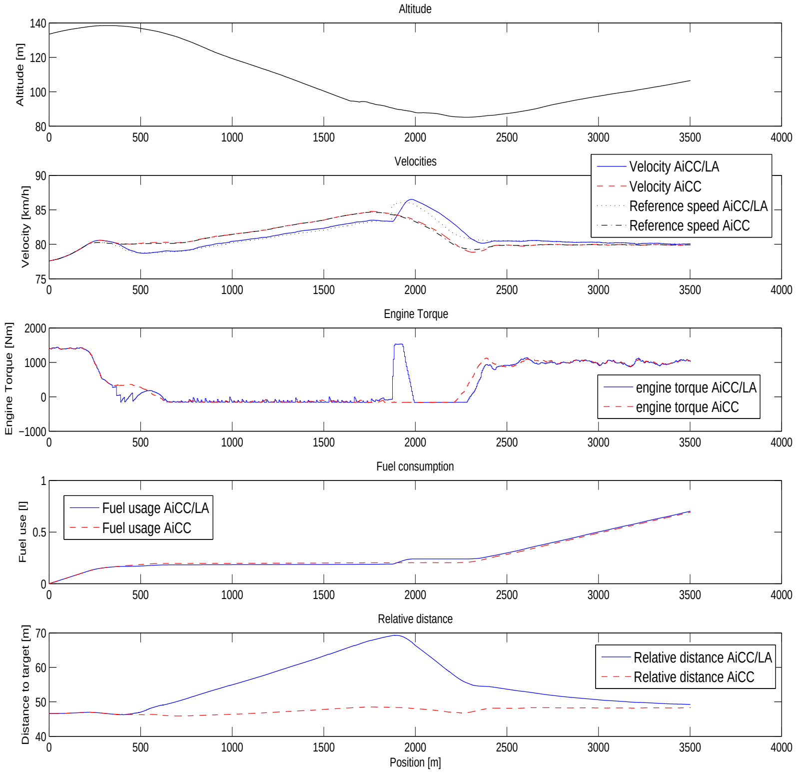

Figure 4.4. The result for Segment 1 with time gap 3 and target weight 50 tonnes.

Time gap 5

In Figures 4.5 and 4.6 the results for Segment 1 using time gap 5 and target weight 20 tonnes and 40 tonnes can be seen. The reduction in fuel during the segment is 4.56% for the AiCC/LA vehicle with a 20 tonnes target, −1.35% for the AiCC/LA vehicle with a 40 tonnes target and 0.20% for the AiCC/LA vehicle with a 50 tonnes target.

In Figure 4.5 the result with a 20 tonnes target can be seen. The results show that unlike for the simulation with time gap 3 the AiCC/LA vehicle speed is greater at the end of the downhill which makes the engine torque required less than for the AiCC. Also the distance to the target becomes the same as for the AiCC vehicle later using time gap 5 instead of time gap 3.

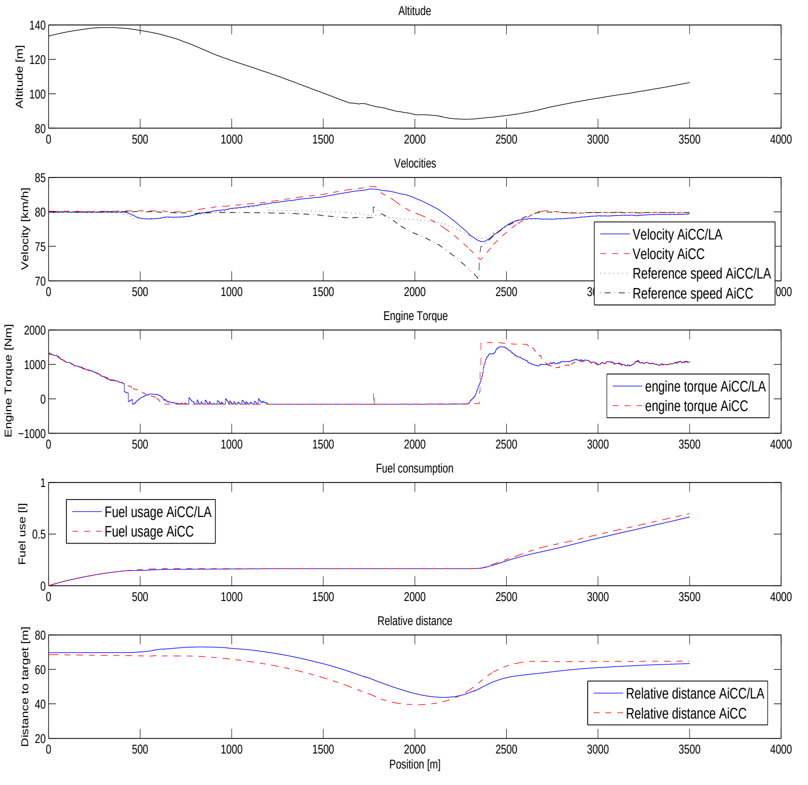

Figure 4.5. The result for Segment 1 with time gap 5 and target weight 20 tonnes.

Unlike the results from the simulation using time gap 3 the result is for time gap 5 better when the target weight is 20 tonnes. When the target weight is 40 tonnes the fuel usage even increases when the AiCC/LA is used instead of the regular AiCC. Just like in the simulation for time gap 3 the speed is reduced before the downhill, but this time the speed becomes smaller for the case when the target weight is 40 tonnes. The requested speed from the AiCC/LA is too high in the downhill which makes the AiCC/LA vehicle supply the engine with fuel in the downhill. This makes the fuel consumption for the AiCC/LA increase and when the end of the downhill is reached the AiCC/LA increases the speed before the AiCC vehicle.

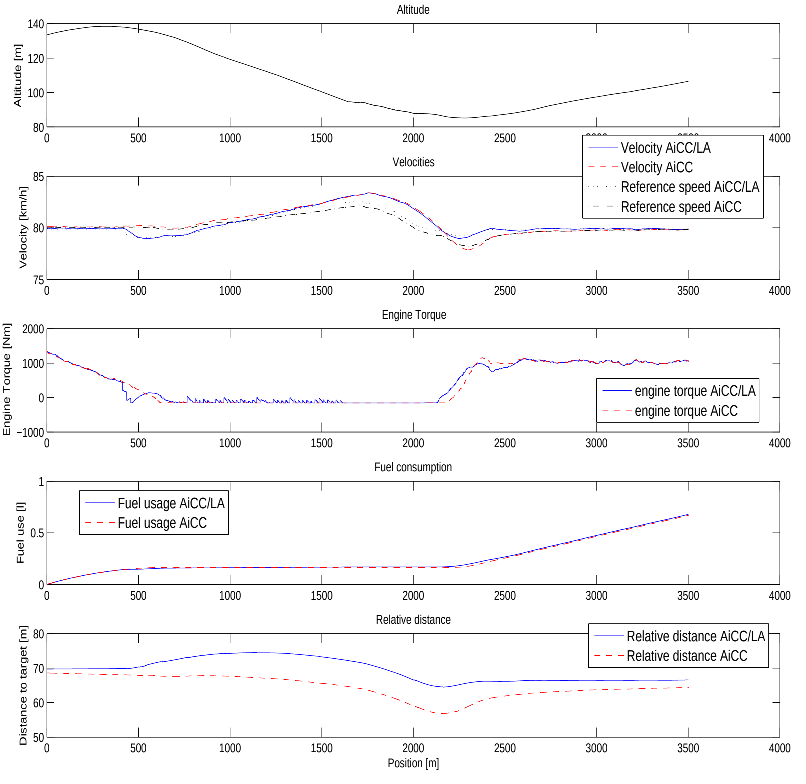

Figure 4.6. The result for Segment 1 with time gap 5 and target weight 40 tonnes.

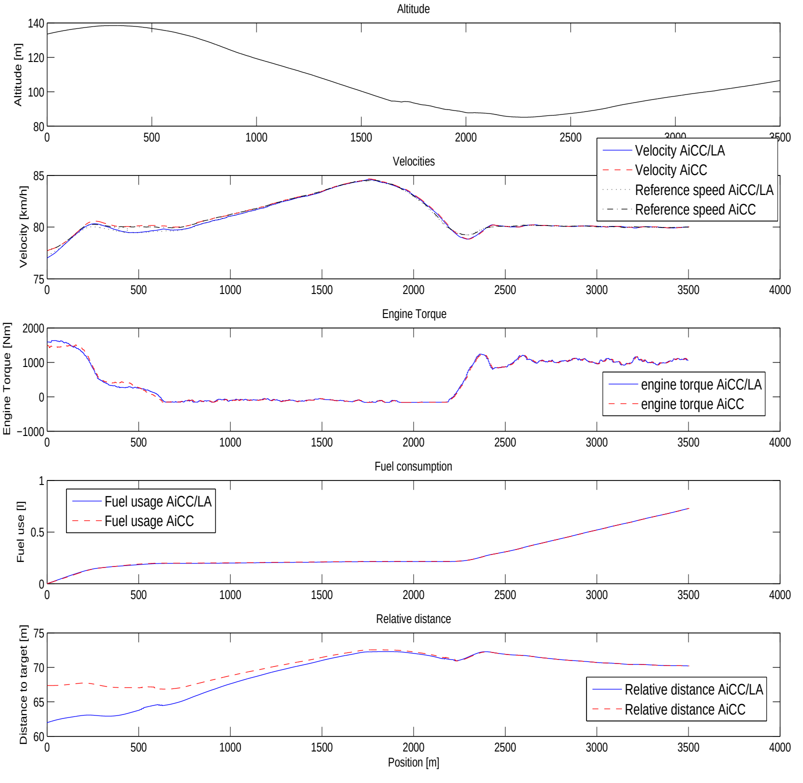

Figure 4.7. The result for Segment 1 with time gap 5 and target weight 50 tonnes.

For the case when the target weight is 50 tonnes the distance to the target is too small in the beginning of the segment, making the regular AiCC request a lower speed then for the AiCC vehicle. This means that the AiCC/LA does not have to reduce the speed before the downhill. When the downhill has been entered the AiCC/LA cannot lower the speed further.

4.2.2 Segment 2

Time gap 1

In Figure 4.8, 4.9 and 4.10 the results from the simulations over the segment with time gap 1 and target weight, respectively, 20, 40 and 50 tonnes can be seen. The reduction in fuel consumption over Segment 2 is for the AiCC vehicle with a 20 tonnes target 3.83%, the AiCC/LA vehicle with a 40 tonnes target 1.56% and for the AiCC/LA vehicle with a 50 tonnes target -1.95%.

In the case when the target weight is 20 tonnes the speed is reduced before the downhill, increasing the distance to the target. During the downhill the speed increases enough to regain the distance lost when the speed was reduced. The AiCC/LA vehicle also starts the fuel use after the downhill later then the AiCC vehicle.

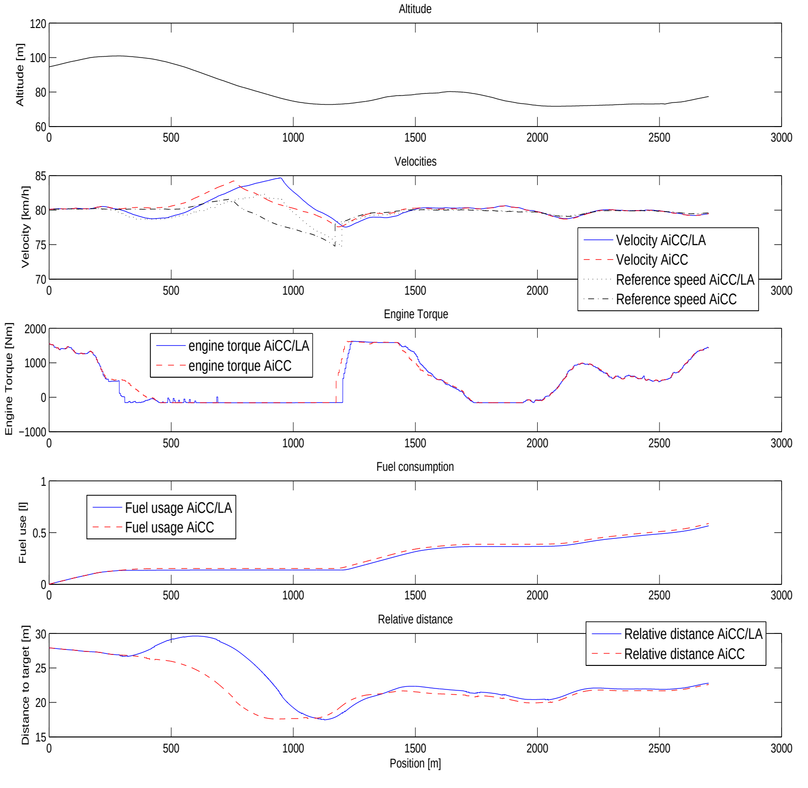

Figure 4.8. The result for Segment 2 with time gap 1 and target weight 20 tonnes.

For the cases when the target weight is 40 and 50 tonnes the beginning of the segment is similar to the case when the target weight is 20 tonnes. The AiCC/LA does not let the vehicle lose as much speed as the regular AiCC in the end of the downhill. This makes the engine torque for the AiCC/LA vehicle increase before the engine torque for the AiCC. However the torque is reduced earlier for the AiCC/LA then for the AiCC making the total fuel usage be smaller for the AiCC/LA.

At the end of the last downhill the distance to the target is still larger then desired for both the target weights. This makes the AiCC/LA vehicle accelerate to reduce the distance. This makes the fuel usage for the case with the 50 tonnes target increase over the one for the AiCC. The AiCC/LA vehicle with the 40 tonnes target still has a lower fuel usage then the AiCC vehicle.

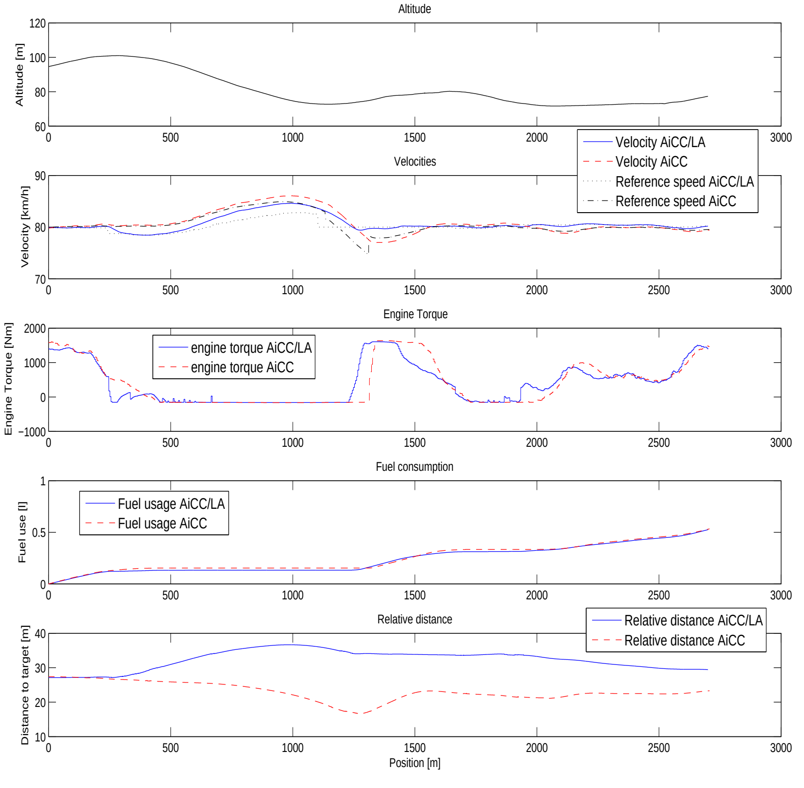

Figure 4.9. The result for Segment 2 with time gap 1 and target weight 40 tonnes.

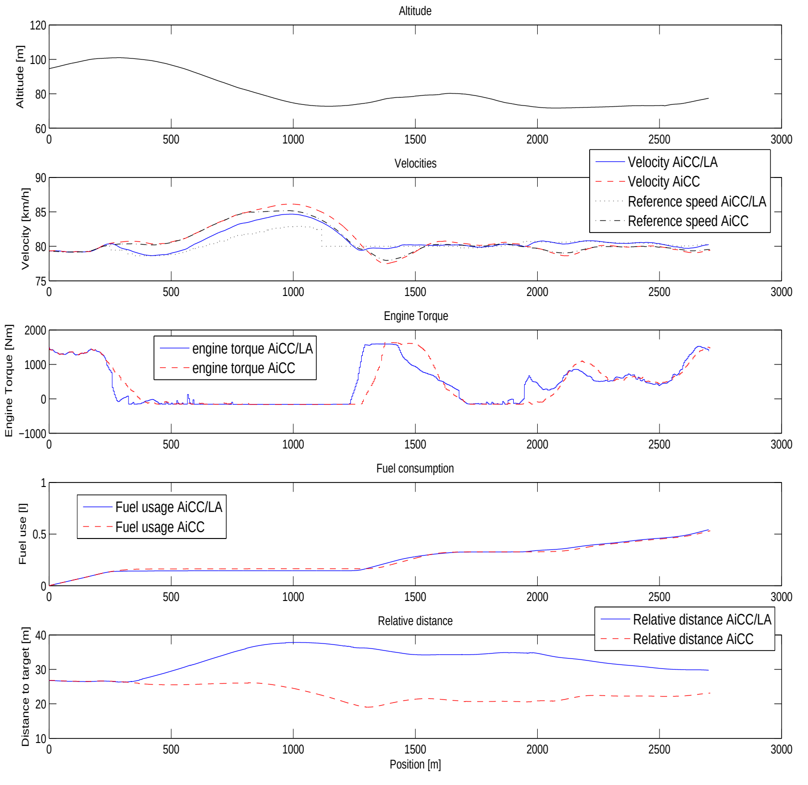

Figure 4.10. The result for Segment 2 with time gap 1 and target weight 50 tonnes.

4.2.3 Summary of the road between Södertälje and Jönköping

When simulating the overall best result for the AiCC/LA is obtained when the target weight is 20 tonnes and the time gap is 1 second. The overall best result in fuel consumed is obtained for target weight 40 tonnes and time gap 1 second. When driving with time gap 1 the distance to the target is smaller than for the other time gap, which gives a greater reduction in air resistance. Thus the AiCC/LA gives the best result when the target is light; one reason is that when the target has the same weight as the AiCC/LA vehicle or is heavier the brakes will not be used in a shorter more shallow downhill. Then the best thing to do is to just apply the strategy for the regular AiCC.

4.3 Road Koblenz-Trier

The road between Koblenz and Trier consist of many large altitude changes and large slopes. This makes the possibilities of fuel savings good and by using the AiCC/LA instead of the regular AiCC between 0.3% and 0.7% fuel can be saved over the entire road. The altitude and road slope for the road can be seen in Figure 4.11. The variation in slope and altitude is more significant on this road then on the road between Södertälje and Jönköping, and the parts with steep slopes are longer than for the Södertälje-Jönköping road. This is the reason for the greater fuel savings, with steeper downhills the possibilities for using the gravity to accelerate increase which make the possibilities for fuel savings greater.

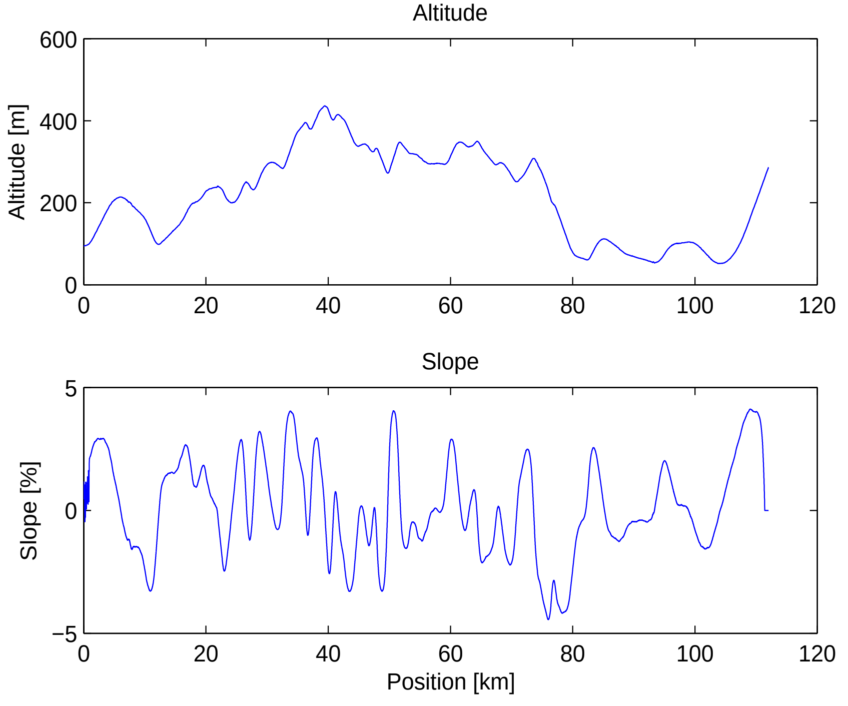

Figure 4.11. The road between Koblenz and Trier.

Table 4.3 shows the total reduction of fuel for all the different time gaps and target weights on the road between Koblenz and Trier. For this road the best results are received when the target weight is 40 tonnes for time gap 1 and 3, for time gap 5 the best result is received when the target weight is 20 tonnes. This result differs from the result when simulating the road between Södertälje and Jönköping. The reason for this difference is that the road between Koblenz and

Trier has such big slopes that when there is an uphill the 20 tonnes target is often lost. That makes the regular cruise controller to step in and take control over the vehicle and increases the air resistance. There are also some downhills where the distance to the target is so great that the AiCC/LA will not be able to step in and do corrections.

Table 4.3. Table over the total reduction of fuel for the different time gaps and target weights on the road between Koblenz and Trier.

Target weight	Time gap 1	Time gap 3	Time gap 5
20 tonnes	0.37%	0.57%	0.62%
40 tonnes	0.63%	0.76%	0.45%
50 tonnes	0.52%	0.70%	0.30%

In Table 4.4 the total amount of fuel consumed, in litres, for the AiCC and the AiCC/LA vehicle during the simulations for the road Koblenz-Trier can be seen. Like the results from the road between Södertälje and Jönköping, the best results are obtained when time gap 1 is used. The reason is once again the greater reduction of the air resistance due to the smaller distance to the target. It can be seen that even though Table 4.3 shows that the greatest reduction is obtained for target weight 40 tonnes and time gap 3 the lowest fuel consumption is obtained for target weight 50 tonnes and time gap 1. For all time gaps the smallest amount of fuel is consumed when the target weight is 50 tonnes. This can be explained with the fact that the 50 tonnes target will have a higher reduction of speed in steep downhills than the AiCC and AiCC/LA vehicle, which generates a lower fuel consumption but also a longer trip time. The 20 tonnes target, as mentioned before, will be lost in the long steep uphills since it will not reduce its speed as much as the AiCC/LA vehicle. When the target is lost the AiCC and AiCC/LA vehicle will lose in air reduction and also has to increase the speed to be able to catch up with the target. However, the shortest trip time is obtained for the 20 tonnes target.

Table 4.4. The total amount of fuel consumed for the different time gaps and target weights, for both the AiCC and the AiCC/LA

Target weight	Time gap 1	Time gap 3	Time gap 5
AiCC			
20 tonnes	35.98l	35.99l	36.58l
40 tonnes	34.79l	35.77l	36.60l
50 tonnes	34.35l	35.01l	35.91l
AiCC/LA			
20 tonnes	35.85l	35.78l	36.35l
40 tonnes	34.57l	35.50l	36.43l
50 tonnes	34.17l	34.76l	35.80l

Two smaller segments have been chosen along this road also so the performance of the AiCC/LA better can be studied. The first segment along this road lies between $47.3km - 50.1km$ from Koblenz and is called Segment 3. The second segment is placed at a distance of $73.2km - 81.3km$ from Koblenz.

4.3.1 Segment 3

Time gap 1

In Figure 4.12, 4.13 and 4.14 the results from Segment 3 can be seen, where the target weight is 20, 40 and 50 tonnes respectively. The reduction in fuel usage for the AiCC/LA over Segment 3 is 11.92% when the target weight is 20 tonnes, 13.63% when the target weight is 40 tonnes and 16.40% when the target weight is 50 tonnes.

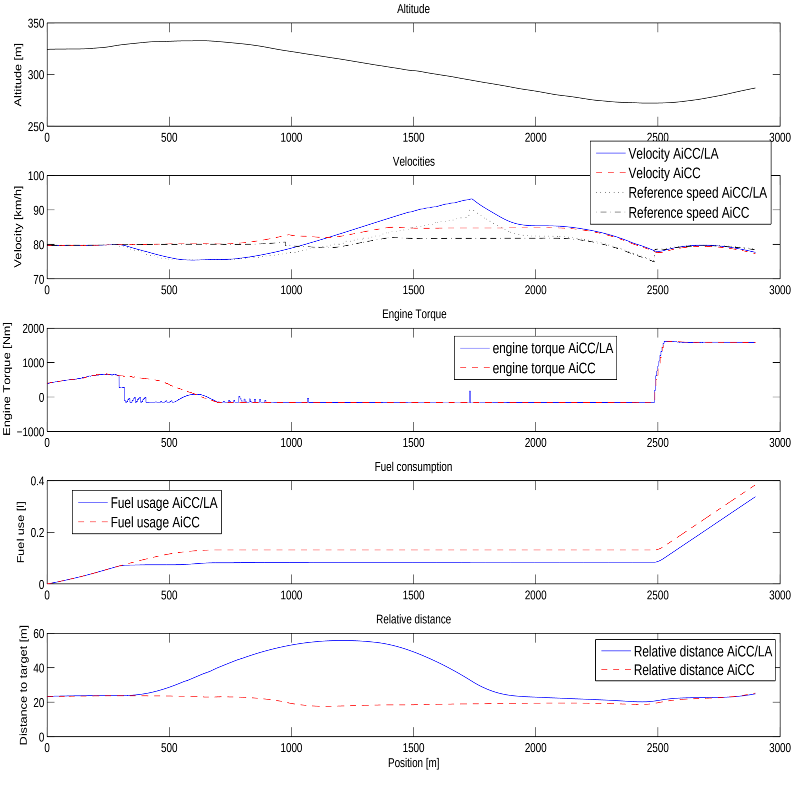

Figure 4.12. The result for Segment 3 with time gap 1 and target weight 20 tonnes.

As can be seen in the figures the performance over the segment is the same for all the different target weights. The speed is lowered in the beginning of the segment making the target distance increase. The distance is increased with approximately the same value for all the different target weights. The vehicle then accelerates in the downhill increasing the speed and reducing the distance. Before the downhill has ended the speed has to be lowered again, because the distance becomes too small and the relative velocity to low. This generates a brake request from the AiCC, making the speed adapt to the target speed and adjusting the distance to the desired.

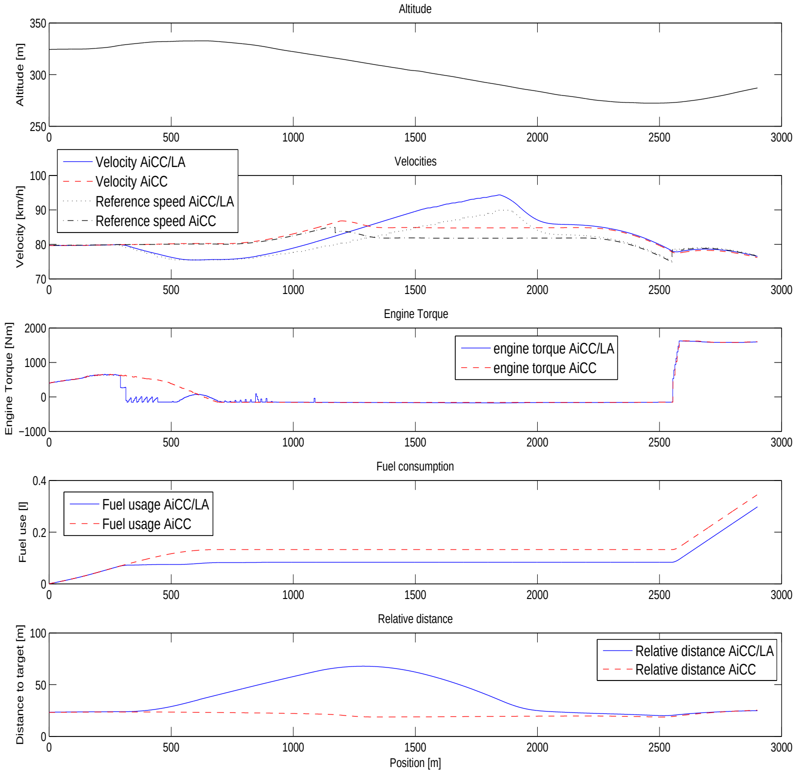

Figure 4.13. The result for Segment 3 with time gap 1 and target weight 40 tonnes.

Since the maximum distance, d_{max}, is reached during the segment, the AiCC/LA cannot reduce the speed further to avoid brake use. Using the brakes in unavoidable in this long steep downhill.

The difference in the fuel reduction between the different target weights depends on that the acceleration at the end of the downhill starts earlier when the target is lighter. This makes the reduction of fuel usage less when the target is lighter.

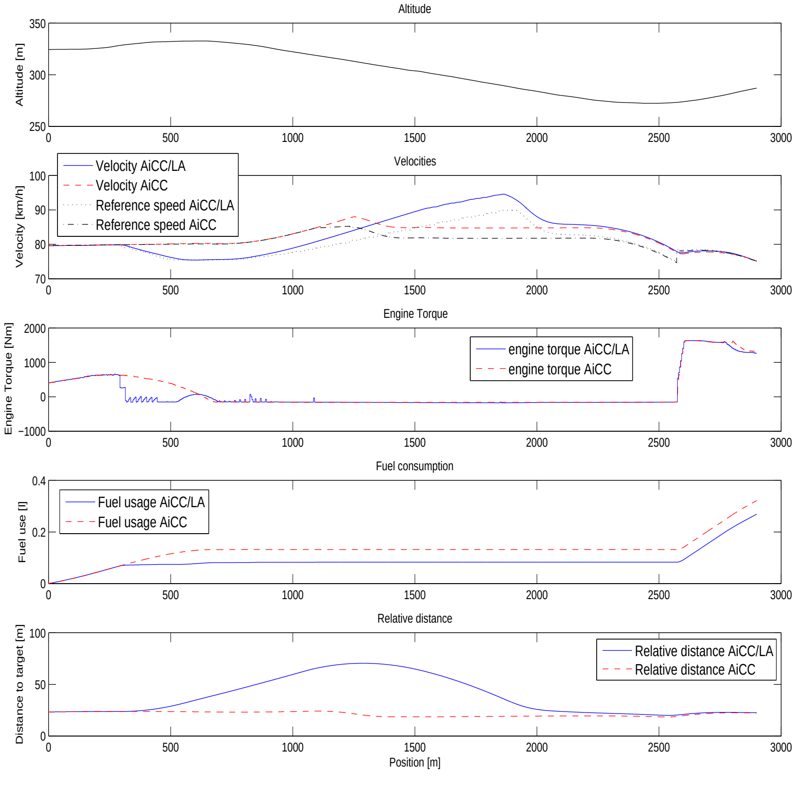

Figure 4.14. The result for Segment 3 with time gap 1 and target weight 50 tonnes.

Time gap 5

The results using a time gap at 3 seconds can be seen in Figure 4.15, 4.16 and 4.17. In Figure 4.15 the target weights 20 tonnes and the reduction in fuel usage over the segment is 18.07%. While in Figure 4.16 the target weight is 40 tonnes and the reduction in fuel usage is 26.54%. In Figure 4.17 the target weight is 50 tonnes and the reduction in fuel usage is 21.04%.

The result for the simulation with time gap 5 is similar to the one using time gap 1. The speed is lowered in the beginning, increasing the distance. The brakes must be used in this case as well. The velocity profile for the AiCC/LA is the same as before, with the difference that the speed is reduced slightly earlier for time gap 5. This is due to that the distance is allowed to increase more than for time gap 1. The main difference is that the acceleration occurs later for time gap 5, making the total amount of fuel lower.

Interesting is the fact that despite the great increase in distance for time gap 5, which means no reduction of the air resistance, the percentage reduction is larger for time gap 5. So it is better to increase the distance as much as possible before the downhill than have a shorter distance and keep some of the reduction in air resistance.

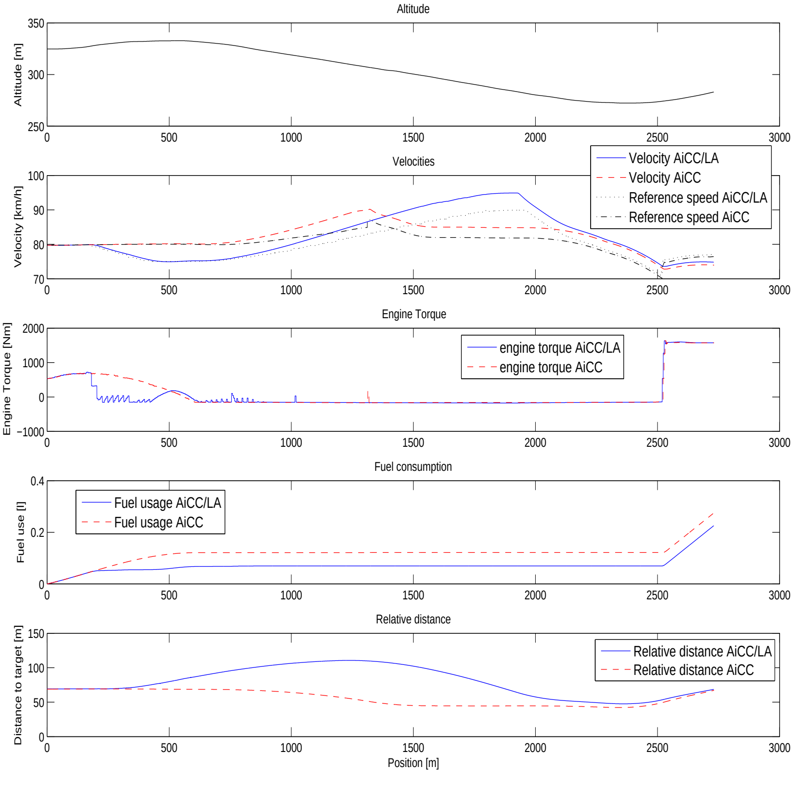

Figure 4.15. The result for Segment 3 with time gap 5 and target weight 20 tonnes.

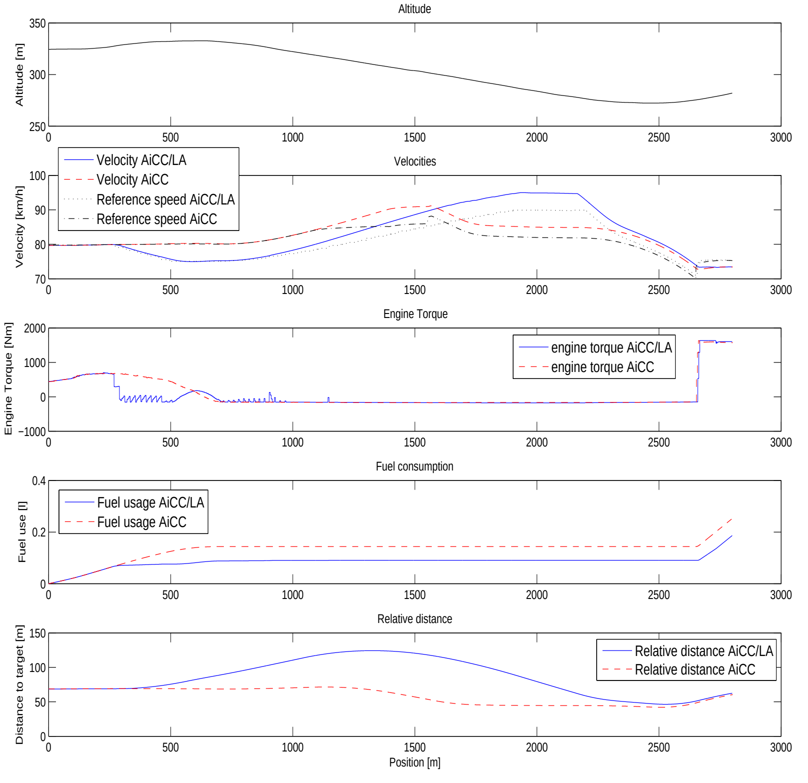

Figure 4.16. The result for Segment 3 with time gap 5 and target weight 40 tonnes.

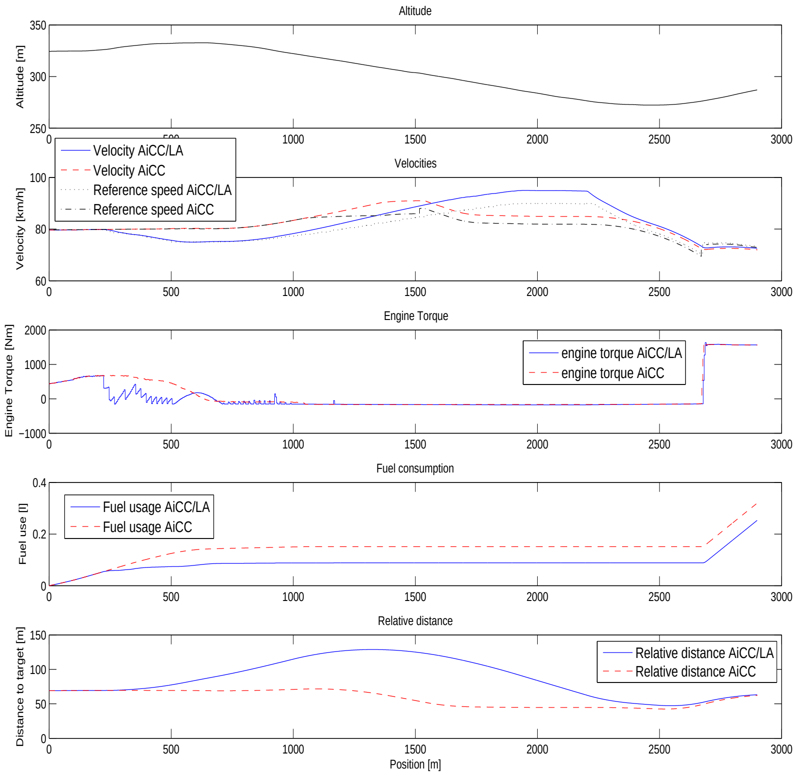

Figure 4.17. The result for Segment 3 with time gap 5 and target weight 50 tonnes.

4.3.2 Segment 4

Time gap 3

In Figure 4.18, 4.19 and 4.20 the results from simulations with a 20, 40 and 50 tonnes target can be seen. The fuel reduction in the case when the target weight is 20 tonnes is 18.47%, the reduction when the target weight is 40 tonnes is 21.62% and the reduction when the target weight is 50 tonnes is 21.45%.

The reduction is largest when the target weight is 40 tonnes, the same result as from Segment 3 when using time gap 5. The difference between this segment and the previous is that before the downhill in Segment 4 there is a steep and long uphill, which makes the speed of the vehicle lower than the set speed of the target in the beginning of the segment. When studying Figure 4.18 it can be observed that the distance to the target is greater than for the other two target weights in the beginning of the segment. Since the distance is increased to approximately the same value for all the target weights before the downhill the deceleration stretch is smaller when the initial distance is larger. This makes the reduction in fuel smaller then for the other target weights.

When the target weight is 40 and 50 tonnes the initial distance is smaller, and the reduction in fuel is larger since the distance can be increased more than in the case when the target weight is 20 tonnes.

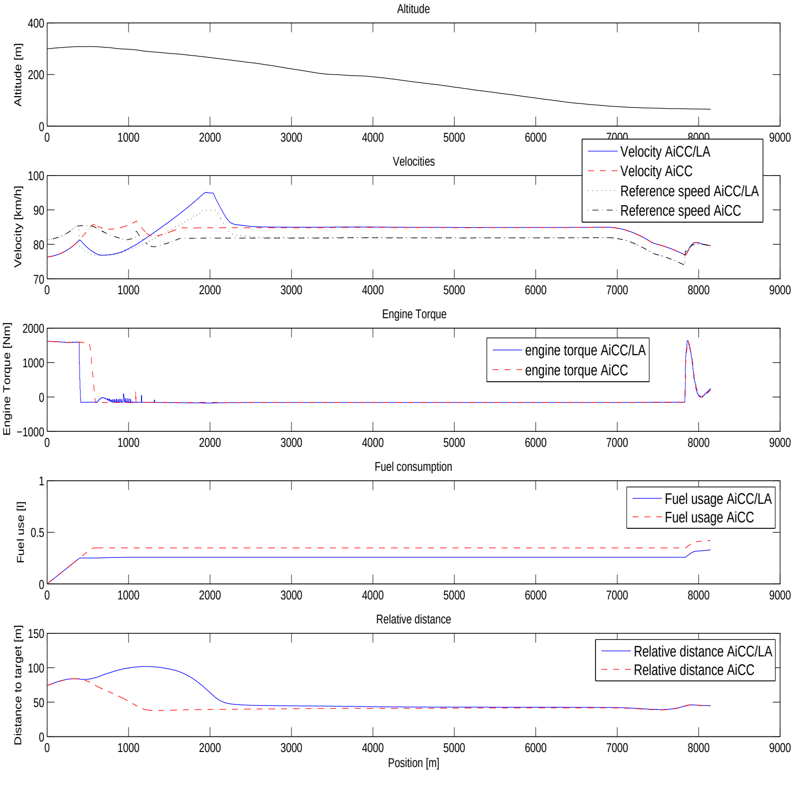

Figure 4.18. The result for Segment 4 with time gap 3 and target weight 20 tonnes.

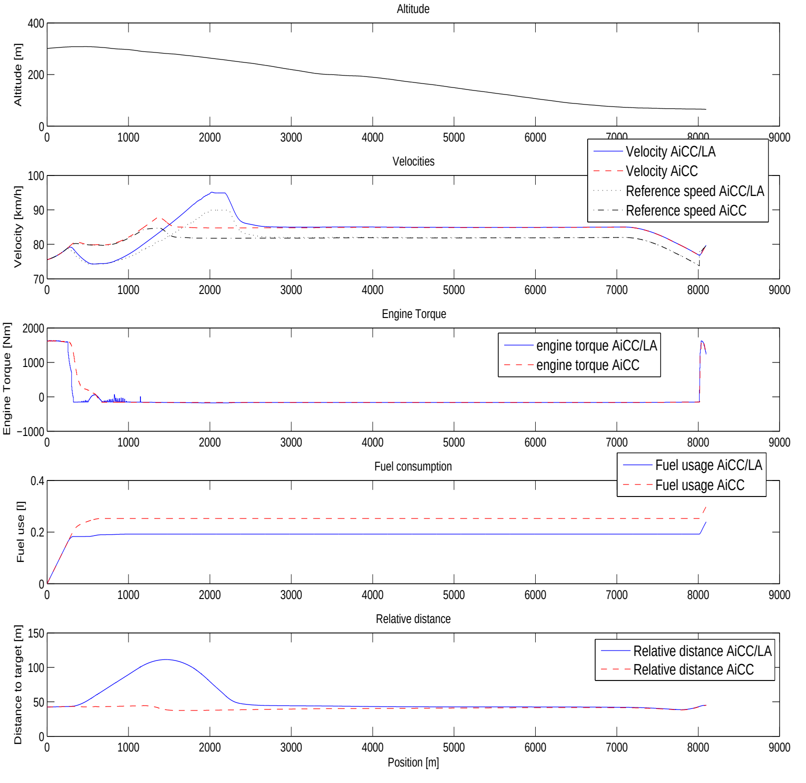

Figure 4.19. The result for Segment 4 with time gap 3 and target weight 40 tonnes.

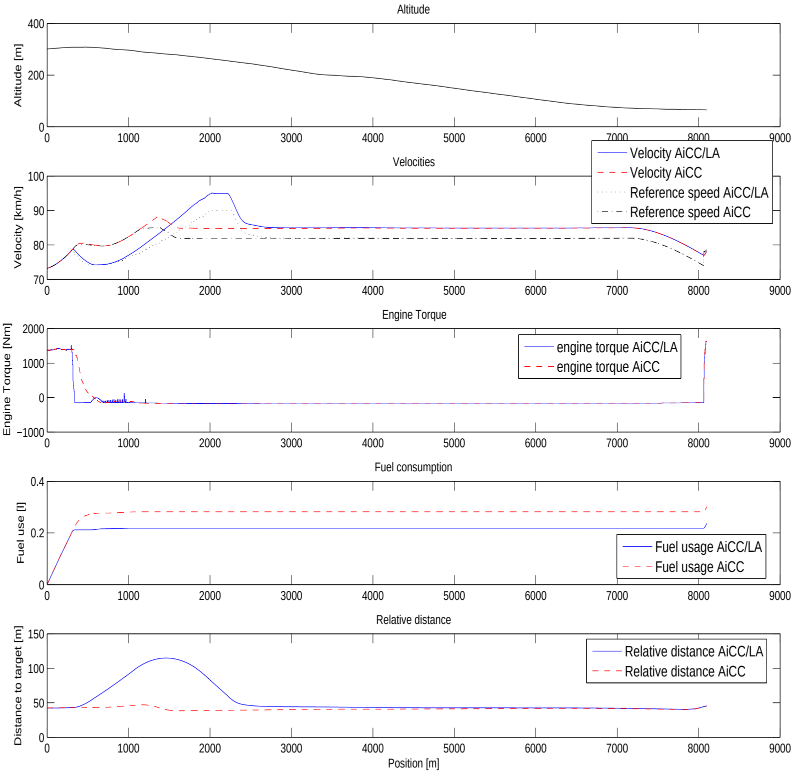

Figure 4.20. The result for Segment 4 with time gap 3 and target weight 50 tonnes.

4.3.3 Summary of the road between Koblenz and Trier

Observations of Segment 3 and Segment 4 show that the best results are obtained when the target weight is 40 or 50 tonnes. This agrees to the overall result for time gap 1 and time gap 3. The overall result for time gap 5 gives the best result when the target weight is 20 tonnes. Like the simulations on the road between Södertälje and Jönköping time gap 5 has a different behaviour then the other two time gaps. One reason for the result is that when time gap 5 is used the distance seldom becomes so small that the AiCC finds it necessary to use the brakes. Even if the downhills is longer and steeper on the road between Koblenz and Trier there are shorter and less steep roads which will affect the result. Note that the overall best result when considering litres of fuel consumed is when the target weight is 50 tonnes also for time gap 5.

4.4 Comparison between Södertälje-Jönköping and Koblenz-Trier

When studying the result from the simulations with the two test roads some interesting results can be found. When studying the results from tables 4.1 and 4.3 it can be seen that for the road Södertälje-Jönkping the best results are received when the target weight is 20 tonnes, for all the time gaps. The second best results are received for a target weight of 40 tonnes and the worst results are received when the target weight is 50 tonnes. Considered the assumption that the target travels at constant speed this result is the expected. The behaviour of the 20 tonnes target agrees the most with the assumed behaviour of the target used in the model.

The results from the simulations with the road between Koblenz and Trier give a different result. For this road the results differ between the different time gaps. The simulations with time gap 1 receive the best result with a target weight of 40 tonnes, the second best result for a target weight of 50 tonnes and the worst result when the target weights 20 tonnes. Time gap 3 receives best result for target weight 40 tonnes, second best is the result when the target weight is 20 tonnes and worst is the result for the 50 tonnes target. Time gap 5 still receives the results in the same order as for the Södertälje-Jönköping road.

The reason for this difference is that on the road between Södertälje and Jönköping the downhills are fewer and also not as long and steep as those between Koblenz and Trier. When the target does not keep constant velocity in the downhills, this makes the distance in the end of the target longer than predicted by the model. The AiCC/LA vehicle has to increase the speed to catch up with the target again, which consumes fuel. When the downhills are steeper and longer as those between Koblenz and Trier the distance is increased to d_{max} before the downhill and we still catch up with the target before the downhill ends so the brakes must be used. Here it does not matter that the target increases the speed in the downhill since the AiCC/LA vehicle still got time to catch up before the downhill has past.

Chapter 5

Conclusion

The results in the previous chapter shows that fuel can be saved by combining an adaptive cruise controller with Look-Ahead. The best results are obtained when driving on a road with long steep downhills. In such downhills braking is unavoidable making the vehicle always catch up with the target in the downhill, this reduces the risk for the distance to become too large in the end of the downhill. For these steep, long downhills the miscalculations due to the assumptions about the target do not affect the final result.

When driving on a road with small altitude changes without many steep downhills the deviations from the assumptions affect the final result in a more evident way. For a target which agrees with the assumption of constant speed the AiCC/LA controller reduces the fuel usage. But when the target becomes heavier it differs from the assumption of keeping constant speed and then the fuel usage reduction will become lower. For time gap 5 and 3 the fuel usage even increases using the AiCC/LA controller.

The problem with the model is that the target seldom will agree with the assumptions made when creating the AiCC/LA controller. The control strategy is based on predicting the distance to the target which depends on the behaviour of the target in the downhill. When the downhill is short there is a risk that the estimated distance to the target in the end of the downhill is smaller than the real distance. This will lead to acceleration for the vehicle after the downhill to catch up with the target.

If the model of the target can be improved and include information about how the target will behave in steep downhills the results can be improved further.

Another important conclusion is that even though the AiCC/LA will increase the distance to the target which will increase the air resistance fuel is saved.

Chapter 6

Future work

Since the digital maps used by the Look-Ahead in the future will contain more information than just the topography it would be interesting to explore other map information of interest, like curve radius and turn-offs. With this information there is a potential to increase the comfort and driver experience as well as further fuel reductions. Since the radar has a narrow field of vision the target is often lost in sharp curves. The information from the Look-Ahead could give information when the target is assumed to be lost and when it should be found by the radar again.

Information about curve radius can also be used to adapt the speed, like in [1]. This can lead to further reduction in fuel usage and also decreasing brake usage.

Another interesting extension is to predict the target behaviour in steep uphills and downhills. If the behaviour of the target can be estimated better the results can be improved, especially when driving on roads with shorter downhills.

Bibliography

[1] Assad Al Alam. Optimally fuel efficient speed adaption. Master's thesis, KTH, 2008.

[2] Erik Hellström, Maria Ivarsson, Jan Åslund, and Lars Nielsen. Look-ahead control of heavy trucks to minimize trip time and fuel consumption. *Control Engineering Practice*, 17(2):245–254, 2009.

[3] Uwe Kiencke and Lars Nielsen. *Automotive Control Systems: For Engine, Driveline and Vehicle*. Springer Verlag, 2000.

[4] Rajesh Rajamani. *Vehicle Dynamics and Control*. Springer, 2006.

[5] Hucho Wolf-Heinrich and Syed R. Ahmed. *Aerodynamics of Road Vehicles*. Warrendale: Society of Automotive Engineers, Inc, 1998.