Mission Optimized Speed Control

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Abstract

Transportation underlines the vehicle industry’s critical role in a country’s economic future. The amount of goods moved, specifically by trucks, is only expected to increase in the near future. This work attempts to tackle the problem of optimizing fuel consumption in Volvo trucks, when there are hard constraints on the delivery time and speed limits. Knowledge of the truck such as position, state, configuration etc., along with the complete route information of the transport mission is used for fuel optimization.

Advancements in computation, storage, and communication on cloud based systems, has made it possible to easily incorporate such systems in assisting modern fleet. In this work, an algorithm is developed in a cloud based system to compute a speed plan for the complete mission for achieving fuel minimization. This computation is decoupled from the local control operations on the truck such as prediction control, safety, cruise control, etc.; and serves as a guide to the truck driver to reach the destination on time by consuming minimum fuel.

To achieve fuel minimization under hard constraints on delivery (or arrival) time and speed limits, a non-linear optimization problem is formulated for the high fidelity model estimated from real-time drive cycles. This optimization problem is solved using a Nonlinear programming solver in MATLAB.

The optimal policy was tested on two drive cycles provided by Volvo. The policy was compared with two different scenarios, where the mission demands hard constraints on travel time and the speed limits in addition to no traffic uncertainties (deterministic).

- with a cruise controller running at a constant set speed throughout the mission. It is observed that there is no significant fuel savings.
- with maximum possible fuel consumption; achieved without the help of optimal speed plan (worst case). It is seen that there is a notable improvement in fuel saving.

In a real world scenario, a transport mission is interrupted by uncertainties such as traffic flow, road blocks, re-routing, etc. To this end, a stochastic optimization algorithm is proposed to deal with the uncertainties modeled using historical traffic flow data. Possible solution methodologies are suggested to tackle this stochastic optimization problem.

Keywords: cloud computation, optimization, non-linear programming, uncertainties
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Chapter 1

Introduction

Advancement in computation, sensing, and low cost of cloud based storage has made it possible for incorporating a wide range of facilities on modern road cargo. Karlström [1] mentions that according to International Energy Agency (IEA) digitization plays a key role in improving logistic chains. Currently, most of desired operations (safety, driver assistance etc) are performed locally using closed loop controllers like PID, predictive controller etc. However, additional functionalities like optimizing the fuel consumption, arrival time, safety, etc are becoming a necessity. In this thesis, a cloud based system is proposed to take care of most of the high level computations and just the functionalities based on limited horizon are transferred to the local controller.

Trucks constitute a significant percentage in the total modern vehicle fleet. It was reported that most of the truck manufacturers in European Union have been mainly focusing on improving engine performance and less efforts have been put in achieving reduction in fuel consumption [2]. As can be seen from Figure 1.1, the cost of fuel is an important factor in the total operating cost of a truck.

Arrival time is another important aspect that needs to be considered when it comes to commercial trucks as most businesses are heavily dependent on trucks for deliveries and transport missions. In a road transport mission, the driver usually tries to travel at higher speeds to reach the destination on time. This is not desirable as it results in higher costs (driver wages\(^1\), fuel cost etc.) for the vehicle transportation agencies. This motivates the present work on minimizing fuel consumption, when there are constraints on arrival time and speed limits, in modern Volvo trucks.

![Figure 1.1: Operating costs of a truck. It is clear from the pie chart that the fuel cost is higher than other costs in a truck. This figure is adopted from [4].](image)

\(^1\)In the USA, driver salary is based on miles covered [3]
Contribution of this thesis

The objective of the thesis is to calculate a speed plan by considering both fuel efficiency and time optimality. The work carried out in this thesis is based on the information about the truck such as vehicle mass, maximum engine torque, gear characteristics, etc. provided by Volvo.

The work is briefly summarized as follows:

- By simulating various drive cycles provided by Volvo, the variation of fuel consumption with speed for the entire mission was generated.

- An optimization algorithm is developed by incorporating suitable constraints to calculate the speed plan for the entire transport mission. The algorithm was implemented in MATLAB. The calculation of speed plan (vehicle set-speed) is done in a cloud system, also called as Volvo-Back Office. The speed plan is communicated from the back-office to the truck, which is used as an input for the local predictive controller or conventional cruise controller.

- Fuel optimization using dynamic information of the road such as traffic flow, road block etc, is discussed.

The block diagram in Figure 1.2 indicates the work flow.

![Block Diagram](image)

Figure 1.2: First step involves choice of the driving cycle. The next step involves dividing it into sections and formulating the optimization problem by applying suitable constraints. Speed plan is then calculated and communicated to the Volvo truck.

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2A high fidelity vehicle model was considered to formulate the optimization algorithm.

3It should be noted that the present approach is different from the approaches followed to ensure arrival time by navigational services like Google Maps, TomTom, etc.

4It should be mentioned that this method considers the entire mission for calculating the speed plan, while the local predictive controller (if used in the truck) makes sure that the vehicle average speed is maintained around the incoming set speed (from Volvo back-office), based on its working horizon and road topography. In other words, real speed of the vehicle will be different from the proposed set speed.
Optimal speed plan

Figure 1.3 represents an optimal speed plan for one of the drive cycles used in this work. An algorithm is developed in the Volvo-Back Office to compute a speed plan by placing hard constraints on fuel consumption and final arrival time. The complete mission is divided into stages of certain length and a constant set speed for each of these stages is proposed. This constitutes the optimal speed plan for the complete transport mission. The proposed speed plan thus acts as a guide to the drivers to reach the destination on time by consuming minimum fuel.

Figure 1.3: Green line indicates the speed plan i.e. set speed for the complete mission with a travel time of 7.3 hours. The light blue line indicates the altitude profile of the road.

1.1 Previous work

Use of cloud for minimizing fuel consumption

Kumar [5] considered optimal energy management in land vehicle, where a cloud system was used. This was done in collaboration with Ford Motor Co. Dynamic Programming was used to compute the optimal speed profile. Fuel consumption was the cost to be minimized.

The work involved using physical model (engine model) of the vehicle to compute the cost functions. The optimization problem was solved with different driving cycles and a few constraints. The constraints considered were speed limits on the road, altitude profile of the road etc. The simulation results thus obtained were tested on a Lincon MKS for validation. Figure 1.4 represents the optimal speed plan in comparison to the actual driving speed. The results of this work further show that this concept achieves fuel saving.
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Figure 1.4: Optimal speed vs. Actual speed. Figure shows the difference between optimal and actual velocity profiles of the vehicle on a road profile with a few stops in between. It can be seen that in some sections of the road, there is a fuel saving potential. This figure is adopted from [5].

Fuel saving using Predictive Cruise Control (PCC)

Lattemann et al.[6] considered using Predictive Cruise Control (PCC) for reducing fuel consumption in heavy ground vehicles. This system works in conjunction with the regular cruise controller in the vehicle. It used a 3D map and GPS to capture the road grade, position and the road information for the upcoming 4 kilometers.

A predictive algorithm based on complete vehicle model was developed which takes the computed road information as an input. Further, speed of the vehicle was allowed to change within certain bounds around the cruise controller set speed in order to achieve fuel saving. Figure 1.5 shows the fuel saving potential of using PCC compared to conventional cruise controller in a vehicle mass of 37.5 tons.

Figure 1.5: Results for a driving cycle having a total distance of 25km. Top plot represents the topography of the road profile used. Middle plot indicates the difference between CC speed and PCC speed w.r.t position. End plot shows the fuel saving achieved by PCC. It can be seen that there is some fuel saving potential. This figure is adopted from [6].
The use of PCC resulted in 4.05% saving in fuel compared to that with conventional cruise controller. However, when PCC was used, the truck took more time to reach the destination. It was noted that this approach provided significant fuel saving in situations where the vehicle approached a hilly section of the road. This is because PCC allows the vehicle to accelerate before it enters the uphill section and decelerate before it reaches the flat surface. It was also observed that the savings in fuel on flatter terrains was minimal.

**Heavy Vehicles with Look-ahead Control**

A few limited prediction horizon approaches have been presented below.

Hellström [7] used the upcoming road topography information to reduce energy consumption in heavy vehicles. An optimization algorithm based on Dynamic Programming was developed to minimize fuel consumption. The work also included gear selection based on physical models to generate optimal speed profile. It was concluded that the fuel economy was improved by the use of look-ahead control with conventional powertrain.

Johannesson et al. [8] made use of the GPS information and speed limits along the tested route to find the optimal speed and gear selection for energy management in vehicles. A two layered predictive control algorithm where, the top layer calculates vehicle speed and lower layer decides the gear selection was incorporated. The calculated vehicle speed takes into account the surrounding vehicle traffic.

Hellström et al. [9] developed a similar energy management system in heavy vehicles by considering GPS information and road geometry. The speed profile was generated based on fuel consumption and the trip time. A predictive controller based on Dynamic Programming algorithm was used for speed calculation, which was constantly fed into the conventional cruise controller in the truck. The trail run performed (120 km long route) showed that there was a 3.5% saving in fuel without increase in the trip time.

**Platooning in Heavy-duty vehicles**

Alam [10] considered using platooning in heavy duty vehicles for reducing fuel consumption, traffic congestion, etc. by optimally controlling the inter vehicle spacing. A two model predictive controller was used to achieve fuel savings. The concept was seen to have achieved nearly 4-6.5% savings on Swedish highway. It was noted that the vehicle position in the platoon, altitude profile of the road and the preceding vehicle’s behaviour played a key role in achieving fuel saving.

**Other related work**

Lindgärde et al. [11] developed a model based controller to reduce fuel consumption in Volvo trucks. The tested truck was modified to have controllable electrical actuators. The controller made use of the prediction information to optimize fuel consumption by controlling various energy buffers such as battery system, kinetic energy of the vehicle and cooling system. It was observed that the tested drive cycle and road topography greatly influenced the fuel saving potential.

Köhler [12] used Dynamic Programming to evaluate the optimal speed plan of the truck mission. The optimal speed was calculated based on minimizing fuel consumption and arrival on time at the destination. It was observed that there was a fuel saving potential in
the tested driving cycles. However, there was no constraints considered in the optimization except road topography information.

*I-see* is a latest feature in Volvo trucks which helps in achieving fuel efficiency on hilly terrains. It makes use of Volvo central server that stores the data of road topography and transmits it to the truck when necessary. Based on this information the acceleration, braking and gear shift is controlled to achieve fuel efficiency on hilly sections of the road. According to Volvo, this technology has the potential to save up to 5% fuel in long-haul trips [13].

*Active prediction* by Scania is a similar technology for saving fuel in heavy duty vehicles. It makes use of GPS to track the position of the truck and topography information of the road lying ahead. This is used as an input for energy management. Scania believes that this technology can achieve 3% fuel saving [14].

### 1.2 Thesis outline

The present thesis work consists of six chapters that includes Background, Motivation and previous work in Chapter 1. Chapter 2 briefly describes the problem at hand and its formulation. In Chapter 3, the optimization framework based on *fmincon* solver is presented.

Chapter 4 consists of the results obtained by solving the optimization problem and discussions based on these results. Chapter 5 details the formulation of uncertainties and steps followed for real-time implementation of the problem. Finally, in Chapter 6, conclusions and a few recommendations for the future work is suggested.
Chapter 2

Problem formulation

2.1 Concept overview

Consider a truck transport mission which starts at point A and ends at B as seen in Figure 2.1. The endpoint, which is the destination can be an overseas shipment, goods to be delivered to an industry etc.

Figure 2.1: Overview indicating the two layers (separated by a purple dotted line) - Volvo-Back Office and the truck. The communication of information is also depicted. Calculation of Speed Plan is the main focus of this thesis work. This figure is adopted from [12].

For this mission to be successful (by customer and transportation agencies), it is crucial that the arrival time is within the desired limit and least fuel is expended. However, incorporating all these functionalities in the controller present locally on the vehicle is a challenging task as it demands high computational costs and increases its complexity. Since these functionalities are at a meta-level and can be decoupled from the computations done locally, a two-layered approach to optimizing the fuel by constraining travel time and speed limits, while performing basic local control operations is proposed. To this end,
optimization is computed on the cloud - termed as Volvo-Back Office - and transfer the basic functionalities\(^1\) to a local controller, also known as the low level controller.

In Figure 2.2, the static and dynamic road information is obtained from the Global Navigation Satellite System (GNSS). The truck information and transport mission information is provided by the transport agencies paying for this service.

An optimization algorithm is developed that utilizes the information collected to calculate an optimal speed plan for the entire mission, which is then communicated to the low level controller in the truck. Communication of speed plan can be achieved by,

- Driver coaching i.e. speed proposal to the driver.
- Integrating it with the existing I-see technology used by Volvo.
- Future for complete autonomous driving.

The speed plan calculation mainly depends on the speed limits used in the algorithm. It is decided in the Back Office based on previously mentioned dynamic road information. Speed bound refers to the upper and lower limits of set speed, which is used as a constraint in reducing fuel consumption.\(^2\)

---

\(^1\)Cruise controller, predictive controller etc. These controllers further optimize the vehicle set speed depending on the road geometry, based on their working horizon.

\(^2\)It should be noted that the speed bound values are dynamic i.e. they change based on the dynamic information.
The proposed speed plan from the Back Office is communicated to the low level controller in the truck. This controller uses the same speed bounds as suggested by the Volvo-Back Office. The low level controllers used in this work include,

- **predictive vehicle control**: This controller further optimizes fuel consumption by maintaining the vehicle set speed based on its working horizon.

- **cruise control**: It is modeled so that in the downhill sections of the journey, vehicle set speed is limited by the upper limit of set speed as suggested by the Back Office.

**Remark.** It should be mentioned that the optimization algorithm developed henceforth does not include route planning, path re-routing, weather forecast information as it is beyond the scope of this thesis work.

### 2.2 Mathematical formulation

In this section, model formulation and the solution approach taken to address the problem is presented.

**Nomenclature**

- $FC$ = fuel consumption of the entire route in l/100 km.
- $V_{set}$ = set speed of the vehicle in kmph.
- $V_{av}$ = average speed of the vehicle in kmph.
- $T$ = total travel time in hours.
- $i = \text{stage number.}$
- $t_i = \text{time taken to complete a stage in hours.}$
- $s_i = \text{distance of a stage in km.}$
- $V_U = \text{upper limit of set speed.}$
- $V_L = \text{lower limit of set speed.}$
- $a_i, b_i, c_i, e_i, h_i$ are constants for different stages.

**Subscripts**

- $(.)_{set_i} = \text{set speed of the vehicle for different stages.}$
- $(.)_{av_i} = \text{average speed of the vehicle for different stages.}$

**Objective**

The optimization problem is formulated as:

\[
\min_{V_{set} \in (V_{set_1}, V_{set_2}, \ldots, V_{set_n})} FC(V_{set})
\]

subject to,

\[
\sum_{i=1}^{n} t_i \leq T
\]

\[
V_L^i \leq V_{set_i} \leq V_U^i, \quad \forall i \in 1, 2, \ldots, n
\]
Discussion

The objective function in this optimization problem involves fuel consumption as a function of vehicle set speed. This function completely captures the speed variations along the entire road profile. It is obtained by simulating a given drive cycle. The constraints are placed on the total travel time needed to complete a truck mission. In addition, limits are also defined on the set speed based on the dynamic road information. These constraints ensure fuel saving over the entire mission.

Model

The proprietary driving cycle data gathered by Volvo was used to assist in modeling the problem.

1.) Road Profiling: The complete road profile of the considered driving cycle was divided into certain number of stages as it is easier to address an optimization problem by dividing it into smaller sections. In this work, the sectioning was done with each section having equal length to simplify the calculations for the considered drive cycles. Based on the simulation results for various set speeds $V_{set}$, a function representing the relation between $FC$ and $V_{set}$ for each of these stages was derived, and noted to be quadratic (convex) in nature.

\[
FC = (a_1V_{set1}^2 + b_1V_{set1} + c_1) + (a_2V_{set2}^2 + b_2V_{set2} + c_2) + \ldots + (a_nV_{setn}^2 + b_nV_{setn} + c_n) \tag{2.2}
\]

2.) Speed Bounds: The bounds of set speed for different stages is determined by the Volvo back-office based on the dynamic road information received from GNSS. It mainly depends on the speed limits along the route, traffic flow, city driving, etc.

\[
V_L^i \leq V_{seti} \leq V_U^i \tag{2.3}
\]

3.) Time constraints: Total travel time of the entire mission was constrained to be within $T$ hours (i.e. the sum of travel times in each of these stages should be within $T$ hours).

\[
t_1 + t_2 + t_3 + t_4 + \ldots + t_n \leq T \tag{2.4}
\]

where,

\[
t_i = s_i / V_{av_i} \tag{2.5}
\]

The average and set speeds are equal when the engine torque is sufficient to maintain the vehicle speed. The complete speed variations along the selected route is captured for calculating the optimal speed plan. Based on the results for the considered drive cycles in this work, it was seen that the relationship between $V_{av}$ and $V_{set}$ was linear. Equation 2.5 can be rewritten as,

\[
t_i = s_i / (e_iV_{seti} + h_i) \tag{2.6}
\]

---

3 Due to the road geometry.
4 A high fidelity vehicle model was considered to formulate the optimization algorithm.
5 Based on observed results, stage length of more than 20km provides reasonable results.
6 In this work, the $V_{set}$ values were chosen in the range from 70km/hr to 90km/hr in steps of 1km/hr for simulation.
7 Departure and arrival times are key while considering this constraint. However, it is decided by the transport agency paying for this service. It may also include driver shifts, i.e. in EU, a driver can drive upto 9 hours per day with a 45 minutes break in-between [15].
Solution using Non-linear Programming (NLP)

The process of solving an optimization problem with a well defined objective function (to be minimized or maximized) subjected to a set of constraints/inequalities, where either one of them is non-linear is called Non-linear programming [16].

\[
\min_x f(x) \\
\text{subject to,} \quad Ax \leq b \\quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (2.7) \\
c(x) \leq 0 \\
lb \leq x \leq ub
\]

where,

$A$ is a matrix, $b$ is a vector, and $f(x)$ & $c(x)$ can be nonlinear functions.

Borrelli et al. [17] mentions that NLP solvers play an important role in solving problems that demands large computational infrastructure. The significant research and faster computing methods has made it possible to solve complex optimization problems with ease in both automotive and aerospace areas.

In the present work, an NLP solver called \texttt{fmincon} has been used. It uses the default interior point algorithm to minimize a smooth function subjected to constraints. The constraints may be linear, nonlinear or simple bounds on the variables involved.

Comparing equations 5.4 & 3.1, it can be seen that variables $f(x)$, $c(x)$ and $x$ are similar to $FC$, $t$ and $V_{\text{set}}$ respectively. The bounds $ub$ & $lb$ are placed on $V_{\text{set}}$. There are no other inequalities present in this work.

Today there are several optimization packages available in \texttt{MATLAB} to solve NLP problems, such as, \texttt{fmincon} provided by MathWorks, \texttt{FORCES PRO} developed by ETH Zurich, \texttt{YALMIP} by GitHub, etc.
Chapter 3

Optimization algorithm

3.1 \textit{fmincon} solver

\textit{fmincon} is a powerful non-linear programming solver in \textsc{Matlab} and it is used to find the minimum value of the nonlinear function with constraints and variables, for example [18]:

\[
\begin{align*}
\min_{x} & \quad f(x) \\
\text{subject to,} & \quad A(x) \leq b \\
& \quad Aeq(x) = beq \\
& \quad c(x) \leq 0 \\
& \quad ceq(x) = 0 \\
& \quad lb \leq x \leq ub
\end{align*}
\]

(3.1)

Where \( x \) is the controlled variable, it can be scalars or vectors. \( A(x), Aeq(x) \) are the linear constraints, \( c(x), ceq(x) \) are the nonlinear constraints. The upper bound and lower bound of the variable \( x \) are \( ub \) and \( lb \). \( b \) and \( beq \) are vectors, \( A \) and \( Aeq \) are matrices, \( c(x) \) and \( ceq(x) \) are functions that return vectors, and \( f(x) \) is a function that returns a scalar. \( f(x), c(x), \) and \( ceq(x) \) can be nonlinear functions, \( x, lb, \) and \( ub \) can be passed as vectors or matrices [18]. The function \( f(x) \) is the objective function which is needed to be minimized. The syntax of \textit{fmincon} in \textsc{Matlab} is:

\[
\text{fmincon}(\text{fun}, x0, A, b, Aeq, beq, lb, ub, nonlcon, options)
\]

This syntax subjects the minimization to the nonlinear inequalities \( c(x) \) or equalities \( c_{eq}(x) \) defined in \textit{nonlcon}. [18].

The \textit{fmincon} has five different algorithm options:

- ‘interior-point’ (default)
- ‘trust-region-reflective’
- ‘sqp’
- ‘sqp-legacy’
- ‘active-set’
The ‘interior-point’, ‘trust-region-reflective’ and ‘active-set’ algorithm options are large scale algorithm options, however, ‘sqp’ and ‘sqp-legacy’ are medium scale. The large scale algorithm and medium scale algorithm is the large scale algorithm uses linear algebra that does not need to store, nor operate on, full matrices. This may be done internally by storing sparse matrices, and by using sparse linear algebra for computations whenever possible. In contrast, medium-scale methods internally create full matrices and use dense linear algebra. If a problem is sufficiently large, full matrices take up a significant amount of memory, and the dense linear algebra may require a long time to execute [19].

3.2 Modeling

In order to get the objective functions in all stages, some initial simulations are done in a powerful simulation environment from Volvo called GSP or Global Simulation Platform. GSP is used to simulate truck transport missions in different drive cycles. The truck model in the Volvo GSP is the Volvo FH13 tractor with semitrailer. It is a very common truck type in Europe, and its configuration is shown in Table 3.1 [12].

In this work, two drive cycles are used in the GSP, one is called Sweden route, which is a drive cycle in Sweden, and the other one is called Kassel-Hamburg route which is a drive cycle in Germany. The Sweden route is flatter and longer than the Kassel-Hamburg route. The two routes are shown in the Figure 3.1.

![Figure 3.1: Kassel-Hamburg route and Sweden route, This figure is adopted from [20].](image)
Each of the drive cycles is divided into 15 equal stages. In each stage, the relationship between fuel consumption and average speed of the vehicle is generated, which is regarded as the cost function of this stage. The objective functions in Sweden Route and Kassel-Hamburg route are shown as Figure 3.2 and the Figure 3.3.

Figure 3.2: *The relationship between fuel consumption and average speed in all stages in Sweden route. The drive cycle is divided into 15 equal stages.*

Figure 3.3: *The relationship between fuel consumption and average speed in all stages in Kassel-Hamburg route. The drive cycle is divided into 15 equal stages.*

To make it easier to compare with each other, the curves in Figure 3.2 and Figure 3.3 are normalized, and according to these two figures. An assumption can be made that the relationships between fuel consumption and average speed in these stages are quadratic. As shown in Figure 3.2 and Figure 3.3, the relationships in different stages are different. In some stages, the fuel consumption curves are steep, and in order to save fuel, the speed...
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should not be high in these stages. However, in the stages which the fuel consumption curves are flat, the speed can be high if the time is limited. An assumption can be made from this figure that an optimal speed plan has potential to save fuel with a guaranteed arrival time.

Although the relationships between fuel consumption and average speed in each stage are generated, in reality, the average speed is not equal to set speed, especially when there are some steep hills in one stage. When a truck is climbing a steep hill, it is hard to keep the speed as the set speed due to the limited engine torque and power. Since the set speed and the average speed are different, their relationship should be found. The relationships between set speed and average speed in all stages for the two drive cycles are shown in Figure 3.4 and Figure 3.5.

Figure 3.4: The relationship between set speed and average speed in all stages in Sweden route.

Figure 3.5: The relationship between set speed and average speed in all stages in Kassel-Hamburg route.

According to Figure 3.4 and Figure 3.5, an assumption can be made that the relationships between set speeds and average speeds are linear. Since the quadratic relationship between
fuel consumption and the linear relationship between set speed and average speed are generated, for these two drive cycles the cost functions in every stage can be calculated, which are the fuel consumption as functions of set speeds. Based on these cost functions, an objective function is formulated to calculate the optimal speed plan.
Chapter 4

Simulation results

4.1 Simulation results

The optimal speed plan can be generated by using the NLP solver called fmincon in MATLAB. In this particular project, the upper and lower limits of the speed are 70 km/h to 90 km/h when generating the speed plan. The examples of the optimal speed plans in the two drive cycles are shown in Figure 4.1 and Figure 4.2.

Figure 4.1: The optimal speed plan for the Sweden route with 7.3 hours travel time.

![Switzerland Route for Travel time = 7.3 hours](image)

Figure 4.1 and Figure 4.2 are examples of the optimal speed plan for the Sweden route and Kassel-Hamburg route. For each drive cycle, every travel time corresponds to an optimal speed plan. In Figure 4.1 and Figure 4.2, the green line represents the optimal speed plan, the dark blue line is the real speed of the vehicle and the brown line is the altitude profile of the drive cycle. As mentioned before, the optimal speed is regarded as the set speed in every stage. A cruise controller on the vehicle is in charge of controlling the real speed of the vehicle. The cruise controller tries to maintain the vehicle speed same as the set speed, however, when the vehicle is in downhills the cruise controller will disengage the drive line and let the vehicle roll to save fuel.\(^1\) When the vehicle is in the

\(^1\)However, it is limited by the upper-bound of the cruise controller.
uphills the cruise controller will shift the drive line to a lower gear to keep the speed. Figure 4.3 shows how the cruise controller works in GSP.

![Figure 4.2: The optimal speed plan for the Kassel-Hamberg route with 4.7 hours travel time.](image)

![Figure 4.3: The cruise controller with $V_{set} = 80\text{km/h}$, $V_{ub} = 90\text{km/h}$ & $V_{lb} = 70\text{km/h}$.](image)

4.1.1 Discussion

The fuel saving performance

In order to see how much fuel can be saved by using the optimal speed plan, comparisons have been made between the fuel consumption from optimal speed plan and the fuel consumption from a fixed speed plan, and the highest possible fuel consumption (worst-case scenario) is also compared. The results of the comparisons are shown in Figure 4.4.
and Figure 4.5.

![Figure 4.4](image1.png)

Figure 4.4: Fuel consumption in Sweden route. The red line is the optimal fuel consumption, the green line is the reference fuel consumption, the blue line is the worst fuel consumption.

![Figure 4.5](image2.png)

Figure 4.5: Fuel consumption in Kassel-Hamburg route. The red line is the optimal fuel consumption, the green line is the reference fuel consumption, the blue line is the worst fuel consumption.

In Figure 4.4 and Figure 4.5, the red line is the lowest fuel consumption curve, which represents the ideal fuel consumption by applying the optimal speed plan. The blue line indicates the highest possible fuel consumption curve, which is the worst case of fuel consumption when drivers drive without the help of optimal speed plan. The green line is the reference fuel consumption, which represents the fuel consumption when the set speed is fixed during the whole drive cycle for different travel times. Although the green line is meaningless to refer reality, it is helpful to see how much fuel does the optimal speed plan save in simulation perspective. These comparisons are fair as the speed boundaries for the simulations are the same. i.e. 70 km/h and 90 km/h.
Although it was believed that for the same travel time, use of optimal speed plan can help to reduce the fuel consumption, the difference between the reference fuel consumption curve and the optimal curve is very small. For Sweden route, comparing to the reference curve, the fuel saving is only 0.36 percent and for Kassel-Hamburg route the fuel saving is 0.64 percent, both of which are very small and can be ignored. It seems the optimal speed plan does not result in fuel savings.

However, this reference curve is meaningless in reality. When a driver is in a transport mission, he does not travel with a constant set speed for the whole journey. In reality, most drivers are used to drive fast in the beginning of a mission to ensure they can arrive on time, and drive slow for the rest of the mission. The proposal of having such an optimal speed plan is to increase the confidence of drivers in ensuring arrival time, so that they can drive in a fuel saving way. However, in reality, the fuel consumption is possible to lie anywhere between blue and red lines in Figure 4.4. In this aspect, an optimal speed plan can help a lot in saving fuel.

An interesting finding is that, the optimal speed plan reduces fuel consumption more in high speed range, and the explanation of this phenomenon is in Figure 3.3 and Figure 3.2. As mentioned earlier, the relationship between fuel consumption and vehicle speed was assumed to be quadratic, which means that the fuel consumption is more sensitive to speed change in high speed range. If the vehicle speed is high in the journey, the optimal speed plan will be more beneficial.

**The influence of altitude changes**

The simulations are done in two different drive cycles, and as shown in Figure 4.1 and Figure 4.2, the Sweden route is longer than the Kassel-Hamburg route, however, as mentioned before the fuel saving in Kassel-Hamburg route is higher. This phenomenon shows that in Kassel-Hamburg route, the optimal speed plan is more effective. As mentioned before, steep objective functions can increase the fuel saving of the optimal speed plan. As mentioned before, Sweden route is much flatter than Kassel-Hamburg route, which means the altitude change might influence the objective funtions. To investigate this, three typical stages in Sweden route are chosen to be compared, as Figure 4.6 and Figure 4.7 show.

![Figure 4.6: The division of the Sweden route. Stage 4, 9 and 14 are picked for comparison.](image-url)
As mentioned before, the drive cycle is divided into 15 equal stages, and objective functions are generated in these equal stages. As Figure 4.6 shows, in Sweden route, the stage 4 is a relative flat stage, the stage 9 has some altitude change and stage 14 is a very hilly stage. The objective function curves of these stages are shown in Figure 4.7. To make them easier to be compared with each other, these objective function curves are normalized. As shown, the stage 14 which is the hilliest stage has the steepest objective function curve, and the stage 4 which is the flattest stage has the flattest objective function curve. Based on these simulation results, a conclusion can be made that the optimal speed plan is more effective in fuel saving on the hilly road.

### 4.2 Improving the fuel saving performance

As shown previously, the optimal speed plan still has potential to be improved, since the relationship between fuel consumption and average speed varies in different conditions. This section will introduce some factors which influence the fuel saving performance and ways to save more fuel. To make it easier to read, only the results of Kassel-Hamburg route will be presented in this section. The results of Sweden route will be discussed in appendix.

#### 4.2.1 Influence of the speed bounds and stages

**Wider speed bounds**

Apart from the road altitude itself, the way to setup an optimization also influences the fuel saving performance. For example, the fuel saving should be increased when the considered speed bounds are wider, because wider speed bounds can give more space for optimal speed plans. To investigate the influence of speed bounds on fuel saving, a similar simulation is performed on the Kassel-Hamburg route, however with speed bound set between 60km/h to 90km/h as in Figure 4.8. It can be seen that, with wider speed bounds, the fuel saving from the optimized speed plan increases.
Increase in number of stages

Another possible way to improve the fuel saving performance is to divide the journey into more stages, because more stages can make the objective function more accurate. In the previous simulations, the number of stages is 15, and the similar simulation is done with 20 stages.

As shown in Figure 4.9, dividing the road profile into more stages can improve the fuel saving performance. Although dividing the road profile into more stages can save more fuel, there are better ways to divide it compared to equal stage division. One possibility can be to divide it based on some key elements such as traffic profile, maximum permissible speed, road gradient and road signs, and these key elements should be constant in all stages [21]. It is hard to divide the journey by these key elements due to limited information, although a potential of saving fuel exists.²

²It was observed that higher divisions of the road profile, results in non-smooth cost functions. This may affect the result. Also, it is not reasonable to have too many stages, since, a predictive controller (low-level) operating locally will have a certain working horizon (in km) of its own.
4.2.2 Fuel saving with the predictive controller

The high level controller in the cloud helps to reduce the fuel consumption by calculating an optimal speed plan for the whole transportation, in addition, there should be a predictive controller in the vehicle which control the vehicle speed to reduce fuel consumption in a lower level. Volvo trucks has a working low level controller in a few of its truck models (as an option). It is called Volvo I-See. I-see detects the altitude profile of the up coming road section, and controls the vehicle speed based on the detected altitude profile. Figure 4.10 shows the working of a predictive controller (I-see).

As shown in Figure 4.10, when I-See detects an up coming hill, the vehicle accelerates to a high speed to generate enough kinetic energy, and by using this kinetic energy, the vehicle can avoid downshifting in the uphill, which saves fuel. After climbing the uphill, the vehicle curbs the speed and prepare for the downhill. In the downhill section, I-See engages eco-roll. This disengages the vehicle drive line, causing the vehicle to roll at high speeds and braking it gently to avoid over-speed. If another uphill is detected afterwards, I-See will increase the vehicle speed again[22].

As mentioned before, Volvo has a simulation environment in Simulink called GSP which is able to simulate the transportation mission of trucks. In GSP there is also a low-level controller on the vehicle. Unlike I-See, this low-level controller is a model based predictive controller, however, it works similar to the I-See. The Figure 4.11 shows how the model predictive controller works in GSP.

As Figure 4.11 shows, this model predictive controller works very similar as the Volvo

Figure 4.10: Working of I-see, as the truck goes through a hill. This figure is adopted from [22].

The light blue line is the altitude profile and the dark blue line is the vehicle speed. Before going into the uphill, the model predictive controller increases the vehicle speed to the upper bound: 90km/h, and the in the uphill the vehicle speed decreases. When the vehicle goes downhill, the controller disengages the drive line, and the speed rises again. As Figure 4.11 shows, this model predictive controller works very similar as the Volvo
Mission Optimized Speed Control

Figure 4.11: The work of predictive controller in simulation, The light blue line is the altitude profile and the dark blue line is the vehicle speed.

I-See in simulation, and the simulation results with the model predictive controller are shown in Figure 4.12 and Figure 4.13

Figure 4.12: The fuel consumption in Kassel-Hamberg route with predictive controller.

These results are also generated with the same speed bounds as before, so it is fair to compare them with the previous results. As shown in Figure 4.12 and Figure 4.13, the fuel consumption of the curves are lower than before, thanks to the low lever controller. A property can be observed that comparing the reference curves shows the optimized speed plan helps to reduce the fuel consumption in high and low speed range, however, in the middle speed range it doesn’t reduce much fuel.

4.3 Comparison

This chapter shows the fuel saving performance of the optimal speed plan. The fuel consumption curves of the optimal speed plan in various cases are shown. To make them easier to compare with each other, a table is made to show the fuel consumption in all cases in two specific travel times in Kassel-Hamburg route, and it is shown in Table 4.1

In Sweden, the maximum allowable speed for a truck without a connected trailer is 90 km/h, and if a truck connects a trailer, the maximum allowable speed is 80 km/h [23]. Regarding these speed limits, the two travel time in Table 4.1 are 270 minutes and 290 minutes, which correspond to 80 km/h and 75 km/h. As shown in Table 4.1, the predictive
Figure 4.13: The fuel consumption in Sweden route with predictive controller.

Table 4.1: Comparison of fuel consumption with the optimal speed plan in different cases.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>T = 270 mins</th>
<th>T = 290 mins</th>
</tr>
</thead>
<tbody>
<tr>
<td>With cruise controller</td>
<td>35.40 L/100km</td>
<td>31.60 L/100km</td>
</tr>
<tr>
<td>With predictive controller</td>
<td>32.82 L/100km</td>
<td>29.47 L/100km</td>
</tr>
<tr>
<td>With 20 stages</td>
<td>35.33 L/100km</td>
<td>31.15 L/100km</td>
</tr>
<tr>
<td>With speed bound: 60-90</td>
<td>35.01 L/100km</td>
<td>31.23 L/100km</td>
</tr>
</tbody>
</table>

controller is very effective in saving fuel. Dividing the journey into more stages and setting wider speed bounds also improve the fuel saving.

In general, the optimal speed plan can guarantee the travel time, and provide a fuel saving speed plan to drives. The fuel saving performance of the optimal plan is dependent on the road profile and optimization setup. With more detailed information the fuel saving can even be improved. Apart from the fuel saving, the optimal speed plan gives a reliable information to drivers, and handles the balance between the fuel consumption and travel time for them. To sum up, the optimal speed plan can make the drivers’ works better and easier.
Chapter 5

Fuel optimization under uncertainty & implementation

The results presented so far are based on the static road information. This means that there are no external factors that influence the speed and arrival on each stage. However, in reality, the local conditions such as traffic flow, temporary speed limits, road block etc. are subjected to change i.e. it is dynamic. Therefore, it is necessary to take the dynamic road information into account in the optimization algorithm to successfully implement the algorithm on a Volvo truck.

Traffic flow is considered in this work by incorporating historical traffic flow data for a route in the algorithm.

Below, a possible approach to incorporate the dynamics local information in the optimization problem is presented.

5.1 Traffic information

TomTom [24] provides speed information in addition to travel times of both smaller and larger road networks around the world. It can be used for precise traffic modelling, analysis of road conditions and improving traffic performance.

In [25], a simple method of modelling the traffic flow is presented. It uses both travel times and travel speeds along a selected route. Thus, a data on average speed distribution along a certain route is determined. Based on this, a time distribution can be deduced. The method is briefly summarized as follows:

- Define the average speed of the vehicle, by observation of few vehicles in a zero-traffic route. It is known as free flow speed.

![Free flow speed in a route with no traffic (4:00 a.m.)](image)

- Observation is made in a similar manner at definite intervals of the day to analyse the average speed variation (affected by traffic) of the vehicles along the same route.
A scaling factor based on the free flow speed is defined. If the free flow speed is indicated as 1 in a scale from 0 to 1, the speed at different intervals are defined as a factor of the free flow speed.

- A traffic profile is created which consists of the scaling factor defined above as a function of the time intervals chosen.

- Traffic profile thus calculated for the route is represented using the graph below.

Similar steps are followed over a certain period to get more consistent traffic data.

### 5.2 Stochastic optimization

**Nomenclature**

- $i$ = stage number.
- $\sigma_U$ = standard deviation in upper limit of set speed.
- $\sigma_V$ = standard deviation in lower limit of set speed.
\( V_L \) = random distribution for lower limit of set speed.
\( V_U \) = random distribution for upper limit of set speed.
\( V_{\text{set}} \) = set speed of the vehicle.
\( \mathcal{N} \) = normal distribution.
\( t_i \) = arrival time at each stage.
\( FC \) = fuel consumption in l/100 km.
\( T \) = set time.
\( V_U \) = upper limit of set speed.
\( V_L \) = lower limit of set speed.
\( \Delta \) = tolerance placed on set time.
\( \epsilon \) = tolerance placed on final arrival time.

**Stochastic model**

1.) *Road Profiling:* The road profile is divided into a number of stages for aiding the optimization. In this work, stages considered are of equal length as discussed in the deterministic case in Section 2.2.

2.) *Speed Limits:* As in the deterministic case, the speed limits \( V_{\text{set}}^U \) and \( V_{\text{set}}^L \) are determined by the road stage and used as the set inputs in the optimization algorithm. Due to the uncertainties like traffic flow, road speed limits, road block etc, the limits on the speed (upper and lower) are subject to change: in other words, are random variables. The limits can have any distribution and can be determined by the historical data on each stage. In this work, problem formulation using a Gaussian distribution is illustrated; whose mean is determined by the set speed limits (\( V_{\text{set}}^U \) and \( V_{\text{set}}^L \)) and the standard deviation is determined from the historical data. The random variables are given as:

\[
V_i^L \sim \mathcal{N}(V_i^L, \sigma_i^L) \quad (5.1)
\]

\[
V_i^U \sim \mathcal{N}(V_i^U, \sigma_i^U) \quad (5.2)
\]

The optimization framework illustrated in case of uncertainty, is done by modeling the speed limits as independent Gaussian random variables. However, the actual distribution need not be Gaussian, and the limits could be dependent; in which case a joint distribution needs to be estimated.

3.) *Time constraints:* Total travel time is the other constraint used in this problem. However, in a stochastic case it depends on the time taken to complete the individual stages. Arrival time \( t_i \) at the end of each stage depends on the speed limits as in Equation 5.3. Thus, \( t_i \) is also a random variable, whose value or realization is decided by the upper and lower speed limits.

\[
t_i = f(V_i^L, V_i^U) \quad (5.3)
\]

where \( f \) captures the functional relationship between the speed limits and the time taken.
Objective

When the optimization problem has random variables in the objective function and/or the constraints, it is well known that it is reasonable to optimize the expected values; see [26]. Thus, the stochastic optimization problem is formulated as follows:

$$\min_{V_{set} \in \{V_{set_1}, V_{set_2}, \ldots, V_{set_n}\}} \mathbb{E}\{FC(V_{set})\}$$

subject to,

$$P[T - \Delta_1 \leq \sum_i t_i \leq T + \Delta_2] \geq \epsilon, \epsilon > 0; \Delta_1, \Delta_2 > 0$$

$$V_i^L \leq V_{set_i} \leq V_i^U, \quad \forall i \in 1, 2, \ldots, n$$

(5.4)

$$V_i^L \sim \mathcal{N}(V_i^L, \sigma_i^L)$$

(5.5)

$$V_i^U \sim \mathcal{N}(V_i^U, \sigma_i^U)$$

(5.6)

where, $V_i^L$, $V_i^U$, and $t_i$ are random variables as described before.

Discussion

In this case, total travel time $\sum_i t_i$ is also a random variable. The constraint in Equation 5.4 is such that the probability that the total travel time lies within the limits specified should be greater than $\epsilon$. In other words, the optimal speed profile should be such that the number of journeys on which the total travel time lies within the specified limits should be greater than $\epsilon$. The values of $T$, $\epsilon$, $\Delta_1$ and $\Delta_2$ are decided by the transport agencies. For example, a higher value of $\epsilon$ means that the delivery of goods is ensured within the specified time limits. It should also be noted that the parameters $\Delta_1$ and $\Delta_2$ can be adjusted to decide the set time $T$. By setting $\Delta_2 > \Delta_1$, it is ensured that the truck does not arrive earlier than expected at the destination.

5.2.1 Possible solution methods

Dentcheva [26] and the references there in suggest a few possible approaches to solve an optimization problem having random variables in constraints and the objective. However, in this work, a heuristic approach to solve the uncertainty problem using a feedback system is presented.

Feedback approach to deal with uncertainty

In this approach, the total travel time of the entire mission is fixed; to contrast with the formulation in equation 5.4, $\epsilon = 0$. The time constraint is forced to meet, at the cost of fuel consumption. Although, the objective of the policy is to minimize the fuel, in the stochastic case, the policy consumes the least possible fuel given the departure time. Below, a simple example is used to illustrate the heuristic procedure.

Consider a transport mission where the route is divided into 3 stages of the same length. After the completion of the first stage, the time taken to complete it is recorded. Let it be
‘$t_1$’. The cost function for stage 1 is removed from the objective function as in equation 5.7. In the nonlinear constraint, the total travel time is recalculated by subtracting $t_1$ from it as in 5.8. This is represented as follows.

$$FC = (a_2V_{set_2}^2 + b_2V_{set_2}^2 + c_2) + \ldots + (a_nV_{set_n}^2 + b_nV_{set_n}^2 + c_n)$$  \hspace{1cm} (5.7)

$$t_2 + t_3 + t_4 + \ldots + t_n \leq T - t_1$$  \hspace{1cm} (5.8)

The cycle repeats at the end of each stage, thereby recalculating an optimal speed profile for the remaining part of the mission. One advantage of this method is that it considers the delays (if any) due to traffic flow, road block etc. if any, present in one of these stages. The delay is captured in the non-linear constraint of the optimization problem, based on which an optimal speed plan for the remaining part of the journey is recalculated. However, it is a very simple case of tackling uncertainty and it may also result in higher fuel consumption if there is a delay in certain stage.

### 5.3 Implementation

This section discusses a possible way of implementing the concept. Consider a truck transport mission, whose travel route is decided by the transport agency. The steps involved for real-time implementation are as follows:

1. Information from transport agency to the Volvo-Back Office.
2. Truck information communicated to the Back Office.
3. Optimal speed plan from the Back Office to the truck.

Figure 5.6: Implementation Overview. 1.) Information from transport agency to the Volvo-Back Office, 2.) Truck information communicated to the Back Office, 3.) Optimal speed plan from the Back Office to the truck.
• Information about the departure and travel time is decided by the transport agency and is sent to Volvo-Back Office represented as a cloud. The truck model information is also sent to the cloud.

• In addition, the Back Office also sends the route information to a screen on the dashboard of the truck.

• Based on this information, an initial speed plan for the complete journey is computed using the optimization algorithm in the cloud and is communicated to the truck.

• Stage 1 is completed by checking the truck’s position using GPS system present in the truck. Time taken to complete the stage is communicated back to the cloud.

• Using this time, the cloud recalculates the optimal speed plan for the remaining part of the mission and sends it to the truck.

• Cloud also sends information about route to screen depending on what parameter (fuel saving, arrival time, driver time) needs to be prioritized.

• Cycle repeats for each new stage until the mission is complete.
Chapter 6

Future work & conclusion

6.1 Future work

Although this thesis has already shown the potential of the optimal speed plan in saving fuel and handling the balance between fuel consumption and travel time for drivers, there are still something to be improved. If the mission optimized speed control is wanted to be implemented in products, these considerations are needed in the future:

6.1.1 Communication between truck and the Back-office

As mentioned, there are two layers in the mission optimized speed control. The lower layer is the truck, and the upper layer is the Volvo back-office. Since the trucks are moving on roads, it is very important to have stable and high efficiency communications between back-office and trucks. Nowadays a real-time web technology called websocket can be used in this case. Figure 6.1 shows how websocket works.

![Websocket Diagram](image)

Figure 6.1: Working of websockets. This figure is taken from [27].

WebSocket is a computer communications protocol, providing full-duplex communication channels over a single TCP connection. The WebSocket protocol was standardized by the IETF as RFC 6455 in 2011, and the WebSocket API in Web IDL is being standardized
by the W3C [28]. As Figure 6.1 shows, once the connection is established between the server and the client, data can be sent in both directions, and it is a persistent connection. Websocket is very proper to mission optimized speed control because in mission optimized speed control both trucks and the back-office are sending data to each other in real-time, which is exactly the property of websocket. Once websocket connection between trucks and the back-office is established, the mission optimized speed control can be implemented in reality.

6.1.2 Dividing stages

For now, the way of dividing drive cycles in the optimal speed plan algorithm is just dividing the journey equally. In fact, there must be some better ways to divide drive cycles. As mentioned in chapter 4, when dividing drive cycles, a lot of information should be concerned. In each stage the key element should be equal or similar, such as the maximum allowable speed, traffic situation and weather. The junctions of stages are preferred to be placed at the traffic lights or stop signs on the road. Further more, when the environment or traffic situation changes, the rest of the journey can even be divided in some other ways. The limited road information and unknown traffic situation in simulation restrict the way of dividing stages. In reality, when a truck is doing a transport mission in reality, the road information and traffic situation can be used to divided the journey, and the performance of the optimal speed plan will be better. An example of a well-divided journey is shown in Figure 6.2.

![Figure 6.2: Example of a well-divided journey. Dash lines represent stages of the journey and the upper speed limits in these stages. There is a traffic light between the first and the second stage, and an uphill between the second and the third stage. The third stage and the forth stage has different traffic flow. This figure is taken from [21].](image)

6.1.3 Proposing a mission start time and rest time

In this thesis, the travel time is set as a linear constraint in the problem formulation shown in chapter 3. Truck drivers set up the wanted travel time, and the algorithm will propose an optimal speed plan in the constraint of the wanted travel time. However, in
reality, arriving time is the factor cared by truck drivers. For most transport missions in reality, the arriving time is the most important thing, and it is fixed, so it makes more sense for truck drivers to set up the arriving time rather than the travel time.

When the truck driver sets up a arriving time, the algorithm should propose a starting time together with an optimal speed plan. In reality, proposing a good starting time is easy. Several factors will influence the proposed starting time. For example, Europe, truck drivers non-stop working hours should not exceed 4.5 hours, for every 4.5 hours truck drivers have to take a 45 minutes break [29] and this breaking time should be considered in the algorithm. Furthermore, when proposing a starting time, the traffic situation must be taken into consider. If truck drivers drive in rush hours, the risk of stuck in traffic jams increases, and it increase drivers’ working time. For future works, when proposing arriving times, traffic situation changes and drivers’ allowable working hours should be taken into consideration.

6.1.4 Initializing optimization automatically

In this thesis project, the initialization of the optimization is done manually. The manual initialization is based on two known drive cycles. However, in reality truck transportation missions will be in several different paths, and the cost functions will be different in these paths. To make the mission optimized speed control work in reality, cost functions must be generated automatically in back office. Furthermore, the speed bounds in every stage should be calculated from the traffic flow information and road information, rather than manually set.

6.2 Conclusion

Mission optimized speed control is an effective and reliable tool for truck drivers. It handles the balance between fuel consumption and travel time. Although the performance of the optimal speed plan is influenced by some factors such as road profile and maximum allowable speed bounds, the fuel saving still has potential to be increased with the help of proper stage division and low level predictive controller.

In this thesis work, fuel consumption of single set speed throughout the whole journey is regarded as the reference fuel consumption. However, it is hard to judge if this is a good reference, as in reality, drivers do not drive with one set speed throughout the journey. Since it is hard to know how drivers choose their speed plan in reality, it is difficult to choose a proper reference fuel consumption. Although based on the reference fuel consumption in this thesis project, the optimized speed plan does not give much positive results in fuel saving, but it might be proved to be beneficial if the stochastic factors are considered in the simulation.

Furthermore, when it is implemented in real trucks, it will bring lots of benefits with the help of more detailed information in transport missions. In the future, the mission optimized speed control can be widely used in the field of autonomous driving. However, although the idea of changing speed to minimize fuel consumption is good for a vehicle, it might have some bad influence on the whole traffic fleet. Hence, this kind of technology should be implemented more cautiously.
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Appendix A

Results for sweden route

Figure A.1: The results in Sweden route with 20 stages.

Figure A.2: The results in Sweden route with predictive controller.