LiU-ITN-TEK-A--19/006--SE

Analysis of Automated Vehicle Location Data from Public Transport Systems to Determine Level of Service

Charlotte Eriksson

Olivia Jansson

2019-05-28

Department of Science and Technology
Linköping University
SE-601 74 Norrköping, Sweden

Institutionen för teknik och naturvetenskap
Linköpings universitet
601 74 Norrköping

LiU-ITN-TEK-A--19/006--SE

Analysis of Automated Vehicle Location Data from Public Transport Systems to Determine Level of Service

Examensarbete utfört i Transportsystem
vid Tekniska högskolan vid
Linköpings universitet

Charlotte Eriksson
Olivia Jansson

Handledare Clas Rydergren
Examinator Anders Peterson

Norrköping 2019-05-28

Abstract

Many cities suffer from problems with high traffic flows in the city centers which leads to a desire to get more people to choose public transport over cars. Public transport providers need to keep developing their services to attract more passengers. For many car drivers, the main reason to take the car is the convenience and time efficiency; the price is often of less importance. The public transport providers should, therefore, strive to improve their Level of Service (LOS).

Östgötatrafiken (ÖGT) is a public transport provider in the county Östergötland in Sweden. ÖGT provides 160 different lines that together form the public transport network of Östergötland. The board of Region Östergötland has set up goals to improve the LOS in the region, to attract more passengers. It is therefore of great interest to ÖGT to measure the performance of their system, both to discover problems before they get bigger and to evaluate if the operators are fulfilling the requirements that ÖGT have set up for them. ÖGT is collecting Automated Vehicle Location (AVL) data every second from their vehicles. The data contains information about where the vehicle is positioned (longitude, latitude and bearing) as well as the speed of the vehicle and the time of the observation. ÖGT wishes to develop a method to use Key Performance Indicators (KPIs) that describe the LOS based on AVL data to analyze where the biggest problems occur.

A general process that can be used by public transport providers or other stakeholders to evaluate the LOS in a public transport system based on AVL data is developed and presented in this thesis. The process values the quality and suitability of the AVL data, propose which KPIs to use and how to use the results to find possible improvements. Four different types of erroneous data were discovered: outliers in position, outliers in speed, outliers in travel time and general errors. KPIs are developed in three main areas: on-time performance, travel time distribution and speed, where each KPI is divided into several sub-areas.

Evaluation of LOS based on the developed general process for four lines (express line, city line, rural line and tram line) operating in Östergötland county is performed. Since different modes are investigated, the calculation of KPIs needs to be adapted to each mode. The analyzes show that the LOS is acceptable for bus line 4, 42 as well as for tram line 2. However, the LOS is bad for bus line 410. Further investigations of each line show identified problem areas of each line and how analyzes can be carried out on different levels of aggregation.

Sammanfattning

Många städer har problem med ett högt trafikflöde genom de centrala delarna vilket medför ett behov av att få fler invånare att välja att åka kommunalt istället för med bil. Förvaltare av kollektivtrafik behöver därför fortsätta att utveckla sin service för att attrahera fler passagerare. Den största anledningen för många att åka bil är att det är smidigare och mer tidseffektivt; kostnaden för resa är ofta mindre viktigt. Därför måste förvaltarna av kollektivtrafik sträva efter att förbättra LOS (Level of Service, servicenivå) gentemot sina kunder.

Östgötatrafiken (ÖGT) är förvaltare av kollektivtrafiken i Östergötland och tillhandahåller 160 olika linjer som tillsammans utgör ett nätverk av kollektivtrafik i regionen. Region Östergötlands styrelse har satt upp mål för hur servicen inom kollektivtrafiken ska förbättras för att kunna locka fler att välja att åka kollektivt. Det är därför av stort intresse för ÖGT att kunna LOS de har, dels för att kunna hitta problem innan de blir för stora och dels för att kunna utvärdera om kollektivtrafikoperatörerna uppfyller de kraven som ÖGT har på dem. ÖGT samlar varje sekund in information från deras fordon, AVL data (Automated Vehicle Location, fordonsdata), som består av fordonets position (longitud, latitud och riktning) samt vilken hastighet fordonet har och vid vilken tidpunkt observationen gjordes. ÖGT vill utveckla en process för att med hjälp av olika KPIer(Key Performance Indicator, nyckeltal) kunna beskriva deras LOS. Denna process ska baseras på data som samlas in från fordonen och ska användas för att kunna analysera vart de största problemen uppkommer i systemet.

I denna uppsats utvecklas och presenteras en generell process som kan användas av förvaltare av kollektivtrafiken samt andra intressenter för att utvärdera LOS i ett kollektivtrafiksystem baserat på AVL data. Processen ska värdera kvaliteten och lämpligheten i den AVL data som används, samt förslå vilka KPIer som är passande att använda och hur resultatet ska användas för att kunna identifiera vart förbättringar kan implementeras. Fyra olika typer av avvikande värden i data har upptäckts: position, hastighet, restid och generella datafel. KPIer har utvecklats inom tre olika huvudområden: rättidighet, restidsfördelning och hastighet, där varje KPI sedan är uppdelat i flera underområden.

LOS utvärderas, baserat på den utvecklade generella processen, för fyra olika typer av linjer (expresslinje, stadslinje, landsortslinje samt spårvagnslinje) som alla erbjuds av ÖGT i Östergötland. Eftersom det är olika typer av transportslag som analyseras, behöver uträkningen av KPIerna anpassas efter transportslagen. Analyserna visar att LOS är acceptabel för busslinjerna 4, 42 samt för spårvagnslinje 2, men dålig för busslinje 410. Vidare analyser av de undersökta linjerna visar vilka områden det är problem i samt hur analyser kan utföras på olika aggregeringsnivåer.

Acknowledgments

There are many people that have helped us throughout the process of writing this thesis. Firstly, we would like to thank Östgötatrafiken (ÖGT) for all the encouragement and dedication this spring. We would especially like to thank Jakob Klasander for helping us to understand how ÖGT plans the public transport and Albert Gunnarsson who has explained and supported us with the structure of the data. Your help and interest have been crucial for this thesis. Secondly, we would like to thank our supervisor Clas Rydergren and examiner Anders Peterson, for all of your feedback and knowledge. Lastly, thank you WSP Norrköping, especially Frida Persson, for welcoming us and for your advices.

Norrköping, May 2019

Charlotte Eriksson and Olivia Jansson

Content

List of figures

List of tables

1. Introduction

Trafikverket (2015) is forecasting that vehicle kilometers performed by private car in Sweden will increase by 30% during the period 2014-2040. With increasing traffic in cities and a desire to get more people to choose public transport over cars, public transport providers need to keep developing their services to attract more passengers. For many car drivers, the main reason to take the car is the convenience and time efficiency; the price is often of less importance. Therefore, improvements in the public transport system are important to increase the number of travelers. Level of Service (LOS) can be measured to find where improvements should be made. However, to measure the LOS in the system, data about the system is needed. This data can be collected in different ways, for example from interviews, vehicle computers, Automated Vehicle Location (AVL) data, equipment at bus stops, etc. This thesis will focus on how AVL data can be used to evaluate the LOS of a public transport system and discuss where improvements should be implemented, as described in Figure 1.

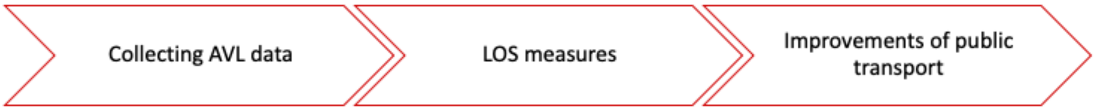

Figure 1 – Process of collecting AVL data and finding possible improvements.

Not only the users of a public transport system profit from improvements, it is also of great importance for the public transport providers and society. For example, the public transport provider can decrease their productions costs. "The traffic gross cost over one year for a one minute longer trip for a public transport provider in city traffic can cost up to SEK 500,000 in increased costs per year" (Klasander, 2019a). It is therefore of high importance for the provider to produce more effective trips to decrease their costs. The society can profit from this by the socio-economic gain of decreasing the travel time for a trip by one minute on a line with many daily passengers. To achieve a decrease in travel time, historical data can be analyzed to be able to discover where minutes can be cut. Another improvement, besides faster trips, could be to find and eliminate the cause of delays to achieve a more reliable system. For example, to find infrastructural problems that have a big impact on the LOS.

AVL data have been collected for over 15 years, but a lot can still be done in the field of developing applications based on AVL data. AVL data is collected by equipping vehicles with a transmitter which sends, for example, the position, speed, timestamp, etc. to a database. One example of an application of AVL data is when it is used to evaluate the performance of a public transport network. AVL data can also be used to forecast arrival time to a stop and based on the result inform travelers about delays. Both examples are beneficial for the public transport provider and society.

1.1 Background

One area where measures of LOS is carried out is in the public transport sector. When measuring the LOS, one could study many aspects depending on the purpose and field. On-time performance or reliability could be one measure of LOS. For example, a public transport provider offers a timetable and a network to their customers. If a provider cannot keep their promise, the service is unreliable, and they fail to provide a perfect LOS. Van Oort and Van Nes (2007) describe in their article that if the public transport is unreliable, it will affect the travel time for the customer. They state that reliability can increase if the right actions are taken already at the planning stage. To improve reliability, planning, operations and infrastructure can be adjusted to provide the best service possible to the customers. In Sweden, there is a measure called customer satisfaction index (Swedish Nöjd Kund Index, NKI) that measures the following:

- Relevance
- Quality/punctuality
- Safety
- Affordableness

These aspects are identified as the primary factors that affect the summarized satisfaction (Svensk kollektivtrafik, 2019). How satisfied a customer is with a service is directly affecting the LOS.

Yang et al. (2018) claim that apart from reliability and on-time performance, bus travel speed and travel time are two important measures for public transportation companies. These types of measures make it possible to investigate and improve different aspects. For example, how the routes should be drawn, how the schedule of the buses should be structured and how the on-time performance can be studied. Earlier, these kinds of investigations were difficult to carry out since the available technologies were expensive as devices needed to be deployed at fixed locations. Therefore, investigations of one single bus line required many devices to be deployed. Equipment of transit vehicles with AVL transmitters have made it easier since AVL data can describe the vehicles' position, speed, etc. when traveling on a route for a specific line.

Östgötatrafiken (ÖGT) is a public transport provider in the county Östergötland in Sweden. ÖGT provides 160 different lines that together form the public transport network of Östergötland. Several different types of vehicles are used by ÖGT: trains, buses, trams, and ferries (Östgötatrafiken, 2018a). Additionally, to the general public transport, ÖGT also provides special public transport such as demand responsive transport. ÖGT wants to offer their customers the best possible service, hence, they want to investigate where and why problems with the LOS in the traffic system occur.

During 2018, 31,400,000 trips were made with Östgötatrafiken (Östgötatrafiken, 2019a). According to Statistiska centralbyrån (SCB, 2019), 461,583 people live in Östergötland and Östgötatrafiken (2018b) claim that a third of those people use their service to get to work and school. On a normal day, ÖGT drives 93,000 kilometers with 4,500 trips and 300 vehicles (Östgötatrafiken, 2018b). In Table 1 the public transport system is described, only the cities that have lines that are investigated in this thesis are presented. The rest of the cities in Östergötland have been omitted.

Table 1 - Overview of ÖGT's public transport system.

	Norrköping	Finspång	Linköping
Habitats[1]	141 676	21 758	161 034
Number of lines[2]	56	21	86
Public transport lane[3]	Yes	No	Yes
City bus lines[2]	11	1	29
Tram lines[2]	2	0	0
Express bus lines[2]	13	5	14
Rural bus lines[2]	20	6	25
Commuter train[2]	1	0	1
Archipelago line[2]	1	0	0
Demand responsive traffic[2]	11	9	14

ÖGT have a commitment to the board of Region Östergötland to provide the customer with an attractive and effective trip with public transport. In keeping with their commitment, a list of goals that should be fulfilled by 2030 have been drawn up by Region Östergötland (2016), this list includes improvements of, for example, LOS. Examples of the goals concerning LOS are stated below:

- The average speed for public transport in the city center should be at least 20 km/h.
- The average speed in the outer parts of the city should be at least 28 km/h.

The average speed today in the city center is 17.5 km/h and 25-27 km/h in the outer parts of the city, which means that there is room for improvements to fulfill these goals. Region Östergötland has also defined goals about increasing the market share, satisfied customers and the availability for customers with disabilities (Östgötatrafiken, 2019b) by the year 2030. In addition, ÖGT also makes demands on their operators. If a trip is canceled, delayed or departed early due to the operator, there is a deductive penalty per trip that the operator has to pay. Other problems such that a vehicle with a lack of function is used in operation or administrative shortages, also result in a deductive fee per vehicle and day or occasion (Klasander, 2019c).

ÖGT have a mission to inform and market the public transport in Östergötland to increase the share of public transport trips relative to the car traffic and improve the customer satisfaction. During 2018, the customer satisfaction index increased (NKI) from 67 to 70 and in total, the number of passengers increased with 3.4% from 2017. However, ÖGTs costs for regular traffic with buses and trams increased by 5% during 2018 (Östgötatrafiken, 2019b). In ÖGTs sustainability report, some risks and future challenges are identified. The cities Norrköping and Linköping have the past years have had more problems with congestions affecting the public transport. To stop this trend, the public transport needs to be prioritized to avoid increased travel times and to make traveling with public transport attractive. Incremented congestion does not only decrease the appeal for public transport, it also causes increased traffic costs and possible decrease in services ÖGT (Östgötatrafiken, 2019c) claims. Therefore, there is a need to find problematic areas where public transport should be prioritized to keep the public transport attractive and increase the number of passengers and their satisfaction. Several case studies to investigate where problems occur have been executed in the past. However, it is difficult to fully connect the results

[1] SCB (2019)
[2] Östgötatrafiken (2018c)
[3] Klasander, J (2019b)

of a case study to the processes used by ÖGT. ÖGT believes that it would be easier to incorporate analyzes based on their own AVL data. ÖGTs vehicles are equipped with a transmitter that every second sends AVL data that contains the speed of the vehicle, longitude, latitude and bearing to their database. Currently, ÖGT mainly uses the data for real-time updates and to forecast delays in the public transport system but see the potential to use the data to evaluate the LOS in the public transport system.

Today ÖGT usually makes changes due to complaints from customers or because a problem was discovered by an employee, which is good because they are always trying to improve their business according to feedback from customers. However, if a general process to discover improvements could be used, this would probably increase the efficiency. For example, ÖGT do not have a functional process to measure the number of delayed trips today. It is therefore of great interest to ÖGT to measure the outcomes and if the operator fulfills their requirements, in an easy way. ÖGT, therefore, wishes to use Key Performance Indices (KPIs) describing the LOS based on AVL data to analyze where the biggest problems occur. Since the KPIs can be a crucial part of the decision making and how to fulfill the goals by 2030, it is important that the AVL data is used- and KPIs are developed in a correct way. It is also important that the KPIs are defined in a way that makes it possible to measure if ÖGT have fulfilled their goals.

Since the data can contain errors, one of the purposes of this thesis is to develop a method to identify and remove erroneous data. Furthermore, a process to evaluate the LOS in the system will also be constructed. Based on the AVL data, many measures of the LOS can be performed depending on the purpose of the analysis. In this thesis, the LOS will be measured in on-time performance, speed and travel time. The LOS can be aggregated on different levels, for a single road segment or stop to the whole system. It will also be described how the LOS can be measured for a line and how to break down the analysis to smaller areas to find where problems occur.

Travel time can be evaluated in different ways. The actual travel time can be used to study variations in time. For example, does the travel time follow the timetable well or does it diverge a lot during a specific time period? Moreover, on-time performance can be used to improve timetables or find problematic areas. Another measure that will be used in this thesis is speed, this measure can be used to evaluate the traffic state on different aggregation levels. The average speed can, for example, be calculated for a whole area or for only one line.

The contribution of this thesis is that different transport modes are investigated, in previous studies it is mainly buses that are analyzed. Since ÖGT provides buses, trams, trains and ferries, it will be evaluated if the same general process can be applied for the different types of traffic modes and if the AVL data should be treated differently depending on the transportation mode. Another contribution is the handling of erroneous data. No previous study found have an overall approach to filter out erroneous data and non-representative trips, this study will develop a suitable method to find and eliminate those. Lastly, this thesis declares what methods that have been used and assumptions that have been made to process the AVL data and calculate the KPIs.

1.2 Aim

A general process that can be used by public transport providers or other stakeholders to evaluate the LOS in a public transport system based on AVL data will be developed in this thesis. The process will value the quality and suitability of the AVL data, propose KPIs and how to use the results to find possible improvements.

The aim of the thesis can be summarized in the following research questions:

- What AVL data should be disregarded and which methods should be used for removal of data, in order to secure the quality of the data?
- What KPIs can be used to evaluate the LOS?
- What levels of aggregation can be used in the calculations of the identified KPIs?
- How should the calculations be adjusted for the different types of public transport modes?
- How should a general process to filter the data and evaluate the LOS in a geographical area or a complete public transport line be formulated?
- What is the LOS for each investigated public transport line?

1.3 Method

When analyzing the LOS of a public transport system different types of data can be used. Depending on which data that is available to use different types of measurements can be performed. The analyzes in this thesis will only be based on AVL data which is quantitative and only contains information about geography, speed and time. Measures and factors such as experienced delay or how many passengers that entered the bus at a certain bus stop are not known. Furthermore, this means that the analyzes will focus on finding areas where there are problems with the LOS, rather than finding solutions.

There is no AVL data available for trains and the planning and operation of train traffic is separate from the rest of the public transport system. Therefore, trains will be excluded from all parts of the thesis. Since the archipelago traffic is not affected by the car traffic, and the demands responsive traffic does not have a fixed route, both of these modes are excluded from the analysis as well. No method to compensate for missing data will be used since the AVL data provided in this thesis was collected every second. No attempt to replace the omitted data point from the filtrations will be done since this aimed to base the analysis on real data and not estimated.

The thesis will be divided into the following three parts:

- Data processing, definitions and filtration of outliers.
- Development of KPIs.
- Analyzes based on the results of the KPIs.

The three parts will together form the general process that will be developed in this thesis. The programing language R will be used for all the different parts of the thesis. R is a programing language often used for statistical analysis, data vizulatioation and data mining (R Foundation, n.d). The quantitative data consists of historical AVL data given from ÖGT for a randomly chosen time period. This means that the analyzes will only be performed on routes where ÖGT is operating. The calculations of KPIs will result in tables and figures where the measures of each KPI are presented.

1.4 Outline

The second section in this paper is called *Literature review*, where previous studies in the topic are described as well as methods that will be used in the thesis. The third section is *Development of general process*, where the general process is presented. The fourth section is called *Data format,* which describes the data that is used in the thesis. This is then followed by the *KPI definition* in the fifth section, which presents the KPIs that will be used in the thesis and how they are defined. Section six is called *Identification and removal of outliers,* which explains what data that have been defined as outliers and how they have been removed from the data set. It also includes known errors in data that could affect the result. This is followed by section seven, *Results of the analysis of selected lines*, where the results from the KPIs used on different types of transportation modes are presented. The eighth section in this thesis is *Discussion*, where several different aspects are discussed, such as the result of the analysis, how the general process should be structured, etc. Finally, the conclusions of this thesis are presented in the *Conclusion,* section nine, where the questions in the aim are answered.

2. Literature review

Firstly, the literature review will describe previous work in the area of processing AVL data. Secondly, general methods of outliers in data treatment such as Six Sigma and Hampel filter will be described. Lastly, the literature review will focus on measures of LOS that can be extracted from the provided AVL data. Measures as boarding time per passenger, waiting time at stops, experienced travel time, etc. are outside of the scope and will not be discussed.

2.1 Processing AVL data

When processing AVL data, some problems can be encountered. These could, for example, be missing data points due to failure to arrive at the bus stop. Data points can also be missing due to technical failures. Re-scheduling of the buses could too be a source of problematic data. Earlier studies have had different approaches to handle missing points and outliers. Some studies have disregarded these types of problems completely, while some have considered them (Barabino et al., 2017). Moreover, Barabino et al. (2017) suggest a method to validate the AVL data before any analysis can be executed. The method works in the following way:

1. Determine whether at least 80% of the scheduled buses arrives at each bus stop on a daily basis. If the criterion is fulfilled, the data can be used in step 2.
2. Using the data from step 1, perform a chi-square test to determine if the approximation of the actual number of buses arrivals fits the scheduled buses arrivals. The suggested value of significance is 5%. The test should be performed for all the bus stops during a day. In the last step, all the days meeting this criterion as well as the bus stops can be used.
3. Summarize the data from the previous step for a month and calculate the ratio between the summarized number of bus stops for a month and the total number of stops. The data is valid if this ratio is larger than 60%.

Yang et al. (2018) also highlight the problem with errors and missing points in the AVL data, therefore they propose a method to process and recover the missing points. Their technique estimates the transit travel speed field information on predetermined places on the bus route in different time slots. Then, fills in the gaps where information is missing by using traversed bus trajectory samples in contemporary time slots and old time slots.

Ma et al. (2014) studied the performance of a bus line in Brisbane, Australia. To minimize the risk of erroneous data two filters were applied to the data. One filter to exclude incomplete trips, abnormal stops and technical failure. The second filter sorted out the falsely recorded trip with extremely long travel times. In order to identify an abnormal trip, the Median Absolute Deviation (MAD) technique was used. A trip was considered abnormal if it was outside of the interval between the lower bound value (LBV) and the upper bound value (UBV), that was calculated by the MAD 3-delta criteria.

The effect of outliers in a data set is discussed by Pearson (2002). Especially the kurtosis, a measure of the probability for extreme values for a given distribution, are affected by single outliers. If the data set contains occasional outliers, deletion diagnostics can be used to evaluate the effect of eliminating a data point. However, this technique is not suitable for groups of outliers. Pearson (2002) describes the data cleaning filter called Hampel filter as an effective filter, using two tuning parameters. The Hampel filter replaces outliers with the median value in the data window. To detect and replace local outliers, nonlinear data cleaning filters should be used.

Kalman filter can be used to produce an estimate based on for example AVL data observations. This can be useful when the connection to a GPS receiver has been bad and either incorrect information was sent from the transmitter or no information at all was sent (Cathy & Dailey, 2003). Predic et al. (2010) also used a Kalman filter to fill in coordinates in their AVL data since the data positions only were collected every 15 seconds. The predicted positions were then mapped on the routes of the bus lines to match the actual path of the bus.

Cronemyr (2015) claims that Six Sigma is a powerful method to use to identify why variations in data occur and how to eliminate it. An example of when this can be useful is variations in the departure time of a train. The train is not supposed to leave at different times, but due to different factors it usually does. A common way to describe data is through an average value. A representation like that can give a misrepresentative picture of reality. Since the average time the train leaves late might be one minute and if it always would do that, it could be considered acceptable. However, the train might leave 10 minutes late one day and then 5 minutes early the other day, this would perhaps not be considered acceptable. Six Sigma can be used to eliminate the variations.

Another application of Six Sigma is to calculate and analyze the variation in data statistically. There can be two types of variations of data according to Six Sigma; common cause variation and assignable cause variation. Common cause variation is when nothing special is happening. This type of variation is typically normally distributed. If the variation is smaller than the average value plus or minus three standard deviations (upper and lower control limits), the data is considered to have a common cause variation. If there are values outside of the control limits, it is considered to be an assignable cause variation (Cronemyr, 2015).

The time period and amount of data that was studied differ in previous studies. Ma et al. (2014) chose to study 85 trips during the morning peak (7:00-9:00). Barabino et al. (2017) analyzed the weekdays of July 2014 in the time interval 7:00-19:59 in Cagliari, Italy. Trompet et al. (2011) analyzed 2 to 3 hours of the morning peak for 5 weekdays in a week during May 2009 and 2010, that did not include a holiday or a special event. Adelsköld and Ejder (2018) based all of their analyzes on the time period February to April 2017; the time interval used was the morning peak between 07.00-09.00 and the evening peak hour 15.00-18.00 for all weekdays. The analysis in this thesis is divided into two time periods: morning and afternoon peak. The remaining part of the day is not considered as interesting since the traffic flow is lower and there should not be as many problems with the LOS. As Adelsköld and Ejder (2018) suggest the morning and afternoon peak in this thesis is defined as 07.00-09.00 and 15.00-18.00.

Lastly, the number of public transport lines to study is also different in previous studies. Both Barabino et al. (2017), Adelsköld and Ejder (2018) and Ma et al. (2014) choose to analyze a single bus line. Trompet et al. (2011) choose to make the analyzes based on three bus routes, where the routes that are selected represent the routes that have the highest frequency in terms of passenger boarding.

Gilmore & Reijsbergen (2015) found that a good way to find errors in AVL data is to first visualize the data on a map. This will make it possible to point out significant errors and to know what kind of AVL data that needs to be cleaned. For example, if the coordinates of an observation seem to be off: in another city, in a lake or out on a field, these observations should be considered invalid. To find out what geographical errors the data in this thesis suffers from, this study too shall visualize the data on a map.

The literature suggests several methods of visualization of AVL data. Yang (2018) presents a graph with the time on the x-axis and distance at the y-axis. Trajectories then show how the buses have traveled on the trip, where they have been standing still and for how long. Gilmore and Reijsbergen propose that every collected GPS point (for example for a specific line) can be plotted to see how frequently the buses deviate from the planned route. The visualization itself is not a KPI though it can be used to find areas of interest to make further analysis and will be used in this thesis.

To summarize, this analysis will be performed on both several lines and different types of modes (bus and tram) in contrast to the previous studies. Many of the methods described above could not be applied to the used data since the methods were either poorly formulated or not suitable for the data. For example, no well formulated approach to filter out erroneous data such as positions, wrongly recorded trip and speed was found.

2.2 Key Performance Indices

To determine when to make further analysis of the data, Barabino et al. (2017) describe how the LOS can be evaluated and categorized as acceptable and not acceptable. The LOS measurements can, for example, be how reliable or punctual the bus is (on-time performance). If the LOS is not acceptable, Barabino et al. (2017) investigate if the problem origins from the terminal or occurs later on the route. In Barabino et al.'s (2017) study, several methods to find the cause of non-acceptable service are presented. For example, study the arrival time at the bus stops, analysis of the speed between the bus stops and time spent at the bus stops.

Camus et al. (2005) propose an extended version of the Transit Capacity and Quality of Service Manual (TCQSM) method to measure LOS. They describe how the existing method does not consider how delayed the departure is, just that the departure is delayed. Furthermore, Camus et al. (2005) discuss the inflexible definition of a threshold of 5 minutes to decide that a trip is late. They propose a new performance measure that considers the amount of delay, early departures and new threshold for reliability which they call weighted delay index. The weighted delay index is defined as Equation (1).

$$R = \frac{\sum_{k=1}^{H} k \cdot p(k)}{H} \tag{1}$$

where

$R =$ weighted delay index;

$H =$ scheduled headway (min);

$k =$ generic delay value (min), with $0 \leq k \leq \mathrm{H}$, and

$p(k) =$ observed frequency for the delay k (based, for example on the AVL data) with $0 \leq \mathrm{p}(k) \leq 1$.

Additionally, Camus et al. (2005) suggest that early departures too should be considered as late since they by a passenger would be experienced as trips with a delay of one headway. This thesis will consider early departures and in a similar way as Camus et al. (2005) consider the amount of delay.

Trompet et al. (2011) propose that time-based service quality indicators can be divided into two different subgroups, regularity and punctuality. It is generally more important for low-frequency routes to be punctual since the customers study the time schedule more carefully if the buses do not departure that often. This means that it is more important for a low-frequency bus to be on time. The punctuality indicator is therefore typically used for low-frequency routes. One definition of a punctual service is that 80% of the buses are arriving between the scheduled time and up to 3 minutes later than the schedule. Trompet et al. (2011) continue, another definition is if 90% of the buses are arriving somewhere between the scheduled time and up to 5 minutes later than the schedule, the service is punctual.

Moreover, Trompet et al. (2011) claim that passengers that are traveling on high-frequency routes value regularity more than punctuality as these passengers usually tend to arrive randomly to the bus stop. Therefore, the number of times the bus is arriving during an hour is more important than that the bus is arriving according to the scheduled timetable. Due to this, many operators only state the headway in minutes in the timetable instead of the actual time.

A route is usually defined as high-frequency when the time headway is less than ten minutes according to Trompet et al. (2011). If the time headway is ten minutes or larger, Tropmet et al. (2011) consider the route to be a low-frequency route. When the time headway is larger than ten minutes, passengers usually check the timetable.

By comparison, Van Oort & Van Nes (2007) define low-frequency as four vehicle per hour or less and high frequency as more than four vehicles per hour. They assume that passengers plan their arrival at the stop regarding the timetable when the frequency is low. Whereas for high-frequency, the passengers arrive randomly at the stop.

Adelsköld & Ejder (2018) suggest four different KPIs to use in order to evaluate the investigated bus line. The KPIs that are used in their study are:

- Average speed during peak hour
- Predictability during peak hour
- Reliability during peak hour
- Distribution of different types of travel time during peak hour

Where different types of travel time stand for the portion of the travel time that is spent in traffic versus at a bus stop. It is not known how any of their KPIs are defined.

One of the goals with Adelsköld & Ejder (2018) study was to improve the LOS. They, therefore, implemented a number of improvements and compared the values of the KPIs before and after the improvements. LOS improvements that were implemented were such measures as implementing new bus lanes and usage of bus prioritized traffic lights. The study showed that these kinds of measures are suitable to implement in order to improve the LOS.

Adelsköld & Ejder (2018) believe that one of the strengths was that they studied a whole line and implemented all improvements almost at the same time for the whole line. This made it easier to see the whole picture of the problems along the way and since all improvements were added at the same time it was easier for the travelers to see a change.

A method that Adelsköld & Ejder (2018) suggest using in order to identify problems along the bus route is to ride along in the bus and make observations regarding problems with LOS. Adelsköld & Ejder (2018) believe that this method increased their success since they could base the improvements on reality.

Traffic signals are used to increase traffic safety, capacity and to give all road users a fair chance to pass the intersection. The goal of traffic signals is to minimize the total delay per vehicle. However, since a bus or tram can carry many more passengers than a car, minimizing the total delay for all vehicles does not minimize the total delay per passenger. Therefore, Wahlstedt (2014) means that public transport should be handled differently in a signalized intersection. Christofa & Skarbardonis (2010) describes how Public Transport traffic Signal Priority (PTSP) can be either active or passive. With support from detectors, an active PTSP can priorities public transport vehicles. A passive PTSP always set the signal timings to priorities public transport with the help of historical data. Wahlstedt (2014) found that the travel time for public transport can be reduced when implementing PTSP. However, reduced travel time for public transport will lead to increased travel time for all other traffic.

Matulin et al. (2011) says that the performance of public transport is highly affected by the regular traffic in a two-lane traffic. The regular traffic suppresses public transport and therefore the performance is debased. The problem is generally occurring during peak hours when there is a high traffic flow. During these states, regular car traffic typically forms queues in front of intersections, this leads to a blockage of the public transport vehicles. This can also affect the effect of prioritizing public transport vehicles since the benefit of this can be removed due to the traffic jam that the regular cars cause. Matulin et al. (2011) believe that there are four major factors that affect the performance of the public transport; the number of intersections, design of signaling plans, number of stops and the number of passengers. These four factors should not be analyzed separately since they usually directly affect each other.

When developing KPIs it is of great importance to construct measures for both macro and micro perspective Matulin et al. (2011) claim. If, for example, only measures of the macro perspective are constructed, important effects of factors on a micro level will be neglected and will not be a part of the analysis. This might lead to incorrect conclusions. Matulin et al. (2011) therefore suggest observing problems that might occur during a trip and based on that define KPIs on both a macro and micro level. Examples of KPIs on a macro level are operation time and speed. Examples of KPIs on a micro level are dwell time, intersection delay, speed per segment, running time and driving time.

Average speed, on-time performance and travel time distribution are measures that have been suggested by previous studies. Since these studies also aim to evaluate the LOS in a public transport network it is considered that these are suitable. However, it is not well described how these measures were calculated in any of the studies.

3. Development of general process

The main purpose with this thesis was to develop a general process to evaluate the LOS in a public transport system based on AVL data. The developed general process can be seen in Figure 2, this has been used to retrieve the remaining results in this thesis. In Figure 2 there are two process steps that are outside of the scope of this thesis, however, it is suggested to use the whole process. The general process describes the different parts that are executed and in what order they should be carried out. Before starting the process, AVL data needs to be collected. The first step in the process, filtration of outliers, will identify and remove erroneous AVL data. The second step in the process, calculations of KPIs, will use the filtered AVL data to calculate the different KPI measures defined in this thesis. The KPIs should measure aspects important for the LOS, for example speed and on-time performance. The result of the calculations will be presented in tables and figures. The tables and figures are then used in the third step of the process, analysis of the result, to evaluate the LOS in the system and possibly find problematic areas. If the evaluated LOS in the third step is not good enough, suggestions of improvements should be developed in the fourth step. The last step in the process, implement improvements, proposes that the suggestions from the previous step should be implemented. Then, new AVL data can be collected and the effect of the improvements can be evaluated.

When using this process, one loop in the process can vary much in time. Small improvements such as to change routines, for example, to always open all doors of the bus, could be implemented in a time period of a couple of weeks. Medium changes, such as changes in timetables or routes, can be done as often as the operator updates the timetables. ÖGT, for example, updates their timetable three times per year. Larger improvements such as changes in the infrastructure have a longer implementation time and therefore the results from those improvements will take time. The time period for those kinds of changes depends on the size and complexity of the change, but most likely more than a year. When improvements have been implemented, analysis of the result should not be carried out directly since the system needs some time to adjust to the changes before reaching steady state. Otherwise, it is likely that the analysis of the result gives a misrepresentative view of the situation.

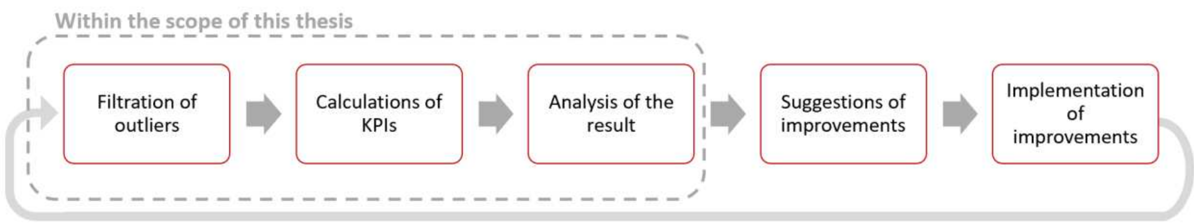

Figure 2 - Process steps in the general process.

To support the general process, there are two subprocesses that should be used. Filtration of outliers includes several steps and therefore the filtration was placed in a subprocess which can be seen in Figure 3. The ordering of the steps of the filtration makes the number of errors that are removed in each step decrease for every step. It is formulated like that to minimize the amount of data to handle in each step and to increase efficiency.

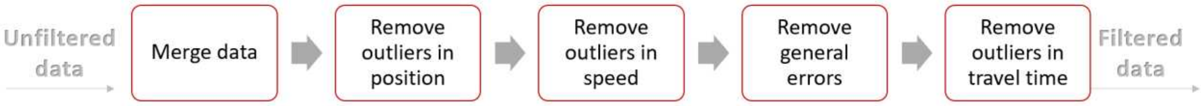

Figure 3 - The subprocess of filtration of outliers.

The KPIs that are calculated in this thesis can be summarized in the three main areas shown in Figure 4 and are chosen to work as a tool for ÖGT to measure some of their goals. For example, the quality/punctuality aspect could be measured with the KPIs connected to the on-time performance, this measure can also be used to evaluate some of the requirements ÖGT have on the operators. The KPIs are described in detail in section 5, where they are divided into several sub areas. Even though the process suggests that the data should be filtered before the calculation of the KPIs, the removal of outliers is described in the section after the KPI definition since the choice of KPIs affects which data that should be excluded from the analysis.

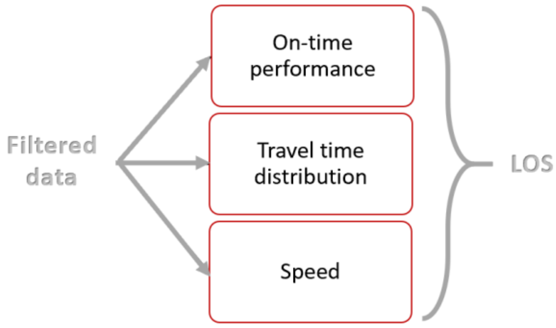

Figure 4 – The subprocess that describes the calculation of KPIs.

4. Data format

The AVL data used in this thesis is on the General Transit Feed Specification (GTFS) Realtime format. Likewise, the timetables and other useful information provided by ÖGT is formulated according to the GTFS static format. GTFS is a standard developed by Google (Trafiklab, n.d.). There are two types of GTFS, Static and Realtime. The static format aims to provide information about public transport timetables, geographic layout and fares (GTFS.org, n.d.). The files are in the format .txt and contains a number of required and optional fields. As can be read from the name, GTFS Realtime delivers updates about the vehicle's current position, speed, etc. and is in .csv format. The AVL data that the analysis is performed on is from a randomly chosen week in November 2018 (5th of November to 9th of November) and was retrieved from ÖGT.

There are three types of GTFS Realtime files. GTFS Trip Updates gives information about the arrival and departure time at stops, the delay, etc. The second file, Vehicle Positions, provides the longitude, latitude, bearing, speed and more. The last file of GTFS Realtime is used to make updates about the network, for example, disturbances in lines, at stops or for the whole agency (Google, 2018).

The GTFS static files used in this thesis is: shapes, stops, stop_times, trips, routes, and they are uploaded once a day. Furthermore, a trip ID is defined for a certain departure time during a day. For example, the same trip ID will be used for a trip that departure 08:04 on Monday as well as for Tuesday. This means that to define a trip uniquely, both the trip ID and the date of the trip is needed. For the GTFS Realtime, Vehicle Positions is used, which is updated once each second. The information present in each file is presented in Table 2. The green tick means that the column is present in the file. Explanations of the columns described can be found in GTFS.org (n.d.). There are other columns that are not presented in Table 2 in the GTFS files. However, since those are not used to calculate the KPIs in this thesis, they are not mentioned.

Table 2 - Used columns in the GFTS files, both static and real-time. The column names in the table shows the name of the file and the row names the name of the columns in the files.

Name of column	Shapes	Stops	Stop_times	Trips	Routes	Vehicle positions
route_id				✓	✓	✓
route_short_name					✓	
route_type				✓	✓	
trip_id			✓			✓
arrival_time			✓			
departure_time			✓			
stop_id		✓	✓			
stop_sequence			✓			
shape_dist_traveled			✓			
timepoint			✓			
stop_name		✓				
stop_lat		✓				
stop_lon		✓				
direction_id				✓		
service_id				✓		
shape_id	✓			✓		
shape_pt_lat	✓					
shape_pt_lon	✓					
shape_pt_sequence	✓					
shape_dist_traveled	✓					
entity.id						✓
trip_schedule_realtionship						✓
latitude						✓
longitude						✓
bearing						✓
speed						✓
timestamp						✓
vehicle.id						✓

5. KPI definition

This section describes how the used KPIs are defined and calculated in this thesis. The KPIs will be used to investigate the LOS in the public transport system of Östergötland. The purpose of the development is to have different types of indicators that together will provide an indication of the LOS. The pseudocode for the KPIs is attached in Appendix 1.

Since the LOS in this thesis is measured in on-time performance, speed and travel time, the KPIs presented below are based on one of these factors. On-time performance is chosen since a public transport provider offers a promise to their customers. The promise is the timetable, and if the timetable is not fulfilled, the public transport provider fails to deliver what they have promised. Consequently, they also fail to provide a good service. Speed is chosen since ÖGT aims to reach certain goals in average speed for their buses in different types of areas. Therefore, speed is also an important aspect when evaluating the LOS of the public transport system. Travel time is chosen since this is directly affecting the on-time performance of a trip and can be studied to find where problems occur. Moreover, the KPIs are used to measure how well ÖGT meets their goals and promises, and in the extension how good the LOS is. The KPIs can, therefore, be used to evaluate different important aspects for ÖGT. Table 3 describes in which area each KPI can be useful. Some lines can have unnecessary stops, where for example very few passengers use the stop. Travel time distribution and low speed can, therefore, be used to evaluate if there is a stop that could be removed. The KPI low speed can be used to visualize where problems occur geographically. For example, if there is a specific area where there are a lot of observations with a low speed. ÖGT have requirements regarding early departures that their operators are supposed to fulfill. On-time performance and travel time distribution can therefore be used to check if this requirement is fulfilled. To evaluate how well the timetable is functioning, on-time performance, travel time distribution and average speed can be used. If the actual driving time is diverging a lot to the timetable, there might be a need to update the timetable. Then for example the on-time performance can be studied to see which trips that need to be re-planned. If it is obvious that operators are not following a routine that a public transport provider has it might be shown with all the KPIs. Infrastructural issues regarding, for example, the design of a bus stop and whether a public transport lane exists or not, can be discovered by the KPIs travel time distribution, average speed and/or low speed.

Table 3 - Areas where each KPI is useful.

To evaluate	On-time performance	Travel time distribution	Average speed	Low speed
Number of stops		✓		✓
Problems geographically				✓
If operators fulfill goals	✓	✓		
Timetable	✓	✓	✓	
Routines	✓	✓	✓	✓
Infrastructure		✓	✓	✓

In Table 4 the notations used in the description of how the KPIs are calculated is presented.

Table 4 - Notations used in the Equations used to calculate the KPIs.

Notation	Unit	Explanation
$\boldsymbol{D}$	Meters	Travelled distance by a vehicle
$\boldsymbol{T_{last}}$	[MM:SS]	Average delay per vehicle at last stop
$\boldsymbol{T_{time}}$	Seconds	Travel time for a trip
$\boldsymbol{T_{veh.low}}$	Minutes	Average number of minutes vehicles drive at a low speed
$\boldsymbol{T_{start}}$	Unix time	First timestamp of a trip
$\boldsymbol{T_{end}}$	Unix time	Last timestamp of a trip
$\boldsymbol{T_{sched.dep}}$	[HH:MM:SS]	Scheduled time of departure for a trip
$\boldsymbol{T_{sched.arr}}$	[HH:MM:SS]	Scheduled time of arrival for a trip
$\boldsymbol{T_{arr}}$	Unix time	Actual time of arrival for a trip
$\boldsymbol{T_{dep}}$	Unix time	Actual time of departure for a trip
$\boldsymbol{T_{slack}}$	Minutes	Slack time for one trip for a trip
$\boldsymbol{T_{driving}}$	Seconds	Time during a trip spent driving
$\boldsymbol{T_{dwell}}$	Seconds	Time during a trip spent at a stop
$\boldsymbol{T_{sign.delay}}$	Seconds	Delay during a trip caused by signalized intersections
$\boldsymbol{T_{traf.delay}}$	Seconds	Delay during a trip caused by traffic
$\boldsymbol{ST}$	Minutes	Deviation from Scheduled Time for all stops but the last for a trip
$\boldsymbol{ST_{end}}$	Minutes	Deviation from Scheduled Time for the last stop for a trip
$\boldsymbol{N_{veh}}$	Nr	Number of vehicles
$\boldsymbol{N_{obs.low}}$	Nr	Number of observations with a low speed
$\boldsymbol{A_{speed}}$	Km/h	Average speed of a vehicle
$\boldsymbol{lat_i}$	Coordinate	The latitude coordinates of a point $\boldsymbol{i}$
$\boldsymbol{lon_i}$	Coordinate	The longitude coordinates of a point $\boldsymbol{i}$

Table 5 shows the different threshold values that are used in the calculations of the KPIs described in the subsection below. However, the values are calibrated for ÖGT's transport system and might need to be adapted if used in another setting. The thresholds should, therefore, be seen as a value that can be changed to be appropriate for a certain analysis. The thresholds in Table 5 are further described in the subsections below.

Table 5 - Describes the different threshold values that are used.

Notation	Threshold value
$\boldsymbol{D_{stop}}$	20 meters
$\boldsymbol{D_{sign}}$	100 meters
$\boldsymbol{V_{slow}}$	60%
$\boldsymbol{D_{TL}}$	100 m
$\boldsymbol{D_{BS}}$	100 m

5.1 On-time performance

The two subsections below together form the measure on-time performance. On-time performance is important both from the passengers and the operator's point of view. Passengers will have a greater experience and higher trust in public transport if the on-time performance is good. The operator can have less idle time in the schedule and consequently needs a smaller vehicle and staff fleet. Trompet et al. (2011) suggests measuring the punctuality whereas Camus et al. (2005) propose a more complex method to weight the delay. The KPIs concerning on-time performance in this thesis more nuanced rather than binary.

5.1.1 Delay and early departure

The delay can be aggregated on several levels. For the whole system, for a specific line, for one direction of a specific line, for individual trips or the delay at a certain bus stop. It can also be aggregated for a specific time period. What is considered delayed can vary depending on the stakeholder, the distance or time of the trip or the purpose of the analysis. It is also common to define the on-time performance at the last stop as the punctuality and then measure how many trips were punctual to the last stop. The threshold for punctuality is often set to three or five minutes and if a trip is later than the threshold, it is not punctual (Trompet et al., 2011).

A common approach when planning timetables is to keep the schedule tight at the beginning of the trip. To compensate for the tight schedule, extra time is added at the end of the trip. Therefore, a measure of how much delay there is at the last stop could work as a complement to the overall analysis of delays. This measure is supposed to give an indication of the magnitude of the delay at a route. The calculation of the delay per vehicle at the last stop is performed as in Equation (2).

$$T_{last} = \frac{\sum_{j=1}^{J} ST_{end_j}}{N_{veh}} \tag{2}$$

Where J are all the trips to the last stop for the chosen line and time period and $j \in J$.

ÖGT have pre-defined stops where the vehicle is not allowed to leave early, so called regulation stops. This means that ÖGT promise their customers that the bus or tram will not depart earlier than the time stated in the timetable.

The approach to determine the delay or early departure at a stop is different depending on if the stop is any of the stops but the last, or the last stop. For all the stops that are not the last stop, the delay and early departure are computed as the difference between the scheduled departure time and the actual departure time as in Equation (3). At the last stop, the delay is computed as the difference between the scheduled arrival time and the actual arrival time since the bus/tram cannot departure late or early from the last stop as in Equation (4). If the actual arrival is before the scheduled arrival at the last stop, the difference is set to zero since it is not negative for the customer to arrive early to the stop. Both Equation (3) and Equation (4) gives the deviation from scheduled time at a stop for one trip. The result from several stops and trips can then be summarized to give measures on different aggregation levels.

$$ST = \left\lfloor \frac{T_{dep} - T_{sched.dep}}{60} \right\rfloor \tag{3}$$

$$ST_{end} = \left\lfloor \frac{\max(T_{arr} - T_{sched.arr}, 0)}{60} \right\rfloor \tag{4}$$

The delay is trunked to whole minutes, i.e. a delay of 59 seconds is considered as 0 minutes delay, one minutes and 59 seconds as 1 minute, etc., which is a common method when evaluating delays.

Early departures, on the other hand, is rounded up to whole minutes. For example, an early departure of one second will be considered as leaving one minute early.

A number of measures can be calculated from the delay and early departure. For example, the number of delayed and early departure and the average/minimum/maximum delay and early departure. The delay and early departure can be determined for the area between specific stops, a direction of a trip, the whole line or the whole system.

5.1.2 Slack time

Since ÖGT have stops where the vehicle is not allowed to leave early (regulation stops), sometimes the vehicle must wait at a stop before it can leave. When planning public transport, there is a trade-off between robustness and travel times. With shorter scheduled travel times, there is a risk that a delayed vehicle cannot catch up with the schedule. Delays can also occur when a vehicle has been delayed during an earlier trip and there are not enough margins in the schedule to catch up with the delay. Planning a timetable with more generous marginals will give a more robust schedule that is not as sensitive for delays. However, with more slack in the schedule, the demand for resources may increase. A single extra minute added to the travel time on a trip could cause a need for one additional vehicle and driver that the public transport provider would have to obtain. This would lead to increased production costs, but possibly also a more robust plan.

To measure the slack time at a stop for one trip, the scheduled arrival/departure time to the actual arrival time is compared, see Equation (5). If the vehicle arrived before it is planned to do, the vehicle will have to wait before it can leave. This waiting time is called slack time. If a vehicle arrives after the scheduled departure time, there is no slack and $T_{slack} = 0$. The slack time is rounded down to whole minutes, meaning an early arrival time of 59 seconds is interpreted as 0 minutes slack time.

$$T_{slack} = \left\lfloor \frac{\min(T_{arr} - T_{sch.dep}, 0)}{60} \right\rfloor \tag{5}$$

The slack time can be computed and aggregated on several levels. For the whole system, some type of lines, a specific line, a specific trip or a specific stop. Similar to the delay and early departure, the slack time can be calculated as the number of vehicles with slack time at stops and the average/minimum/maximum slack time for vehicles with slack. It is not certain that all the slack time is time waiting for departure, it is possible that some passengers board or leave the vehicle as it waits as well.

5.2 Travel time distribution

To find problems in the system, the variation in travel time (travel time distribution) and the cause of variation will be studied as Adelsköld and Ejder (2018) suggests. The travel time can be divided into four parts. Dwell time (time at bus stops), driving time, signalized intersection delay (stops due to traffic signals) and traffic delay (stops due to unsignalized intersections, infrastructure or traffic). To evaluate the source of variation in travel time, the variation of these four components of the travel time can be analyzed.

The first step to compute the distribution of the travel time is to calculate the T_{dwell} (dwell time), $T_{sign.delay}$ (signalized intersection delay), $T_{traf.delay}$ (traffic delay) and $T_{driving}$ (driving time). Then the ratio between the different parts can be calculated.

When looking at the travel time distribution of a line, the ratio between the different parts should be computed. Sometimes, lines can have different scheduled travel times for different trips during the day. When trips have different scheduled travel times the analysis should be performed with caution.

5.2.1 Travel time

The variation in travel time on a line can be analyzed to see if there is any correlation with the time of the day, type of day, etc. Moreover, the travel time can also be compared to the timetable. The travel time could also be aggregated to travel time of a certain part of the line or just a single road segment to see if there is any variation between trips.

The travel time for one trip is defined as the difference between the end time and the start time, as in Equation (6).

$$T_{time} = T_{end} - T_{start} \quad (6)$$

For some lines, the scheduled travel time can vary over the day. Depending on the purpose of the analysis of the travel time, it may be of interest to only compare trips with the same scheduled travel time.

5.2.2 Dwell time

The dwell time for one trip, T_{dwell}, is defined as the time during a trip that the vehicle has a speed equal to zero km/h and is positioned in a stop area. The data contains information about the trips for every second, therefore, the dwell time is calculated as the number of observations where the vehicle has a speed that is zero km/h and the vehicle is positioned within a stop area. The stop area is defined as a circle with the radius of the threshold D_{stop}. To calculate the distance to the stop, Haversine distance is used. The Haversine distance formula can be used to calculate the great-circle distance between two points in the global reference system WGS84 (Upadhyay, 2019). All of the distances that follow are calculated by Haversine distance. If a vehicle arrives early to a bus stop and must wait before departure, this waiting time (slack time) is included in the dwell time.

5.2.3 Signalized intersection delay

The signalized intersection delay for one trip, $T_{sign.delay}$, in seconds is calculated as the number of observations with a speed equal to zero km/h within an area of a signalized intersection, but not in a stop area. Since a vehicle sends updates about its positions, speed, etc. every second, one observation is assumed to be equivalent to one second. The area of the signalized intersection is defined as a circle with the radius of D_{sign}. At some places, it is possible that the position of a stop is within the area of a signalized intersection as shown in Figure 5. In that case, the stop is assumed to be caused by the bus stop.

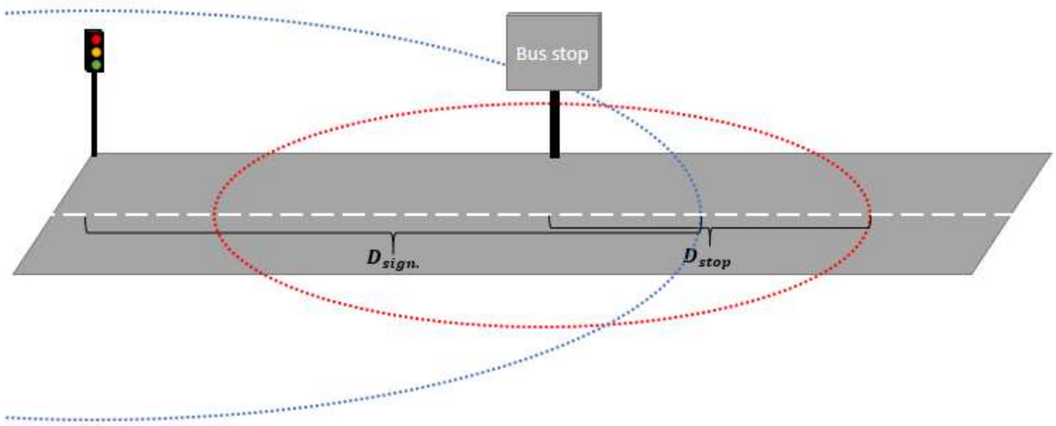

Figure 5 - Example of a bus stop located in a signalized intersection area. The blue circle in the signalized intersection area and the red circle is the stop area.

5.2.4 Traffic delay

The time spent during a trip in traffic delays for one trip, $T_{traf.delay}$, is the time the vehicle has a speed equal to zero km/h and have not stopped due to a stop or signalized intersection. Observations with the speed zero km/h neither within a stop area or a signalized intersection area are supposed to be due to congestion, infrastructure, unsignalized intersections, pedestrian crossings, etc. and are then considered to be caused by traffic delay. The traffic delay in seconds is calculated as the number of observations with a speed equal to zero km/h neither in a stop area or a signalized intersection area. Likewise, to the calculation of dwell time and signalized intersection delay, one observation is equivalent to one second.

5.2.5 Driving time

The driving time for one trip, $T_{driving}$, is defined as the part of the travel time, T_{time}, where the speed of the vehicle is larger than zero km/h. Equation (8) shows how $T_{driving}$ is calculated.

$$T_{driving} = T_{time} - T_{sign.delay} - T_{dwell} - T_{traf.delay} \tag{8}$$

5.3 Speed

The two subsections below together form the KPI speed. Speed is a good indication of if there are problems with the LOS and can for example be used to investigate the average speed in a specific area. It can then be used to point out exactly where the vehicles start to drive with a low speed.

5.3.1 Average speed

As Adelsköld and Ejder (2018) and Yang et al. (2018) suggests average speed can be used to evaluate the LOS. This KPI can be used on different types of aggregation levels, for a complete line, for a road segment or an area. The average speed of a vehicle is in general calculated as Equation (9).

$$A_{speed} = \frac{D}{T_{time}} \cdot 3.6 \tag{9}$$

The average speed can be calculated based on different aspects: timetable, AVL data and when dwell time is removed from the total time. Moreover, T_{time} is therefore different depending on the aspect that is considered when calculating the average speed. When the average speed is based on timetable or AVL data, Equation (6) is used to calculate T_{time}. However, when the dwell time should be excluded from the total time, Equation (10) is used and T_{time} is then replaced by $T_{time.NoDwell}$ in Equation (9).

$$T_{time.NoDwell} = T_{time} - T_{dwell} \tag{10}$$

The distance a vehicle has driven, D , is calculated as Equation (11).

$$D = \sum_i^I Haversine\ distance((lat_i, lon_i), (lat_{i+1}, lon_{i+1})) \tag{11}$$

Where I are the points connected to a trip/geographical area/etc. The calculation gives five different, but similar KPIs. The first measure describes the average speed of the whole line/road segment/area, during a specific time period and can be calculated for the three different aspects described above. The second measure describes how many trips, in percentage, that fulfills the goal regarding average speeds in an urban/rural area. The third measure describes how many trips, in percentage, that have an average speed higher than what the average speed should be according to the timetable. The fourth and fifth measures describe the minimum and the maximum speed during a specific time period.

If there is a high percentage of trips that have an average speed higher than the average speed according to the timetable, this indicates that the timetable can be improved. On the contrary, if there is a high percentage that has a lower speed than the average speed according to the timetable, this indicates that there are most likely problems with the LOS.

To study how T_{time} is distributed along a route for several vehicles, a visualization where the distance is shown on the y-axis and the time on the x-axis can be used. It is only the three trips that have the highest Root Mean Square Error (RMSE) between the actual data and the timetable that is included in the plot. These three trips are supposed to represent the worst-case scenario for the investigated time period. The movement of vehicles according to the timetable is also included in the plot. In ÖGTs timetable arrival time and departure time are defined at the same timestamp and therefore, it will not be possible to see any planned dwell time in the plot.

5.3.2 Low speed

The number of vehicles with low speed is a measure that is not suggested by any of the other studies but is used in this thesis. It is included since it is believed that it can be a good complement to average speed.

When vehicles are driving at a speed much lower than the speed limit in a segment this is an indication that there are problems with the LOS. Therefore, $T_{veh.low}$ describes how many minutes in average that vehicles are driving at a low speed (during the examined time period), this is calculated as Equation (12). If there is not an observation each second (for example due to removal of outliers) for all the vehicles, $T_{veh.low}$ might not be accurate, since it is directly depending on that there are 60 observations for each vehicle in 1 minute. It was therefore checked that the total time including both time when low speed was used and when low speed was not used summed up to time a trip was supposed to take.

$$T_{veh.low} = \frac{\left(\frac{N_{obs.low}}{60}\right)}{N_{veh}} \quad (12)$$

Low speed is defined as a speed lower than a specific threshold, V_{low}, of the speed limit on the road. Observations that are within a specific threshold value, D_{BS}, of a bus stop and D_{TL} of a traffic light will be discarded. It was decided to discard these observations since a low speed close to a traffic light or a bus stop is not supposed to be interpreted as an indication of poor LOS. $N_{obs.low}$, is defined as the number of observations where a vehicle was driving at a low speed and can be presented either in real numbers or as a percentage, depending on the aggregation level.

To be able to deepen the analysis a visualization where low speeds occurred can be used. Where each observation where a vehicle is driving with a speed defined as low speed is represented by a dot in the position of the observation in a map. The visualization is supposed to make it easier to draw conclusions of where low speeds usually occur.

5.4 Definition of the start and end of a trip

For all trips, there is a scheduled start time of the trip. However, not all trips start at that exact time. Therefore, the start of a trip needs to be defined. The start time, T_{start}, of a trip is defined as the last observed time point within the stop area of the first stop.

Likewise, for the start time, all trips have a scheduled end time. Due to traffic, passengers, breakdowns, etc., the trips will not always arrive at the last stop at the exact timepoint stated in the timetable. The end of a trip, T_{end}, is defined as the first observed time point within the stop area of the last stop.

5.5 Definition of a stop and stop area

To determine if a vehicle has arrived at a stop, an area around the coordinates of each stop must be defined. The radius of the stop is set manually for all start and end stops. For all stops between the first and the last stop, the radius is set to the threshold value of D_{stop}.

Since it is unlikely that the vehicle would have passed the exact position defined for the stop, an area around the stops was defined. As Predic et al. (2010) suggested, the area can be seen as a circle around the coordinated stated in the GTFS file stops.txt. The radius of the circle, D_{stop}, can be fixed for all stops, or vary depending on the layout of the stop and the area around it.

There are two cases that need to be considered when defining when the vehicle has arrived and departed at a stop. The first case is when the vehicle has stopped to pick up or drop off passengers. Then, the arrival at the bus stop can be defined as the first position within the circle where the speed is equal to zero. In Figure 6, the arrival at the stop was decided to be placed at time point t_2. The departure time from the stop is defined as the point where the speed of the vehicle is larger than zero and the position still in the circle after the vehicle has had a speed equal to zero. As can be seen in Figure 6, the departure is defined as time point t_3 where the speed is larger than zero.

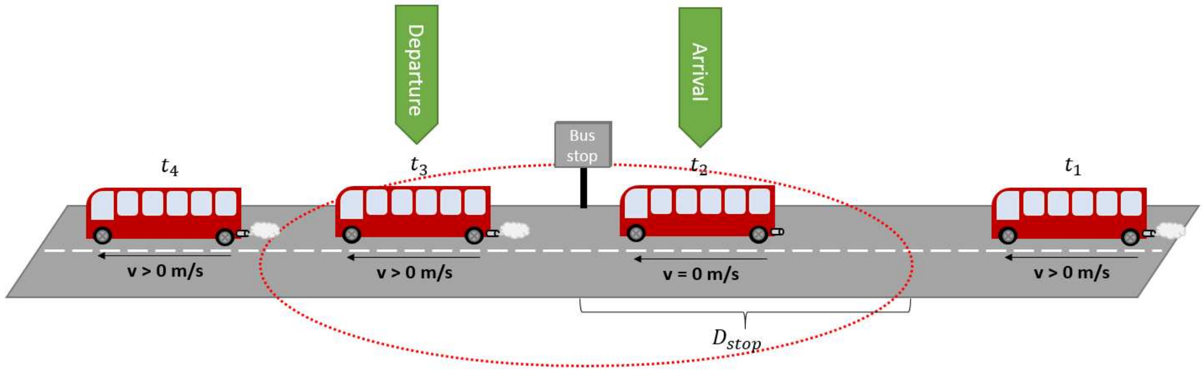

Figure 6 - Definition of arrival and departure, when picking up passengers. The red circle is the stop area.

The second case of defining when a vehicle has arrived and departed at a stop is when the vehicle did not stop to pick up or drop off any passengers, and therefore never had a speed equal to zero. The arrival and departure time are then set to be the first point within the pre-defined stop area. In Figure 7, this is time point t_2.

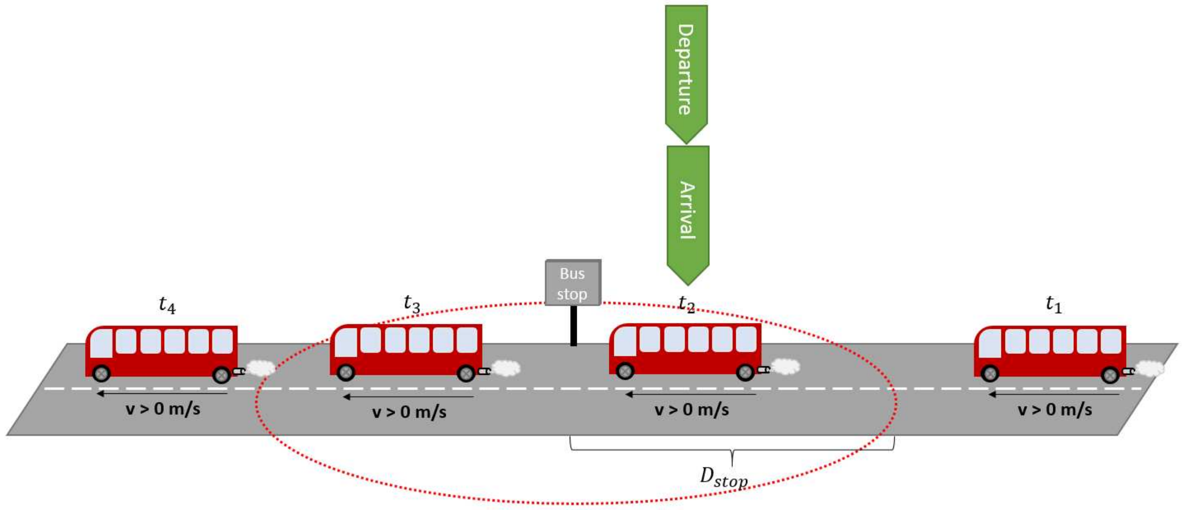

Figure 7 - Definition of arrival and departure, when no passengers are picked up at a bus stop. The red circle is the stop area.

If the vehicle for some reason would not pass a stop that it is planned to do, the data point around this stop has been filtered out, or if there is a technical failure at that point in time, no arrival and departure time will be found for this stop.

6. Identification and removal of outliers

In this section, the methods that are used to disregard observations that do not represent reality in a good way is presented. These types of observations are called erroneous data. The following known errors in the data were described by Gunnarsson (2019). Sometimes the data is not buffering and then the data will then be lost. Sometimes, GPS coordinates are missing because of technical failures. At some areas or bus stops it is problematic to determine the position of a vehicle, data can, therefore, be missing at some points. The bus driver can cause problems if the driver login into the wrong trip, does not finish the trip, taking a different path then planned, etc. If the bus does not arrive at the last stop within 30 minutes, ÖGT's system ends the trip automatically. Many more errors can occur, but these are the most common Gunnarsson (2019) says.

To remove outliers in the AVL data different threshold values are used, these are shown in Table 6. The usage of the thresholds is explained in the following subsections. Similar to the thresholds used to calculate the KPIs, these should also be changed to be appropriate in a certain setting. The thresholds are described further in the subsections below. The pseudocode for the removal of outliers can be found in Appendix 2.

Table 6 - The threshold values used to remove outliers in speed.

Notation	Threshold value	Explanation
$\boldsymbol{D_{ToLine}}$	5 meters for line 4, 410 and 2; 10 meters for line 42	Distance from a position to the planned route
$\boldsymbol{T_{outlier}}$	75% of scheduled time	Lower limit for valid total travel time
$\boldsymbol{V_{outlier}}$	20% over speed limit	How much faster than the speed limit that is valid
$\boldsymbol{Digits}$	4	Number of digits to round to

6.1 Outliers in position

Two types of errors in positions are considered in this thesis. The first is when there is poor coverage in the GPS positioning which leads to observations outside of the expected area. The second one is when the vehicle is driving outside of the route, for example when leaving the garage or if a vehicle has logged onto the wrong trip ID. The later could happen due to a mistake by a driver. An example of this can be seen in Figure 8. These outliers need to be filtered out in order to only use data that represents the reality in the analysis. Thus, a method to identify and eliminate these erroneous positions is used.

Figure 8 – Example of outliers in position.

In the GTFS files, there is a file called shape, that contains information about the path of a route. The positions in the shape file for a specific route is compared to the actual AVL data. Moreover, the positions in the shape file are linked to a line and then the Haversine distance from a point in the AVL data to the line is computed. If the distance from an actual point to the line, D_{ToLine}, is longer than the threshold value, the point is considered invalid. All points where the distance is shorter than the threshold value, D_{ToLine}, is considered valid.

The threshold D_{ToLine} is set to five meters since the positions that should be considered valid should follow the path of the route with high accuracy. In Figure 9 - Figure 11 different thresholds were used to decide which threshold that should be used. When ten meters was used there were a lot of points that were considered valid that were not following the road. With the threshold set to five meters, the valid points were following the street well. It is reasonable for a GPS-coordinate to differ up to five meters, but if a point is in a building and not on the road, that point should not be considered valid. Therefore, the threshold five meters is then chosen based on the result in Figure 9 - Figure 11.

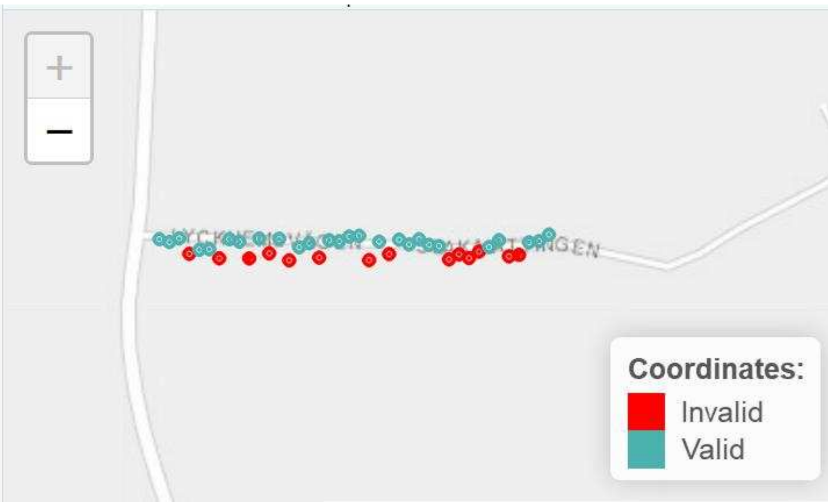

Figure 9 - Distance to line = 5 meters.

Figure 10 - Distance to line = 7 meters.

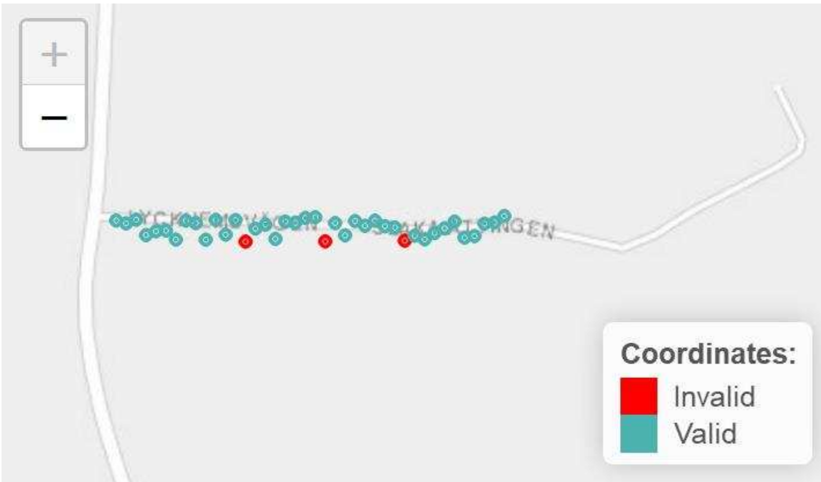

Figure 11 - Distance to line = 10 meters.

However, as can be seen in Table 6, ten meters is used for bus line 42. If five meters was used, it was decided that too many observations were omitted. Due to that fact ten meters was more suitable to use for the data from this bus line. Although, for the other three lines (4, 410 and 2) five meters was considered to give reasonable results.

6.2 Outliers in speed

A method to remove outliers in speed is also used. Outliers, in this case, refer to observations where a bus has a speed that is above a certain threshold value, $V_{outlier}$, compared to the speed limit set on the road of the specific observation.

To find outliers in speed, the AVL data is compared to open data from Trafikverket, that contains the speed limit of all roads in the studied cities. The latitudes and longitudes both in the AVL data and in the open data are rounded to a threshold value, $Digits$, that is considered to have an acceptable level of accuracy. This is done to be able to match the positions in the AVL data to the positions in the open data from Trafikverket. If more digits were used, the positions were not accurate anymore and if fewer positions were used it was difficult to match the AVL data with the open data.

The distance from each point in the AVL data to the line that is formed by open data from Trafikverket is then calculated. The speed on the road where the AVL data point is positioned is determined by the speed of the point with the shortest distance from an AVL data point to the line. If the speed in a point in the AVL data is above the threshold value, $V_{outlier}$, the point is considered invalid.

The threshold is set to 20% higher than the speed limit on the road, as can be seen in Table 6. Because it is believed that every bus driver should always strive to not drive faster than the speed limit and also because it is against the law to drive faster than the speed limit. It is therefore considered that it is important to define these measurements as outliers in order to get a data set that includes speeds that are reasonable.

Experiments were executed to determine if 20% was a reasonable value, where different thresholds were tested for different times of the day. The experiments were executed on data where outliers in positions already were filtered out. The experiments were based on data where only the trips that were going in the outbound direction of the city were included.

Table 7 - The p-value from the Welch two-sample t-test and average speed using different threshold values.

Line, date, time	p-value	Average speed (km/h)	$V_{outlier}$
4, 2018-11-05, 07:00-09:00	0.3173	20.23	20%
	0.7134	20.19	30%
	0.9305	20.19	50%
4, 2018-11-05, 15:00-18:00	0.064	18.12	20%
	0.3952	18.02	30%
	0.8822	18.02	50%

The p-value was calculated with the Welch two-sample t-test which can be used to find if there is a difference in terms of means between two datasets. The used datasets consist of the original data where no speed have been filtered out and the other dataset consists of data where speed limits above a certain threshold (20, 30 or 50%) have been filtered out.

The p-value is >0.05 for all of the experiments in Table 7. This means that the null hypothesis that there is no significant difference in the mean value between the original dataset and the filtered dataset cannot be rejected. In other words, this means that there is no significant difference in the mean value between the two datasets. If the average speeds are studied in Table 7 it is evident that the differences in speeds are very small when the different limits are used.

Based on the experiment above, the threshold does not seem to affect if the null hypothesis can be rejected or not. Therefore, it is interpreted that the value of the threshold did not affect the means of the speed in the data sets significantly. It seems like it is unusual that vehicles drive at a speed higher 20% higher than the speed limit and therefore it is reasonable to believe that observations that have a speed above the threshold for 20% are outliers. The decision to choose this threshold is also based on Swedish law. Since the bus drivers aren't allowed to drive above the speed limit at all, 20% is considered reasonable. The threshold is chosen as a percentage since it will be applied to different types of roads, rural and urban, which have different speed limits.

6.3 General errors

General errors in the AVL data is then removed. This filtering of general errors is similar to Ma et al. (2014) filtering technique to remove incorrect observations caused by technical failure. The following errors are removed:

- Duplicated rows where removed.
- Rows where several trip IDs are assigned to the same vehicle ID during the same time point are removed. Only the trip ID that has the most transmitted observations should be considered valid out of the trip IDs that belong to the same vehicle ID. The other trip IDs are considered invalid since a vehicle can only execute one trip at a time.
- If a specific trip ID is transmitting several updates each second, all the duplicated observations are removed since each vehicle should only be updating one time per second. Problems that a trip ID is assigned to several vehicle IDs during the same time point will also be fixed by this.

6.4 Outliers in travel time

To find other types of abnormal trips, different filtering techniques to sort out outliers in travel time can be used. For example, Ma et al. (2014) applied the median absolute deviation to find abnormally long or short trips. If a trip is much shorter in time than it normally is, this trip is probably not well representative of the travel times of that line. Likewise, a trip with a travel time that is much longer than usual may not be a fair reflection of reality. These abnormal trips could occur if a trip is falsely recorded, a vehicle is delayed due to a breakdown or equipment failure, etc. Since these delays or early arrivals would not be due to congestion or many passengers, they should be excluded from the analysis. At best, the filtering of positions, falsely recorded trips, etc. will solve the problem with abnormal trips length where the travel time is just a fraction or unreasonable long compared to the rest of the trips. However, the filtering will never be perfect and at the same time keep relevant variations in the data. Therefore, as a precaution, the travel times of the trips is studied and used as a cause to exclude trips with abnormal travel times.

One method is to apply Hampel-filter as Pearson (2002) suggests. The filter study observations within a time window, if an observation deviates more than three standard deviations from the median of the rest of the observations, it is identified as an outlier. When the window size varies, the median and standard deviation will vary and therefore, the observations identified as outliers will shift.

When the Hampel filter was applied to the real data, the calibration of the window size was impossible. A window size managing to filter out erroneous trips in one set of data did not manage to detect erroneous trips in another set of data. As an example, for bus line 4, afternoon traffic, direction Landbogatan, a Hampel filter with *k* = 4 or *k* = 7 does not classify any of the trips as invalid, which was considered as correct, see Figure 12 to Figure 15.

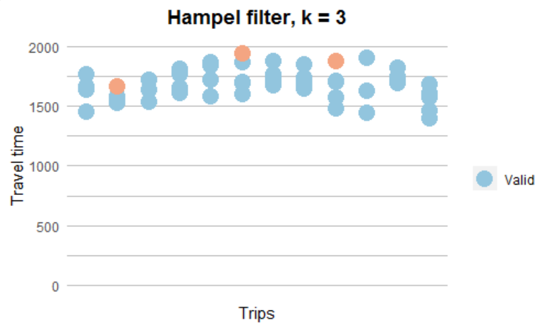

Figure 12 - Hampel filter, *k*=3.

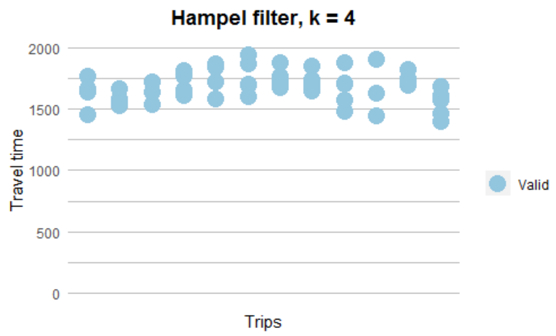

Figure 13 - Hampel filter, *k*=4.

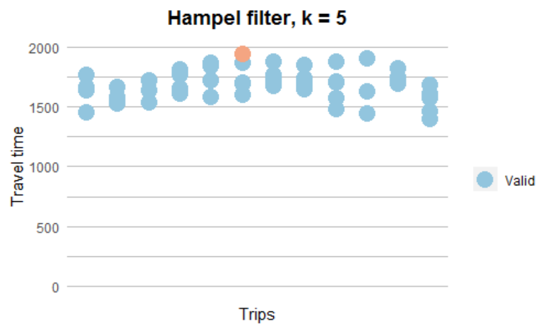

Figure 14 - Hampel filter, *k*=5.

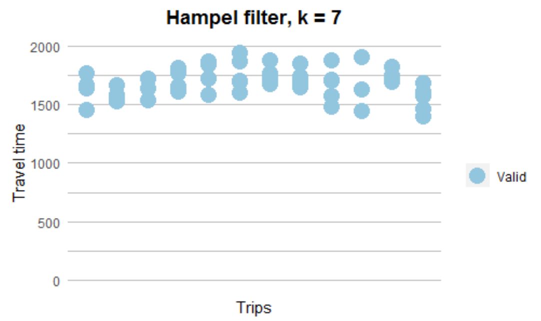

Figure 15 - Hampel filter, *k*=7.

However, for the same bus line, time period but opposite direction, the *k*-values that gave the wanted result for direction Landbogatan did not manage to classify the erroneous trips as invalid, see Figure 16 to Figure 19. Where the Hampel filter did classify the erroneous trips as invalid (*k* = 5, Figure 18), the same *k*-value in the opposite direction classified one of the correct trips as invalid (Figure 14).

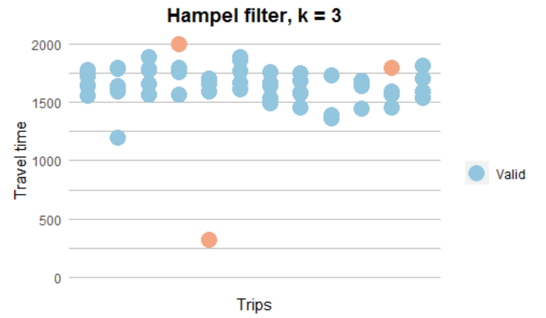

Figure 16 - Hampel filter, k=3.

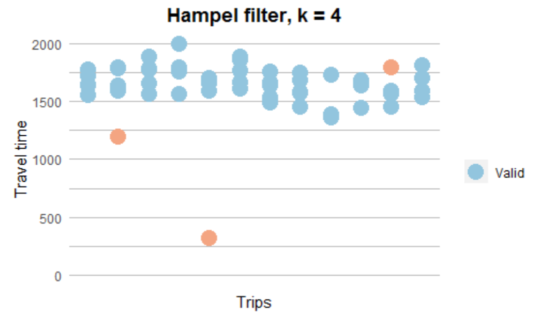

Figure 17 - Hampel filter, k=4.

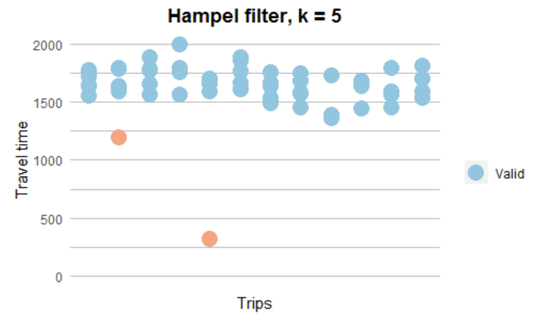

Figure 18 - Hampel filter, k=5.

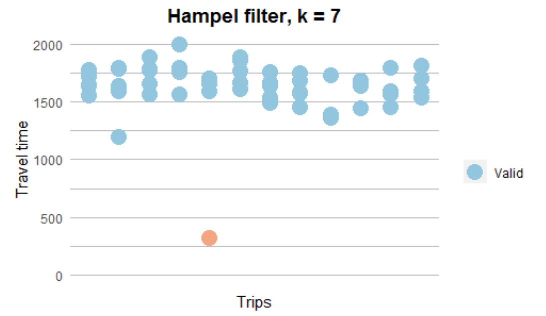

Figure 19 - Hampel filter, k=7.

Since the Hampel filter did not give the wanted result, a new filter was constructed and tested. The filter compares the actual travel time with the scheduled travel time in the timetable. To decide a valid interval for the travel times, the deviation from the timetable is studied. The lower limit of allowed travel times is set to $T_{outlier}$ of the scheduled travel time. No upper limit is set since a trip that has not been reported as finished within 30 minutes after the scheduled end time is automatically set to finished.

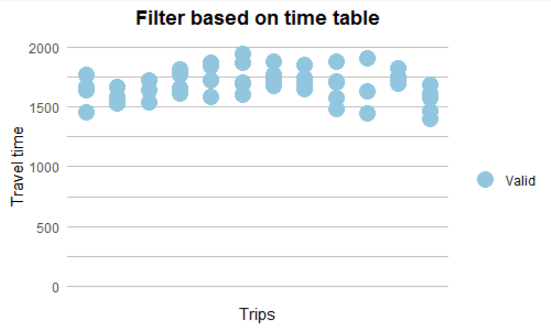

Figure 20 - Filter based on data from direction Landbogatan in the afternoon.

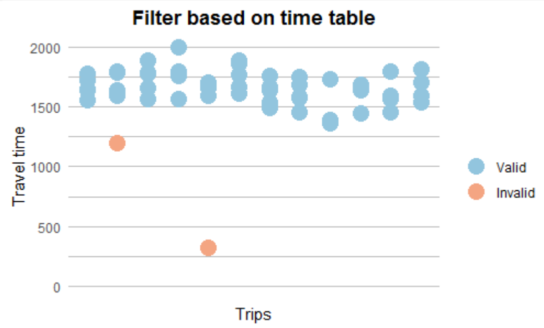

Figure 21 - Filter based on data from direction Linköpings resecentrum in the afternoon.

In Figure 20, the result of the filtration for direction Landbogatan is that, correctly, no trips are classified as invalid. As for Figure 21, two trips are classified as invalid, the same trips are considered erroneous. In conclusion, it was found that the constructed filter based on the timetables was the most suitable to use when filtering the travel times to detect outliers and exclude those trips from the analysis.

6.5 Potential errors in the data

Even though several filters were applied to the data, not all errors will be found and removed. There could also be other errors in the data not caused by the filtration. Known errors in this thesis are highlighted in this section.

For several reasons, not all trips that were scheduled could be found during the analysis. In some cases, no positions connected to a trip could be found. This could be the case if a driver has logged in to another trip by accident, but still drove the scheduled trip. Other sources of error could be that the trip was canceled due to vehicle problems, or that the trip was filtered out in the outlier's detection. As a consequence, the analysis performed may not consider every trip that was actually carried out, only on the ones that could be found among the observations after filtering.

If a bus stop is close to an intersection, this could cause misinterpretation about the time the bus has spent at the stop. If an observation is within both a stop area and an intersection area, the observation will be assumed to belong to the stop and not the intersection. Intersection delay could, therefore, be interpreted as dwell time if the bus has stopped due to a signal within the stop area.

When computing the duration of each type of stops, two alternatives were considered. Firstly, the minimum timestamp of that type of stop for that bus stop that could be found and compared to the maximum timestamp for the same type of stop at the same bus stop. Secondly, the number of observations with a speed equal to zero within the bus stop area can be calculated. The same approaches can be used to calculate the time the vehicle has stopped in a signalized intersection. The two methods could give different results, and both have shortcomings. The first method would interpret that the vehicle had a speed equal to zero for the whole time-interval between the first time-stamp and last time-stamp with the speed zero. However, it is possible that the vehicle has had a speed larger than zero between the two time-stamps. The second method could miss seconds where the speed was zero if some of the points have been considered as outliers and removed. It is also possible that technical failure would result in missing positions whereas the vehicle stood still. The second alternative, where the total time was computed as the number of timestamps where the speed was zero was summarized, was chosen.

Since erroneous data was filtered out, positions for parts of the trips were sometimes missing. Missing data could also derive from poor coverage for the GPS transmitter in the vehicle. As a result, information about arrival at a bus stop, speed, etc. was missing in some cases. The missing positions could have been filled in using different types of estimation techniques. However, the purpose of the analysis was not to use perfectly formed data, but rather data that matched the reality. Therefore, no estimations were done where observations were missing.

The data regarding the placement of traffic lights was retrieved from OpenStreetMap (n.d). OpenStreetMap is a non-profit project where cartographers around the world together create maps with different types of information such as placement of traffic lights, cafés and trails, etc. In other words, anybody that is identifying themselves as a cartographer can make changes to the map. This could affect the dependability of this data. For example, an error in Finspång was detected during the thesis, where a traffic light was missing. However, OpenStreetMap was the best source found for this kind of data, and small errors should not affect the final results significantly.

7. Results for selected lines

The analyzes in this thesis are executed for specific predefined time periods. This is done since the data is massive and when analyzing LOS, it is not of interest to study the system when there is not much traffic, for example during the night. The analyzes are therefore executed for two time periods, morning peak and afternoon peak, see Table 8. These time periods were chosen since it was believed that they represented the system in a busy state.

Table 8 - Describes the peak periods used.

Peak periods	Time period
Morning peak	07:00 – 09:00
Afternoon peak	15:00 – 18:00

In addition, it was decided to only perform the analysis on one line at a time. However, the KPIs could for example also be used to investigate a specific area or to compare the LOS between two years. Although, a part of the purpose with this thesis was to investigate if different modes of transport needed to be handled differently in this type of analyzes. Hence, the analyses were formed per line.

The overall analysis of each line will be presented in the same way for all lines. To show the possibilities to aggregate the KPIs on different levels, the detailed analysis will vary between the different lines. The level of aggregation could, for example, be to calculate the overall results for individual trips, to study specific parts of the trips for one or several trips, studying the variation between the two directions, etc.

7.1 Lines to investigate

The investigations (that include filtration of outliers, usage of KPIs and visualizations) were based on 4 different types of modes that operate in ÖGT's network; city bus, rural bus, express bus and tram. These four modes were chosen since a part of the purpose of the thesis is to investigate if different modes need to be handled in different ways and in that case what differences that need to be applied. All the lines that are investigated in the thesis are operating in the Linköping and Norrköping area.

The city line that was chosen was bus line 4 that operate in Linköping, see Figure 22. This is a bus line that is passing some of the areas in Linköping city center where it is known to be a lot of traffic during peak hours. Another important factor is that it can be seen as a bus line with high-frequency compared to other lines operating for ÖGT since it has a headway of 12 minutes during peak hours. However, this is not defined as a high-frequency route by Trompet et al. (2011), but that definition is proposed for a much larger city.

Figure 22- Bus line 4, operating in Linköping city center.

The rural line that was chosen to perform investigations on was bus line 410 that operates between Norrköping and Finspång. This is a bus line that many people use for everyday commute between the two mentioned cities. There is also an express line that operates a similar route, this bus line was chosen as the express mode. The express bus line between Norrköping and Finspång that was chosen is called 42. Where the bus lines operate can be seen in Figure 23 and Figure 24.

Bus line 42 is not operating in both directions during both peaks. During the morning peak bus line 42 is departing only from Finspång. Meanwhile, during the afternoon peak bus line 42 is departing only from Norrköping. Moreover, this means that during the investigations of this bus line only one direction for each peak will be examined.

Figure 23 - Bus line 410, operating between Norrköping and Finspång.

Figure 24 - Bus line 42, express line operating between Norrköping and Finspång.

The tram line investigated in this thesis is line 2, which is operating in Norrköping city center, see Figure 25. The tram is departing every 10th minute during day time and can, therefore, be seen as a high-frequency line.

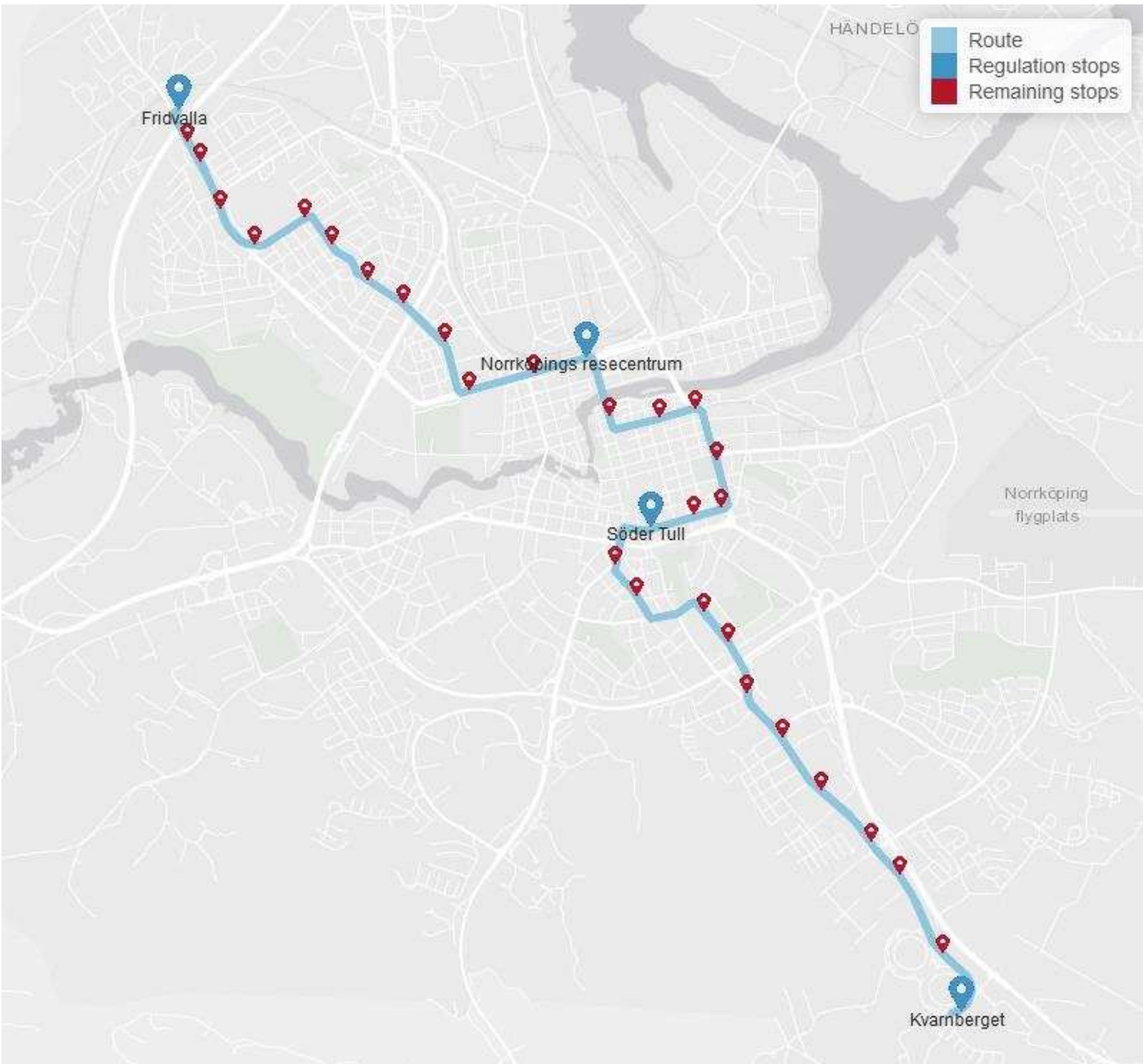

Figure 25 - Tram line 2, operating in the city center of Norrköping.

7.2 Results for bus line 4

The subsections below describe the overall LOS of bus line 4 as well as a detailed investigation of specific parts of the bus line.

7.2.1 Overall LOS of bus line 4

The overall LOS of bus line 4 is described in Figure 26-Figure 41 and Table 9. The detailed results of the KPIs regarding low speed, average speed, on-time performance and travel time distribution can be seen in Appendix 3 for both directions. All the results are based on data from the 5th to the 9th of November.

Figure 26 and Figure 27 shows where vehicles have been running with a speed lower than 60% of the speed limit (the red dots). The figures show positions collected during the whole week. It can be seen in Figure 26 and Figure 27 that the positions where vehicles are driving at low speed are quite similar during the morning and the afternoon peak.

Morning peak **Afternoon peak**

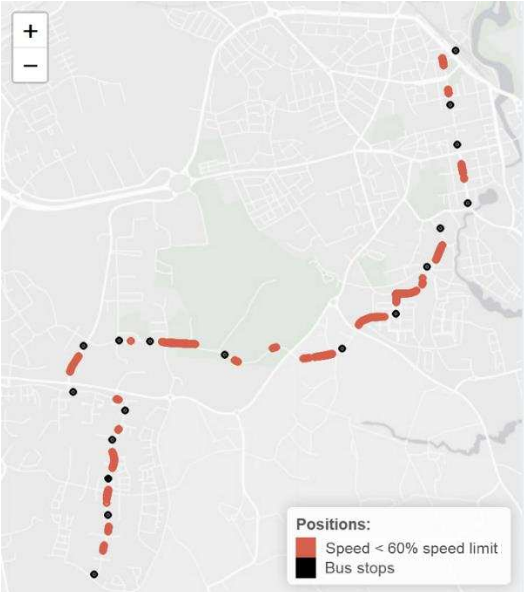

Figure 26 - Observations where a vehicle drove at a low speed during the morning peak for both directions.

Figure 27 - Observations where a vehicle drove at a low speed during the afternoon peak for both directions.

The average speed of each trips carried out during the different time periods and directions are shown in Figure 28-Figure 31. Each bar represents a trip and the date below each bar indicates with day the trip was carried out. The color gives information about which time the trip was scheduled to start. The dashed line represents what average speed the trips should keep according to the timetable and the solid line is the speed goal ÖGT have set up for the city center.

Morning peak

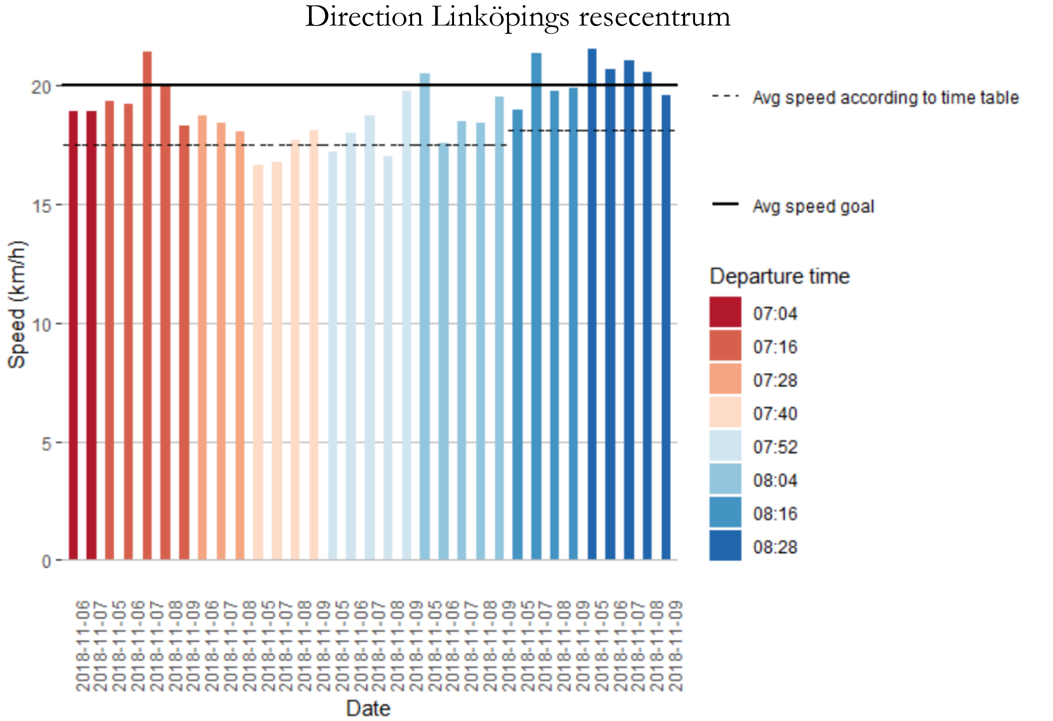

Figure 28 - Average speed in direction Linköpings resecentrum of all vehicles during the examined week in the morning peak.

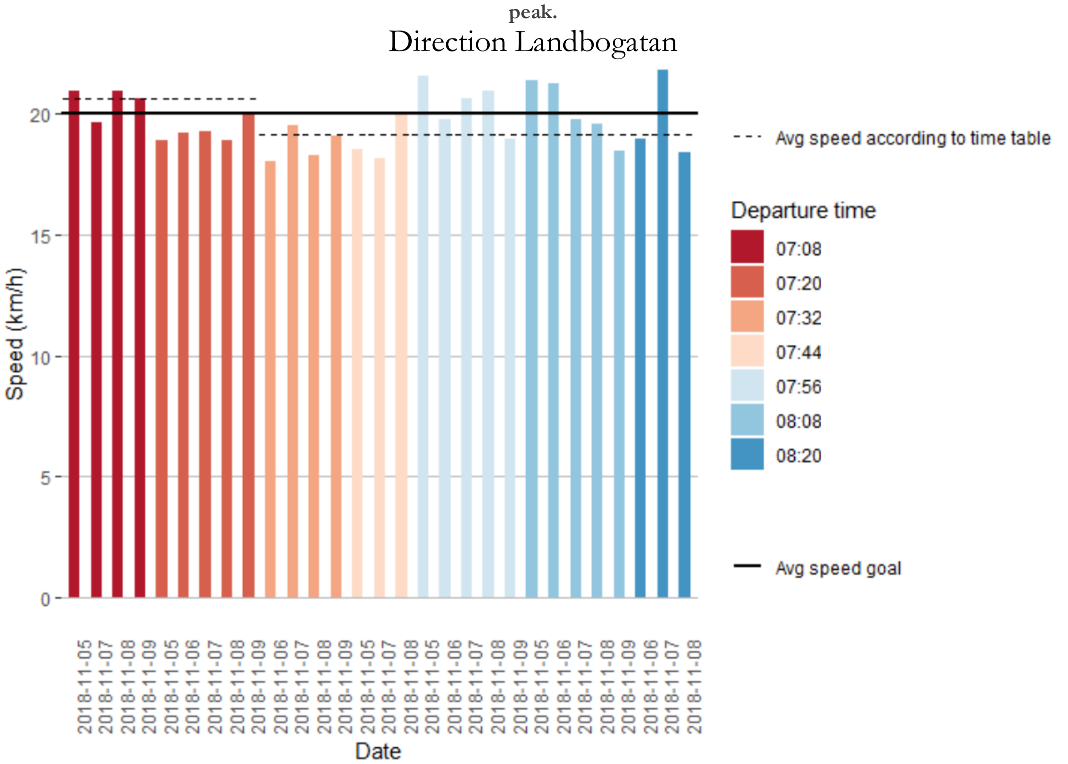

Figure 29 - Average speed in direction Landbogatan of all vehicles during the examined week in the morning peak.

Figure 30 and Figure 31 show that the average speed is generally lower during the afternoon peak than during the morning peak. The majority of the average speeds are below both the average speed goal and the average speed according to the timetable in the afternoon peak. Meanwhile, in the morning peak hour, see Figure 28 and Figure 29, the majority of the average speeds are above the average speed according to timetable but only a few have an average speed above the average speed goal.

Afternoon peak

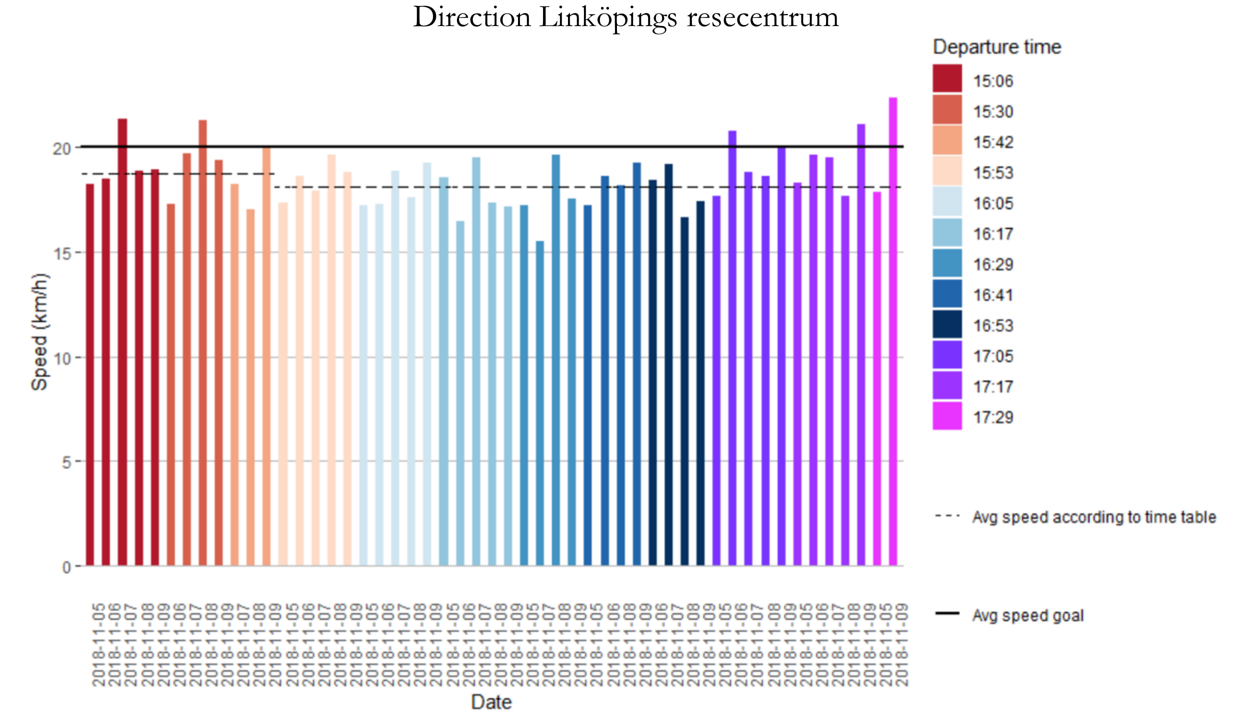

Figure 30 - Average speed for all vehicles in direction Linköpings resecentrum during the examined week.

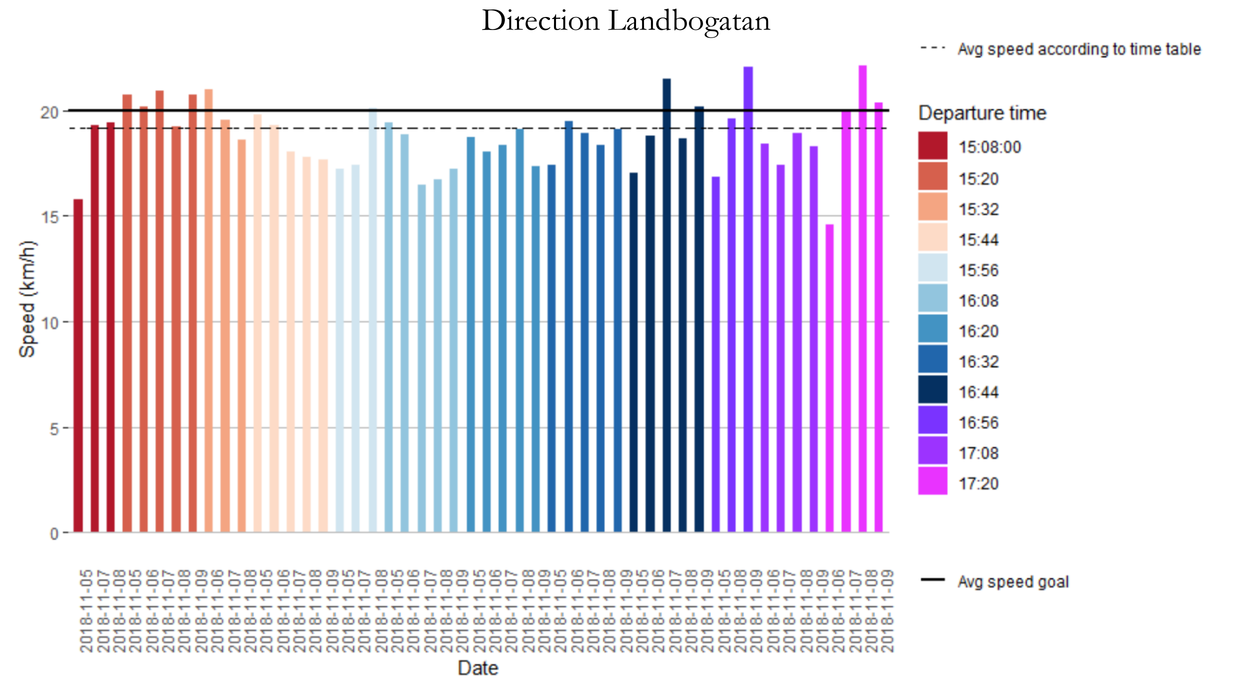

Figure 31 - Average speed for all vehicles in direction Landbogatan during the examined week.

To compare the movement of the vehicles to the timetable, the time and distance were plotted as can be seen in Figure 32-Figure 35. The dashed line is an approximation based on the departure time in the timetable to visualize the movement between the stops. The solid, colored lines are actual trips and the figures shows the three trips with the worst RMSE for each direction and time period. The color of the lines indicates with scheduled start time the trip had. In some figures, there are more than one line with the same color which means two trips with the same start time on different days are among the three worst trips. Only the name of the regulation stops is displayed on the y-axis.

Morning peak

Direction Linköpings resecentrum

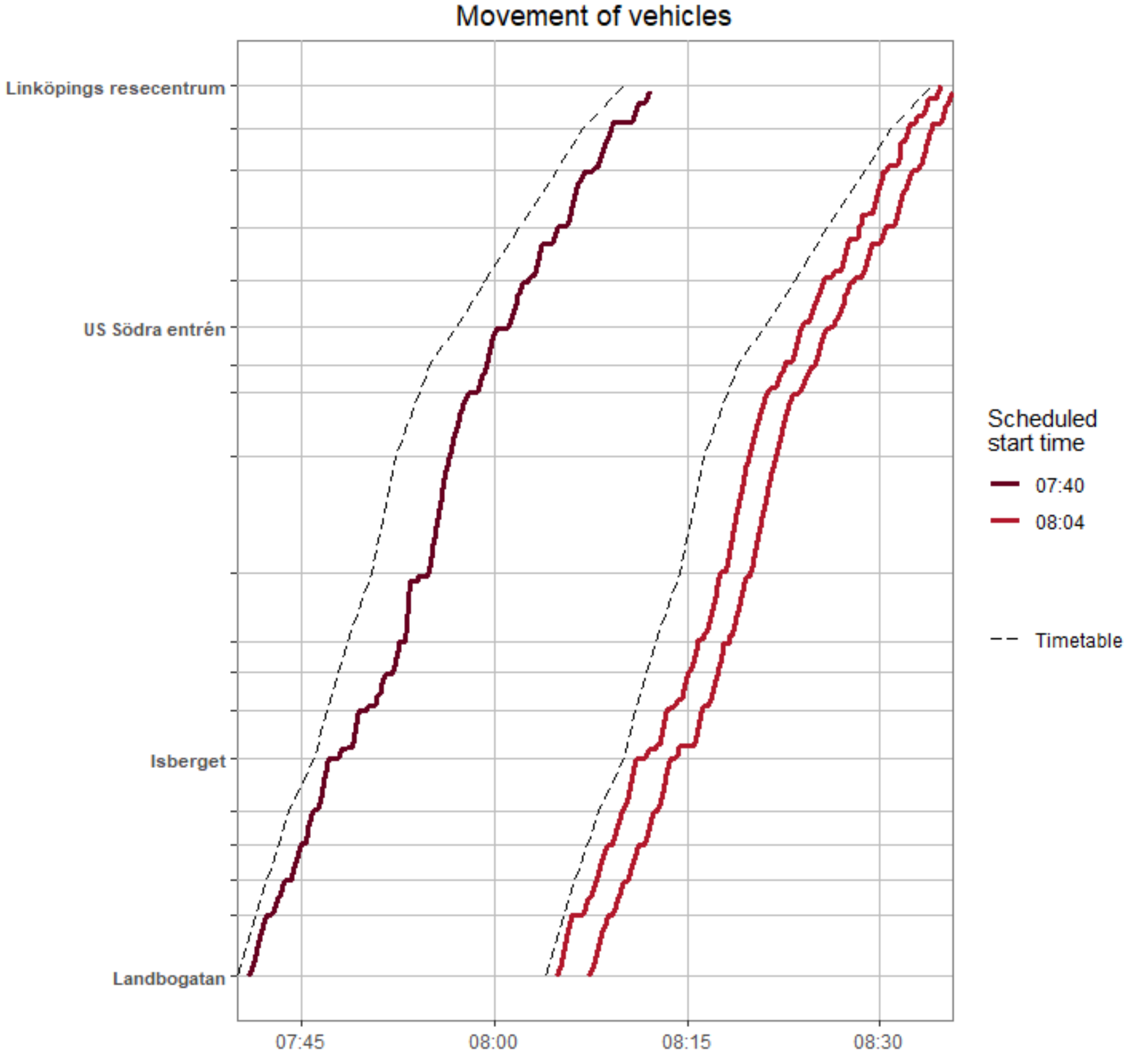

Figure 32 - Movement of the buses with the worst RMSE during the week in the morning peak, direction Linköpings resecentrum.

Direction Landbogatan

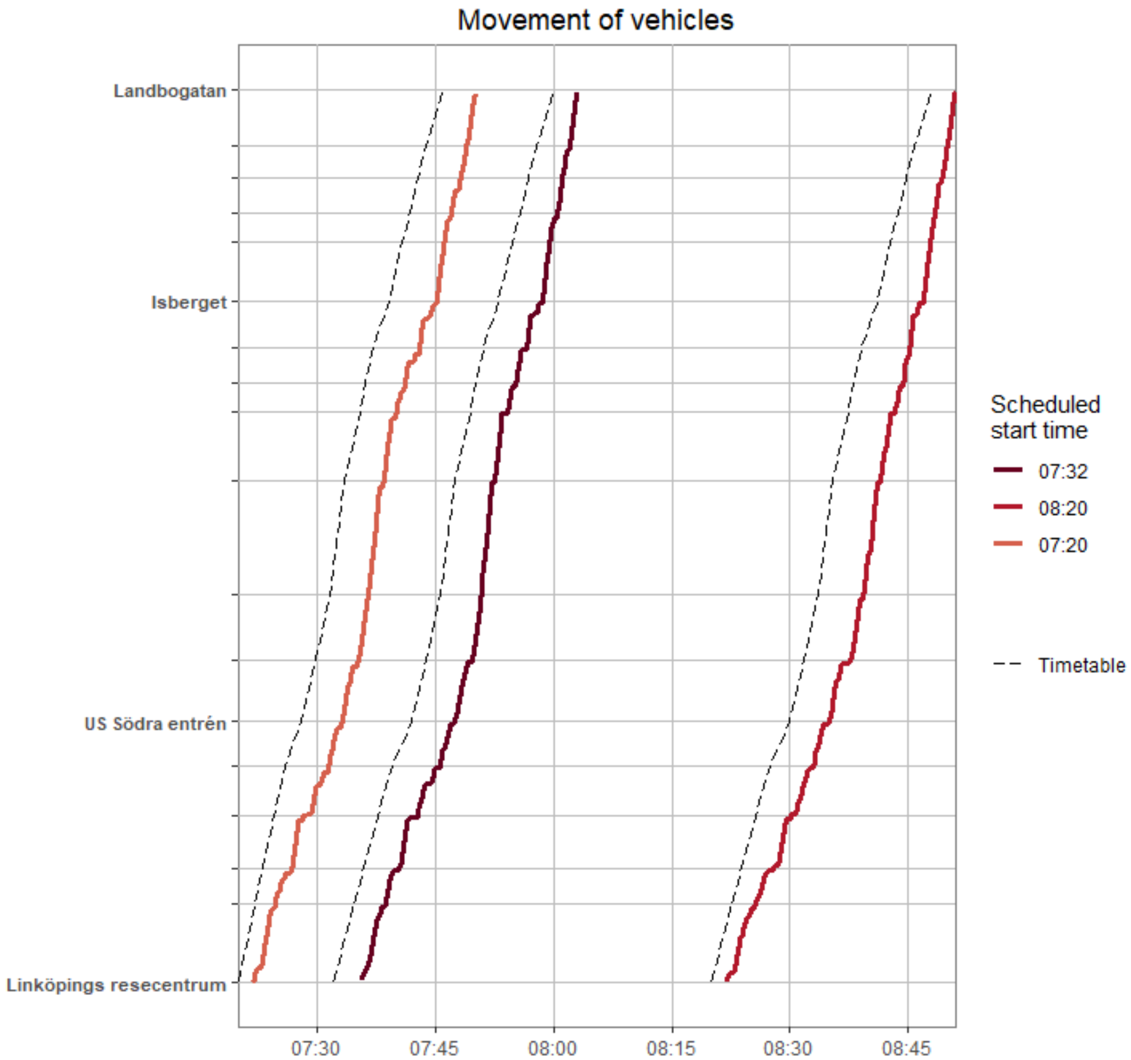

Figure 33 - Movement of the buses with the worst RMSE during the week in the morning peak, direction Landbogatan.

In Figure 32 one trip ID has the worst RMSE two times during the analyzed week in direction Linköpings resecentrum. Meanwhile, in Figure 33 where direction Landogatan is studied, there are three different trip IDs that have the worst RMSE.

Afternoon peak

Direction Linköpings resecentrum

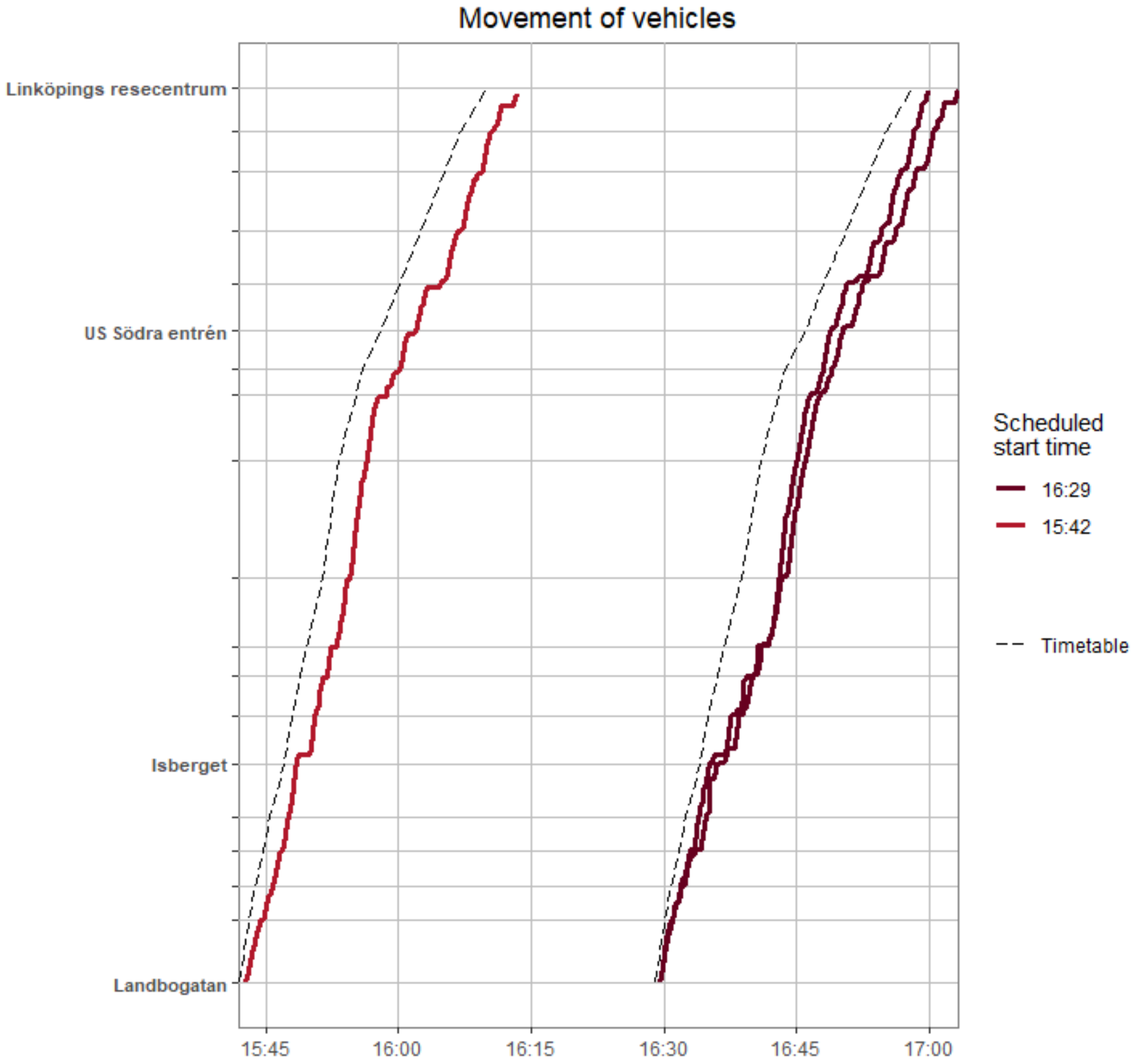

Figure 34 - Movement of the buses with the worst RMSE during the week in the afternoon peak, direction Linköpings resecentrum.

Direction Landbogatan

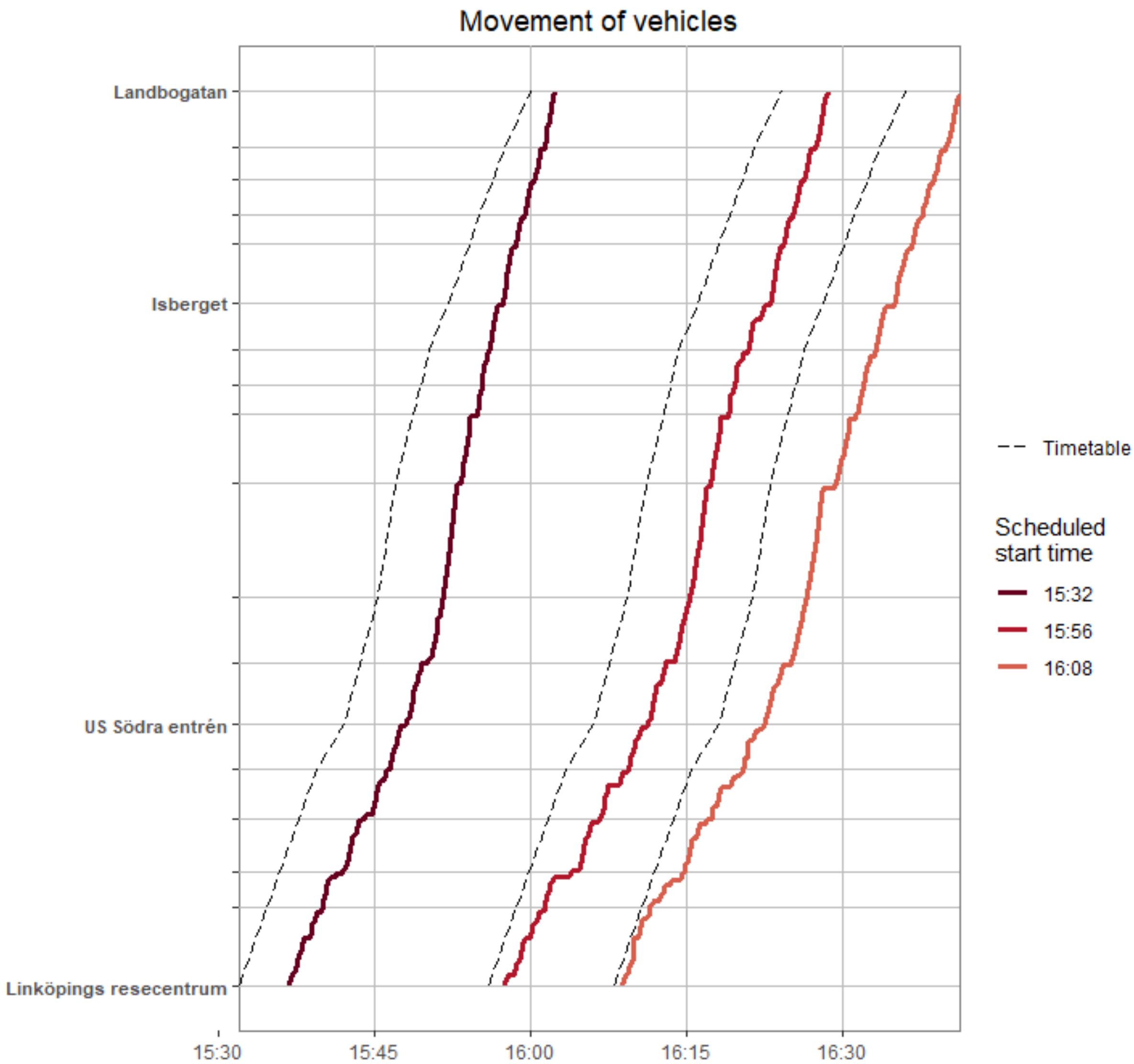

Figure 35 - Movement of the buses with the worst RMSE during the week in the afternoon peak, direction Landbogatan.

In the afternoon peak there is also a trip ID that is represented twice in the "Movement of vehicles" graph in direction Linköpings resecentrum, see Figure 34. However, in direction Landbogatan there are three different trip IDs represented, see Figure 35.

Table 9 gives the overall measure of delays to regulation stops, Figure 36-Figure 39 gives a more detailed picture. The average delay of the delayed trips at each regulation stop is marked with a blue point. The red bars start in the minimum delay and end in the maximum delay. Below each red bar, the number of delayed trips to each stop is displayed.

In Figure 36 the variation of delay at regulation stops for direction Linköpings resecentrum line 4 during morning peak can be seen. For all stops but the last, 33 trips were found. For Linköping Resecentrum, 21 trips were found. In Figure 37 the variation of delay for direction Landbogatan line 4 during morning peak can be seen. The total number of trips that were found at each stop was 29.

Morning peak

Direction Linköpings resecentrum

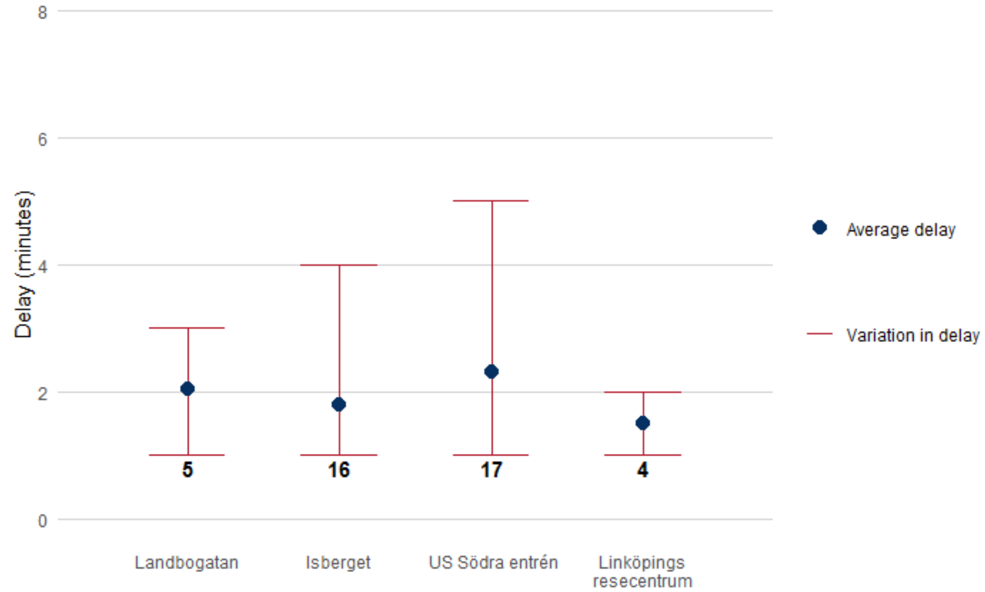

Figure 36 - Delay in direction Linköpings resecentrum during the morning peak.

Direction Landbogatan

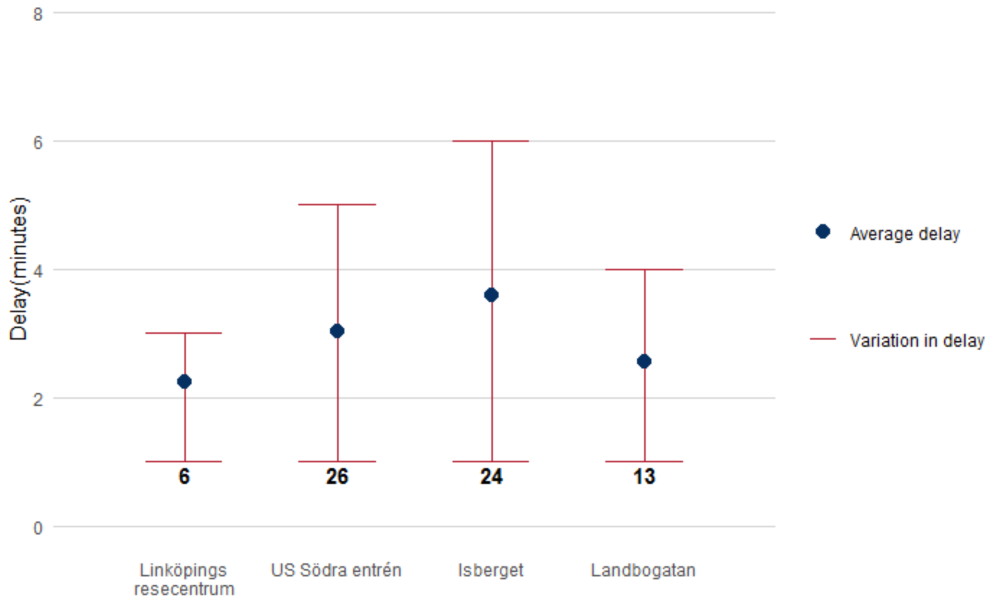

Figure 37 - Delay in direction Landbogatan during the morning peak.

In Figure 38 the variation of delay for direction Linköpings resecentrum bus line 4 during afternoon peak can be seen. The total number of trips that were found at each stop was, starting with Landbogatan, 51, 51, 49 and 31. In Figure 39 the variation of delay for direction Landbogatan for bus line 4 during afternoon peak can be seen. The total number of trips found at all the stops were 50.

Afternoon peak

Direction Linköpings resecentrum

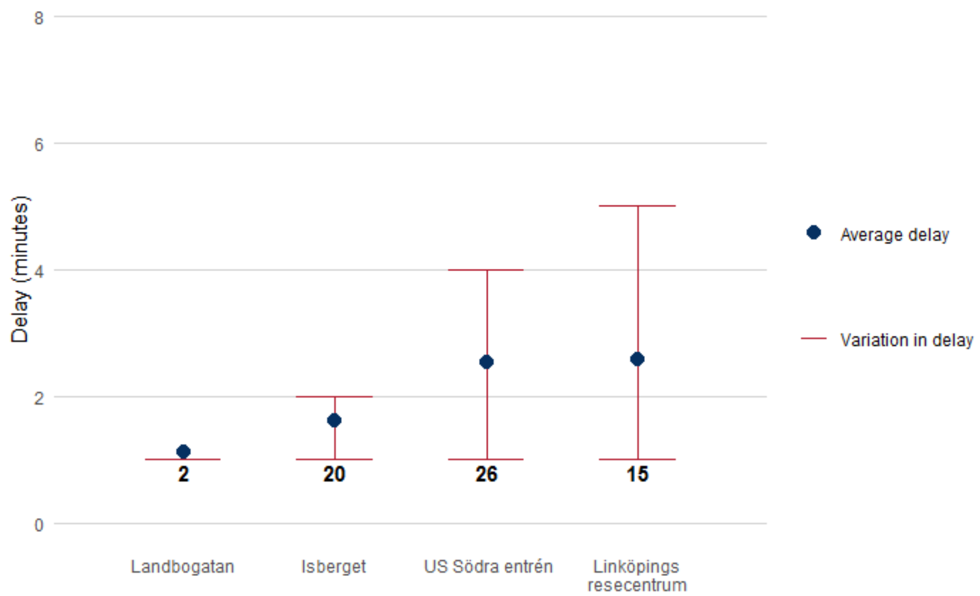

Figure 38 - Delay in direction Linköpings resecentrum during the afternoon peak.

Direction Landbogatan

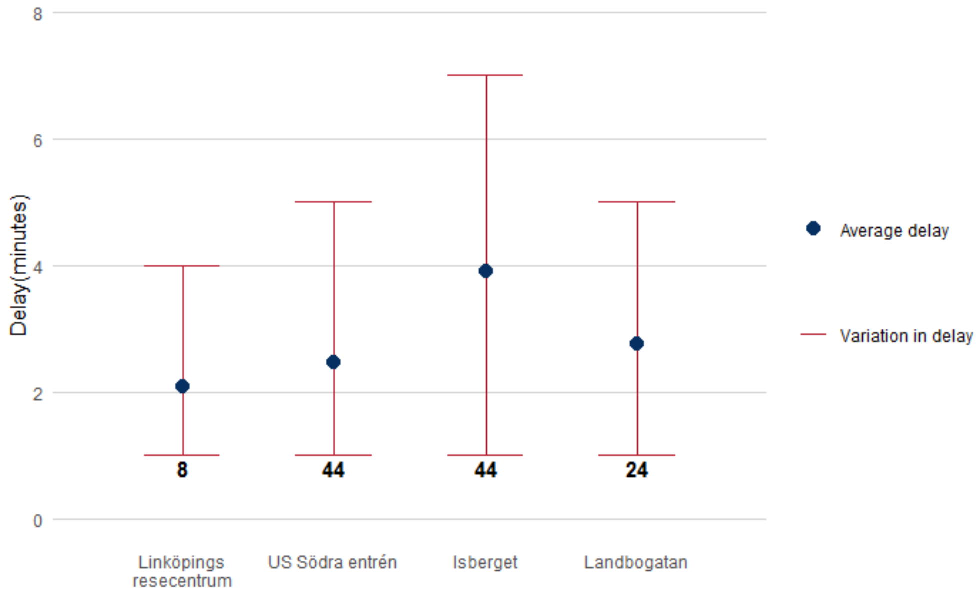

Figure 39 – Delay in direction Landbogatan during the afternoon peak.

Figure 40 and Figure 41 shows the travel time distribution for the both peaks. The number at each part of the bar shows the percentage of each part. As can be seen in Figure 40 and Figure 41, the travel time distribution is similar in the morning and afternoon peak. However, as Table 9 shows, there are more variation between the minimum and maximum for each part of the total travel time.

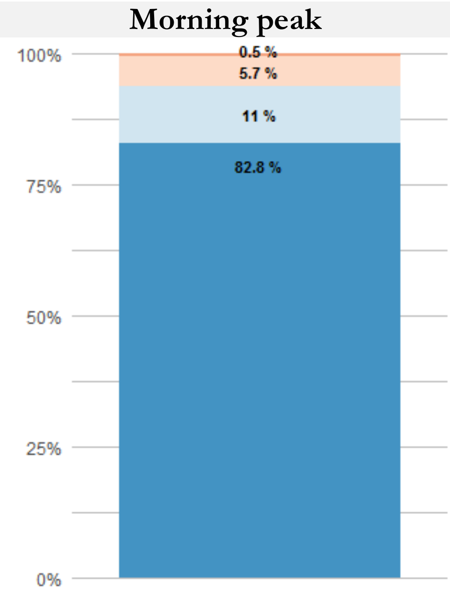

Figure 40 - Travel time distribution during the morning peak in both directions for bus line 4.

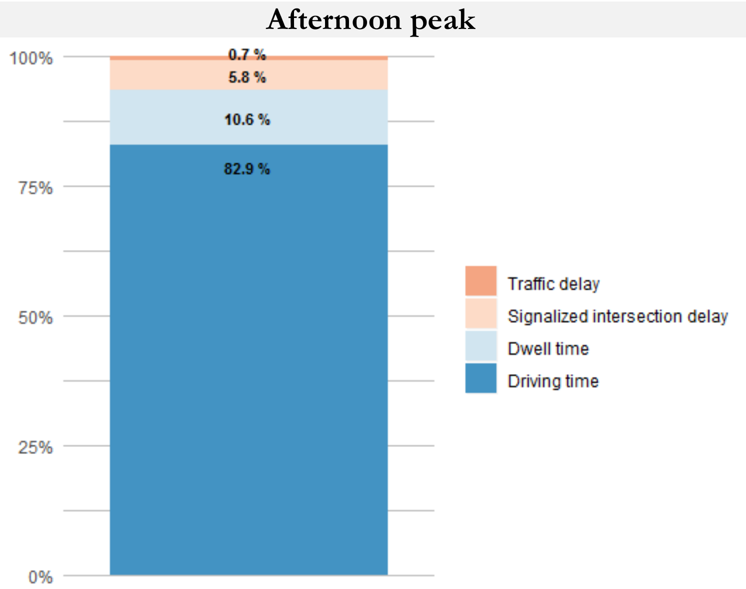

Figure 41 - Travel time distribution during the afternoon peak in both directions for bus line 4.

The table with the overall performance of bus line 4, Table 9 shows the result of each of the KPIs for the morning and afternoon peak. Both during the morning and afternoon peak, the line was running in two directions, the results in Table 9 are a summary of both directions. The table is divided into six parts for each of the KPIs low speed, average speed, delay, slack time, early departure and travel time distribution. For all KPIs but low speed, the average, minimum and maximum value is presented to show the variance of each KPI. As can be seen in Table 9, there are more problems with the LOS in the afternoon peak than in the morning peak during the studied week.

Table 9 - The overall performance of bus line 4.

KPI measure	Morning peak	Afternoon peak
Low speed		
Nr obs. with low speed	3 %	3 %
Low speed (MM:SS/vehicle)	00:31	00:42
Average speed		
Average speed (km/h)	19.36	18.69
Minimum average speed(km/h)	16.69	14.56
Maximum average speed(km/h)	21.80	22.35
Average speed without dwell time (km/h)	21.79	20.93
Minimum average speed without dwell time (km/h)	18.72	17.87
Maximum average speed without dwell time (km/h)	25.40	25.37
Nr vehicles with speed > speed goal	29 %	17 %
Nr vehicles with speed > speed based on timetable	55 %	50 %
Delay		
Average delay per trip at the last stop (MM:SS)	01:03	01:06
Share of trips at least one minute delayed to a regulation stop	47 %	48 %
Average delay at a regulation stop (MM:SS)	02:11	02:19
Minimum delay at a regulation stop (MM:SS)	01:00	01:00
Maximum delay at a regulation stop (MM:SS)	06:00	07:00
Slack time		
Share of trips with slack time at a regulation stop	32%	27%
Average slack time at a regulation stop (MM:SS)	01:46	01:49
Minimum slack time at a regulation stop (MM:SS)	01:00	01:00
Maximum slack time at a regulation stop (MM:SS)	03:00	05:00
Early departure		
Share of trips that departed early from a regulation stop	5%	6%
Average early departure from a regulation stop (MM:SS)	01:05	01:20
Minimum early departure from a regulation stop (MM:SS)	01:00	01:00
Maximum early departure from a regulation stop (MM:SS)	02:00	03:00
Travel time distribution		
Number of trips	62	101
Shortest dwell time	7%	5%
Average dwell time	11%	11%
Longest dwell time	20%	38%
Shortest traffic delay	0%	0%
Average traffic delay	1%	1%
Longest traffic delay	3%	6%
Shortest signalized intersection delay	0%	1%
Average signalized intersection delay	6%	6%
Longest signalized intersection delay	11%	14%
Shortest driving time	75%	61%
Average driving time	83%	83%
Longest driving time	91%	92%

7.2.2 Further investigation – Bus line 4

The area between the bus stops "Djurgården" and "Vallastadens skola" on Kunskapslänken was identified as a problem area regarding low speed based on the overall performance of bus line 4. Therefore, additional investigations were done in this area. The overall performance of bus line 4 on Kunskapslänken is shown in Table 10.

Table 10 - The overall performance for bus line 4 in the chosen area of Kunskapslänken.

KPI measure	Morning peak	Afternoon peak
Low speed (MM:SS/vehicle)	00:02	00:02
Average speed (km/h)	35.30	34.84
Minimum average speed (km/h)	23.23	23.41
Maximum average speed (km/h)	49.75	51.49
Nr obs. with low speed	2%	3%

Figure 42 and Figure 43 show the number of observations during morning respective afternoon peak where vehicles were driving at a low speed. It can be seen in Figure 42 and Figure 43 that there is a difference in the number of observations with low speed between the morning and afternoon peak. A possible reason for the increased number of observations with a low speed during the afternoon could be that there are more trips during the afternoon peak and more vehicles will pass Kunskapslänken.

Morning peak - Kunskapslänken

Figure 42 - Observations with low speed during the morning peak both directions.

Afternoon peak - Kunskapslänken

Figure 43 - Observations with low speed during the afternoon peak both directions.

The average speed for bus line 4 in the area of Kunskapslänken is presented in Figure 44 and Figure 45 below. Each bar represents a trip. The speed limit for this road is 60 km/h. It can be seen in the mentioned figures that this is never reached, and the highest average speeds are around 50 km/h.

Morning peak - Kunskapslänken

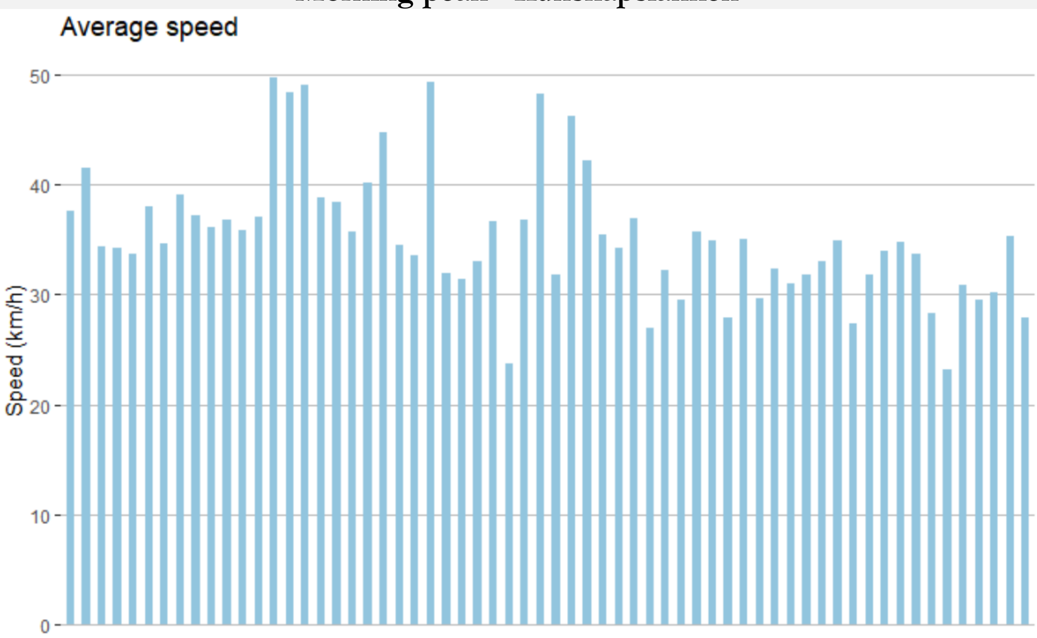

Figure 44 - Average speed during the morning peak for both directions.

Afternoon peak - Kunkapslänken

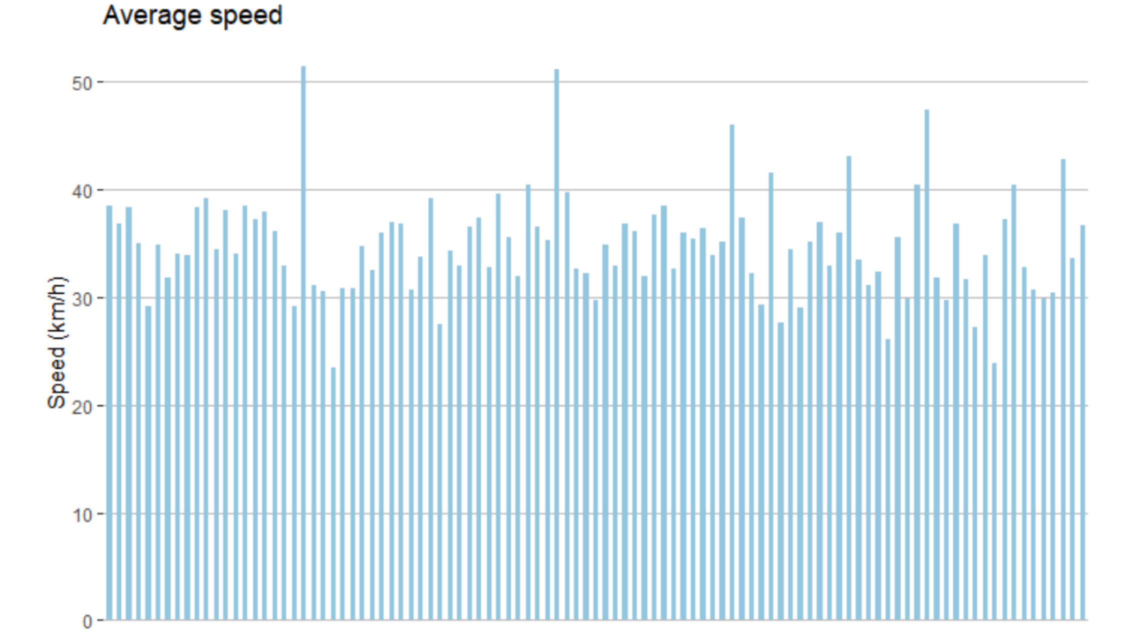

Figure 45 - Average speed during the afternoon peak for both directions.

When the signalized intersection delay was examined for this road segment, only two buses had stopped within 100 meters from the traffic signal for 3 respectively 1 second. The stops at Kunskapslänken are not regulation stops, therefore the punctuality for these stops was not examined.

There were two trips that for more than one day had the worst RMSE. Therefore, these two trips were investigated further. Table 11 shows the overall performance of these two trips, belonging to bus line 4.

Table 11 - The overall performance of the investigated trips.

KPI measure	08:04 direction Linköpings resecentrum	16:29 direction Linköpings resecentrum
Low speed		
Nr obs. with low speed	3%	4%
Low speed (MM:SS/vehicle)	00:36	00:45
Average speed		
Average speed (km/h)	18.90	17.46
Minimum average speed(km/h)	17.56	15.52
Maximum average speed(km/h)	20.49	19.58
Delay		
Delay per vehicle last stop (MM:SS)	01:20	1:15
Delay at all regulation stops	60%	56%
Average delay at a regulation stop (MM:SS)	02:34	2:43
Minimum delay at a regulation stop (MM:SS)	01:00	01:00
Maximum delay at a regulation stop (MM:SS)	5:00	05:00
Slack time		
Slack time at a regulation stop	13%	19%
Average slack time at a regulation stop (MM:SS)	01:00	01:40
Minimum slack time at a regulation stop (MM:SS)	01:00	01:00
Maximum slack time at a regulation stop (MM:SS)	01:00	02:00
Early departure		
Early departure from a regulation stop	0%	0%
Average early departure from a regulation stop (MM:SS)	-	-
Minimum early departure from a regulation stop (MM:SS)	-	-
Maximum early departure from a regulation stop (MM:SS)	-	-
Travel time distribution		
Shortest dwell time	9 %	8 %
Average dwell time	11 %	12 %
Longest dwell time	15 %	16 %
Shortest traffic delay	0 %	0 %
Average traffic delay	1 %	1 %
Longest traffic delay	1 %	1 %
Shortest signalized intersection delay	5 %	3 %
Average signalized intersection delay	6 %	7 %
Longest signalized intersection delay	8 %	9 %
Shortest driving time	78 %	74 %
Average driving time	82 %	80 %
Longest driving time	85 %	90 %

In Figure 46, Figure 47 and Figure 48, the average speed for each trip, observations where low speed is observed and the travel time distribution for vehicles driving the trip departing 08:04 to Linköpings resecentrum is presented.

Morning peak – 08:04 to Linköpings resecentrum

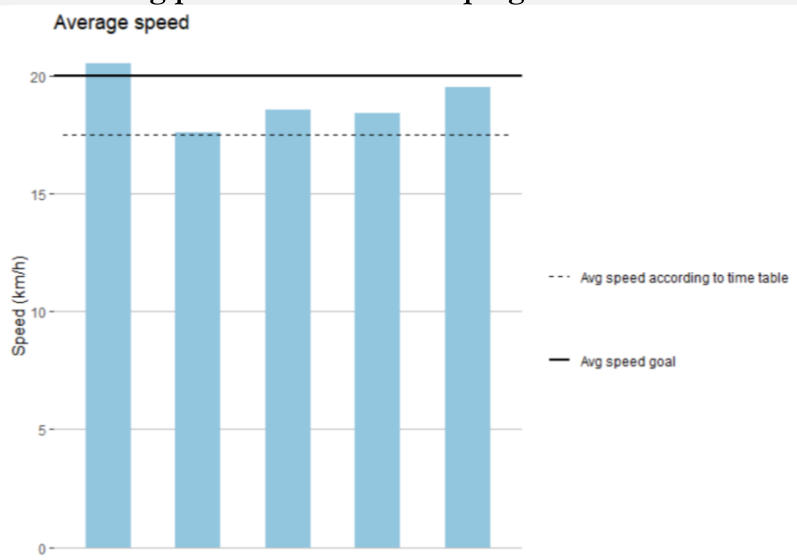

Figure 46 - Average speed during the morning peak for the trips departing to Linköpings resecentrum at 08:04.

Morning peak – 08:04 to Linköpings resecentrum

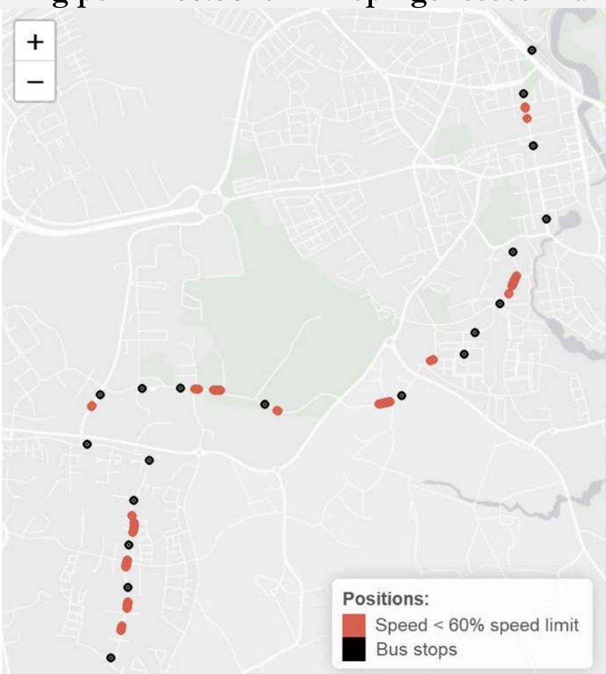

Figure 47 - Observations where a vehicle drove at a low speed during the morning peak for the trip departing to Linköpings resecentrum at 08:04.

Morning peak – 08:04 to Linköpings resecentrum

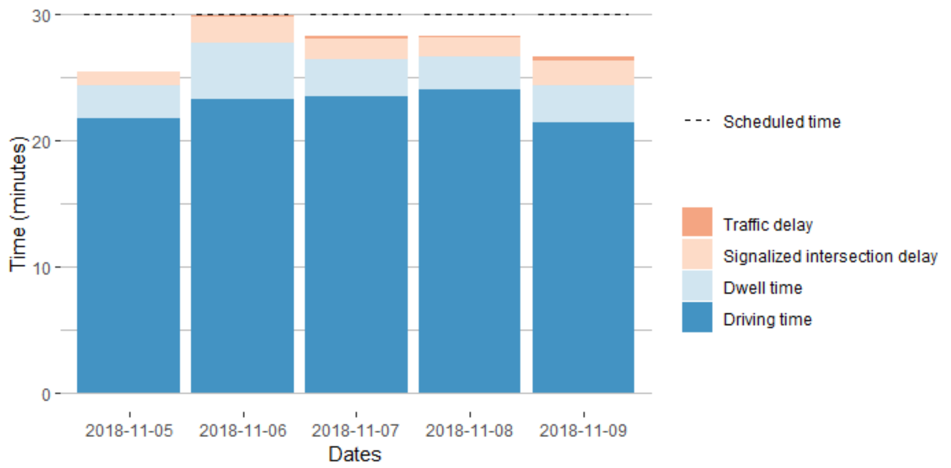

Figure 48 - Travel time distribution for the trips departing to Linköpings resecentrum at 08:04.

Figure 46 shows that the average speeds for this trip are at least equal to or above what the average speed should be according to the timetable. The positions where vehicles are driving at a low speed is generally similar to the places for the trip departing at 16:29 to Linköpings resecentrum. As can be seen in Figure 48, all the buses had the same or shorter travel time than the scheduled travel time.

Figure 49, Figure 50 and Figure 51 show the average speed for each trip, observations where low speed is observed and the travel time distribution for vehicles driving the trip departing at 16:29 to Linköpings resecentrum during the chosen time period.

Afternoon peak - 16:29 to Linköpings resecentrum

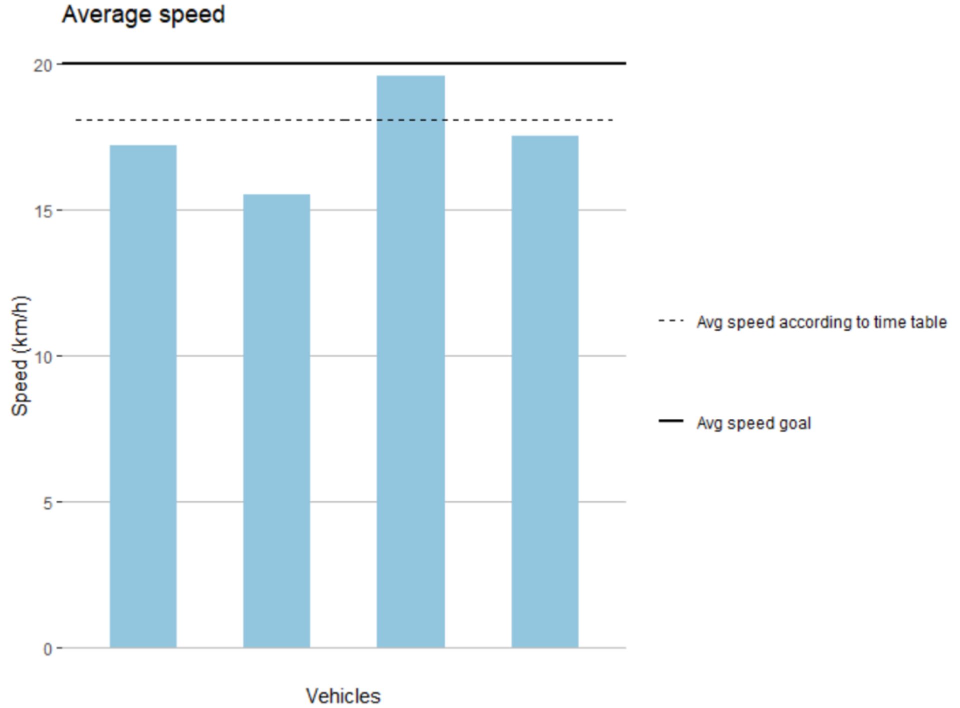

Figure 49 - Average speed for the trips departing to Linköpings resecentrum at 16:29.

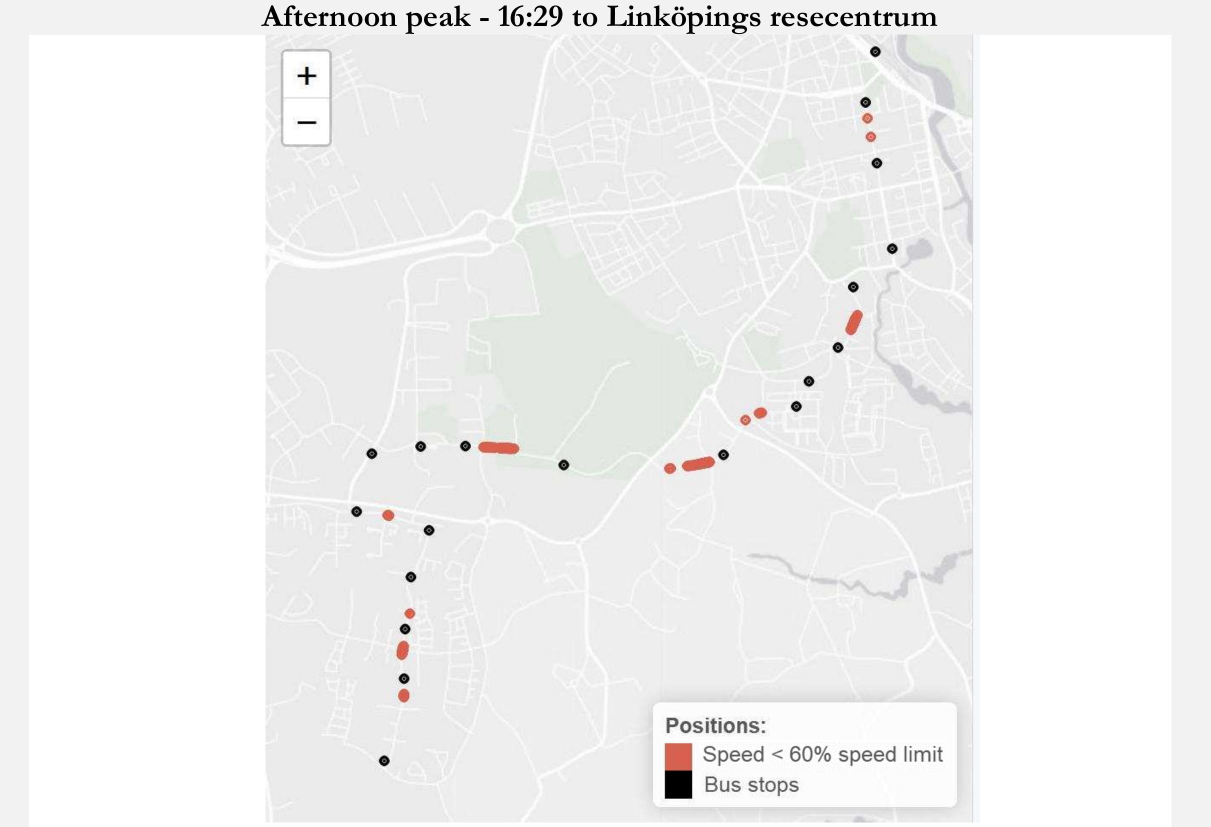

Figure 50 - Observations where a vehicle drove at low speed during the afternoon peak to Linköpings resecentrum.

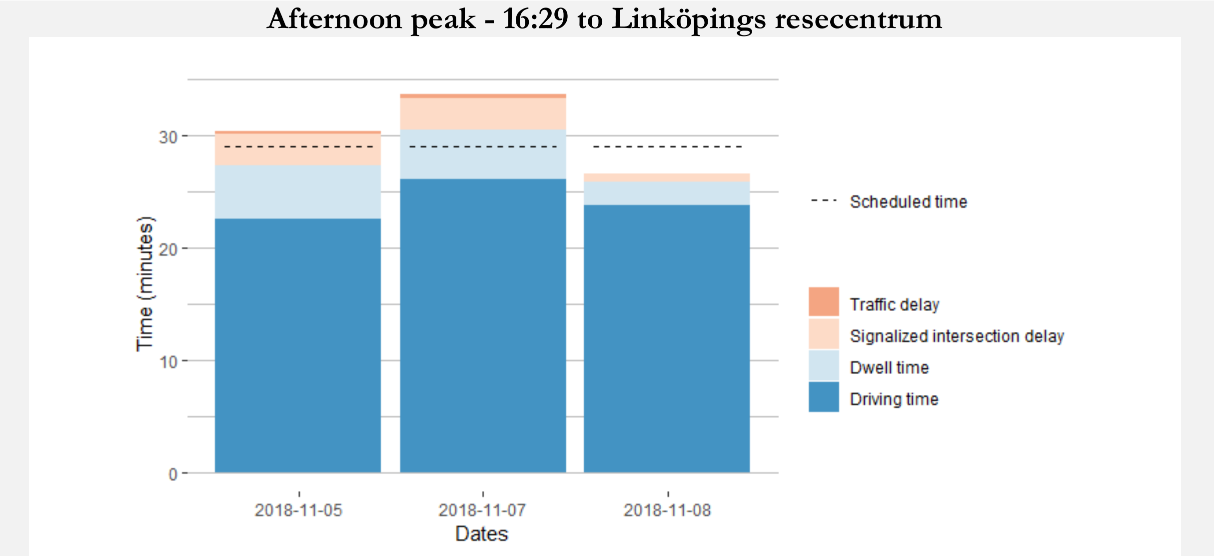

Figure 51 - Travel time distribution for the trips departing at 16:29 to Linköpings resecentrum.

It can be seen in Figure 49 that the speed is generally low compared to what it should be according to the timetable and the goal. Although, there are not that many segments where the speed is low, according to Figure 50. This means that there are areas where problems occur repeatedly. In Figure 51, two out of three trips had a longer travel time than the scheduled travel times. It looks like the trips on the 5th of November and 7th of November had a longer dwell time and spent more time in signalized intersections than the trip on the 8th of November that had a shorter travel time than the scheduled time.

7.3 Results for bus line 410

The subsections below include the overall LOS of the bus line 410 as well as a detailed investigation on specific parts of the bus line.

7.3.1 Overall LOS of bus line 410

The overall LOS of bus line 410 is described in Table 12 and Figure 62 - Figure 78. All of the results are based on data from the 5^{th} to 9^{th} of November and the morning and afternoon peak are defined as Table 8. The detailed results in both directions for bus line 410 can be found in Appendix 4.

Figure 52-Figure 54 shows the observations with slows speed during the morning peak for both directions. As can be seen in the figures, observations with a speed less than 60% of the speed limit are spread out through all of the route and only at a few segments no observations with low speed can be seen.

Morning peak

Norrköping

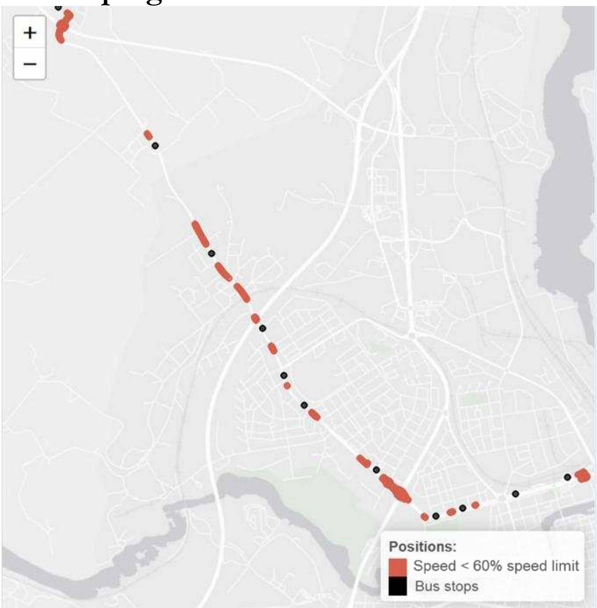

Figure 52 - Observations with low speed during morning peak in Norrköping.

Finspång

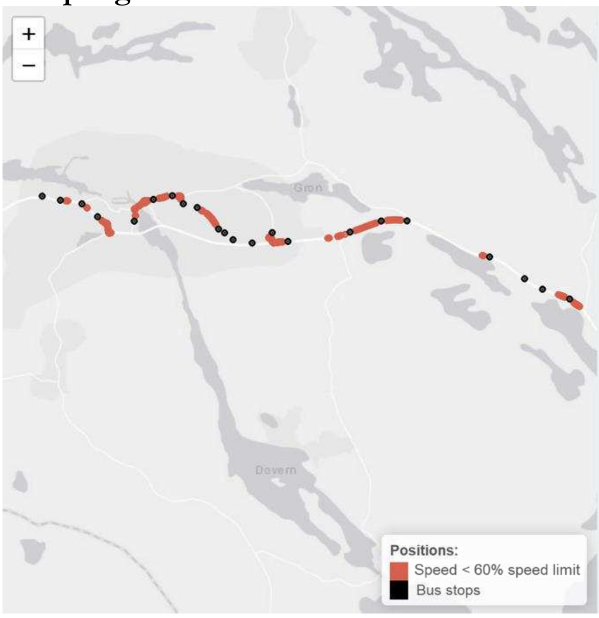

Figure 53 - Observations with low speed during morning peak in Finspång.

Svärtinge

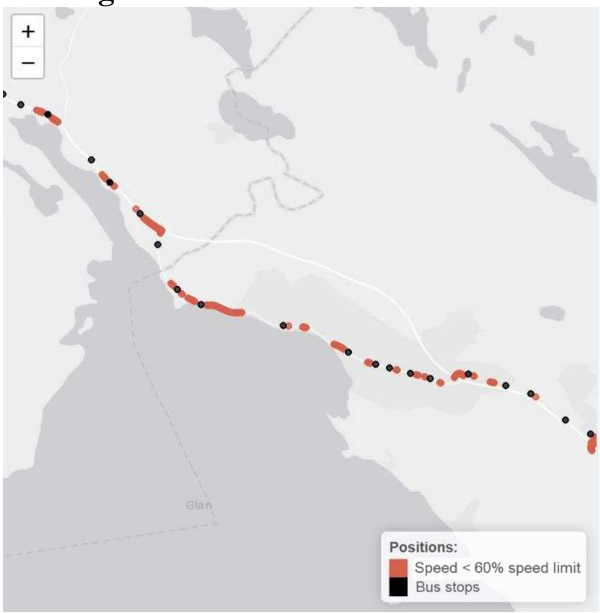

Figure 54 - Observations with low speed during morning peak in Svärtinge.

When comparing Figure 52-Figure 54 to Figure 55-Figure 57 it is evident that there are more observations with a low speed during the afternoon than during the morning peak. The increase in measured low speed is mainly in the area of Norrköping. One reason for the increased number of observations with a low speed during the afternoon could be the longer time period and consequently additional trips will be recorded.

Afternoon peak

Norrköping

Figure 55 - Observations with low speed during the afternoon peak in Norrköping.

Finspång

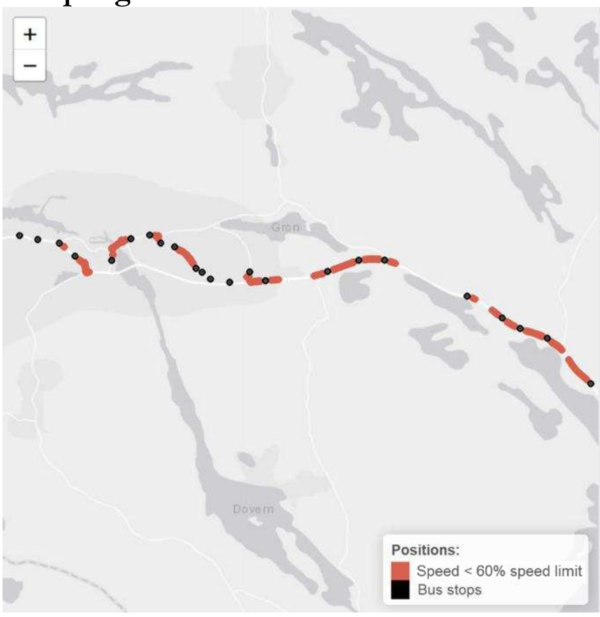

Figure 56 - Observations with low speed during the afternoon peak in Finspång.

Svärtinge

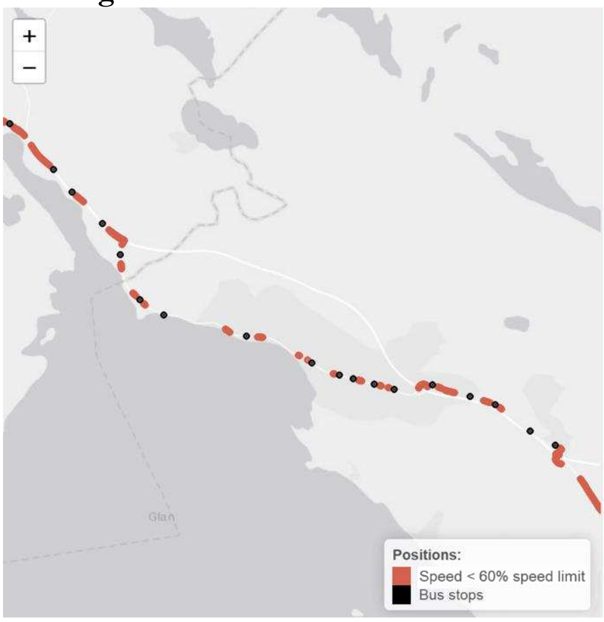

Figure 57 - Observations with low speed during the afternoon peak in Svärtinge.

Each bar in the graphs in Figure 58 and Figure 59, represents a trip driven by a vehicle one day. It can be seen in Figure 58 and Figure 59 that the average speed is always higher than the average speed goal set by the board. The number of vehicles that have an average speed above the average speed according to the timetable is however diverging. There is only one departure time in Figure 58 since that was the only trip that was completed within the studied time period.

Morning peak

Direction Norrköpings resecentrum

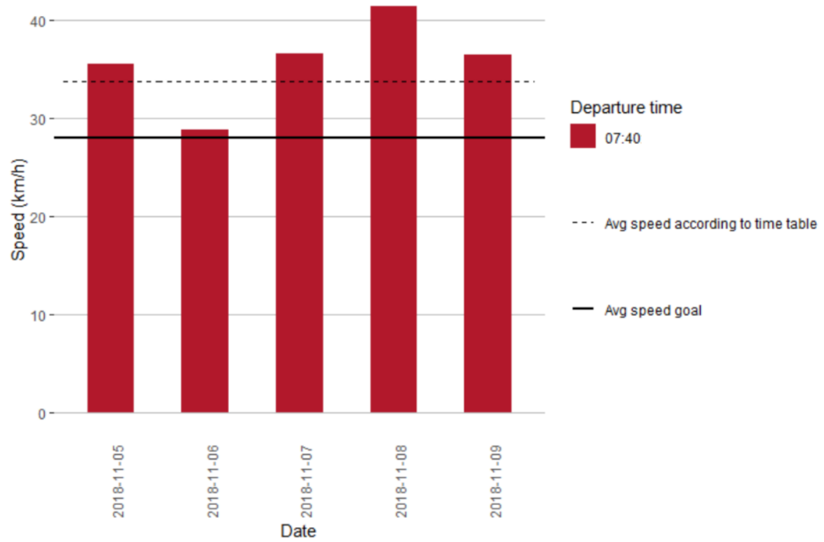

Figure 58 - Variation in average speed during morning peak in direction Norrköpings resecentrum.

Direction Mellangrind

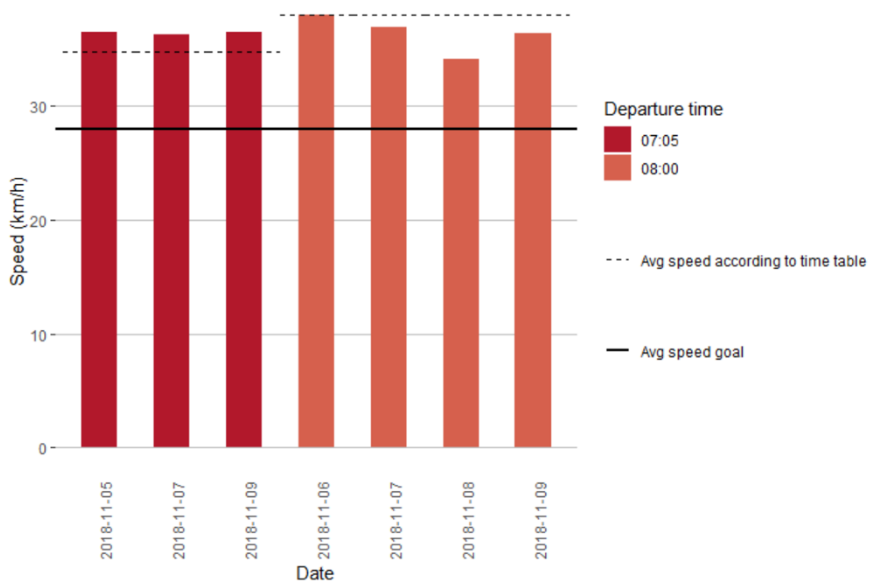

Figure 59 - Variation in average speed during morning peak in direction Mellangrind.

The average speed in the afternoon peak during the studied week was also above the average speed goal for all occurrences(trips). The majority of the occurrences still have an average speed below the timetable which can be seen in Figure 60 and Figure 61.

Afternoon peak

Direction Norrköpings resecentrum

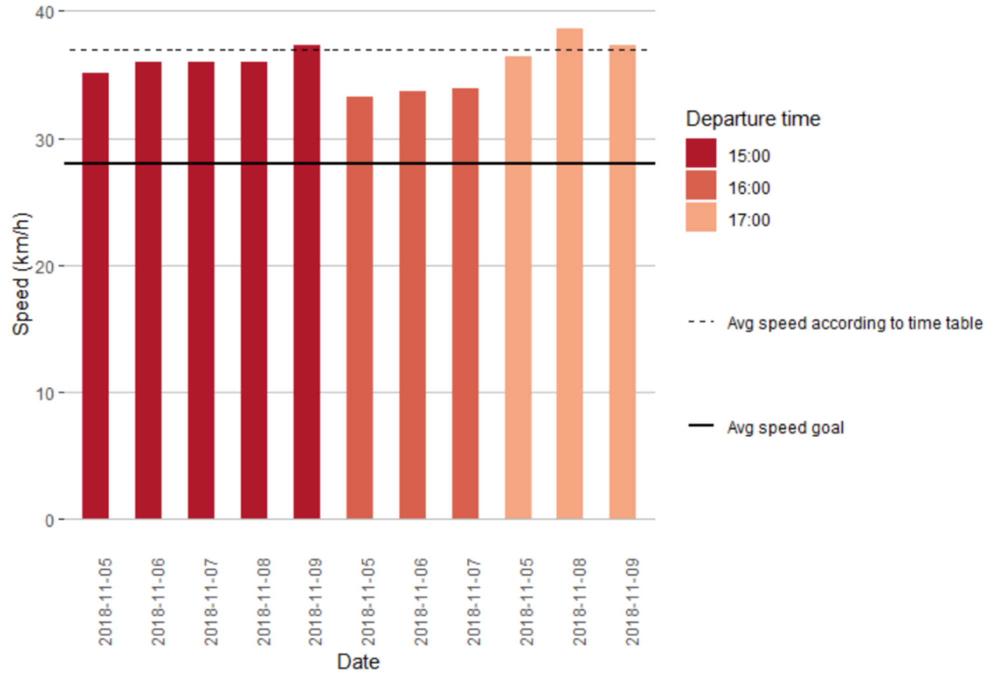

Figure 60 - Variation in average speed during afternoon peak in direction Norrköpings resecentrum.

Direction Mellangrind

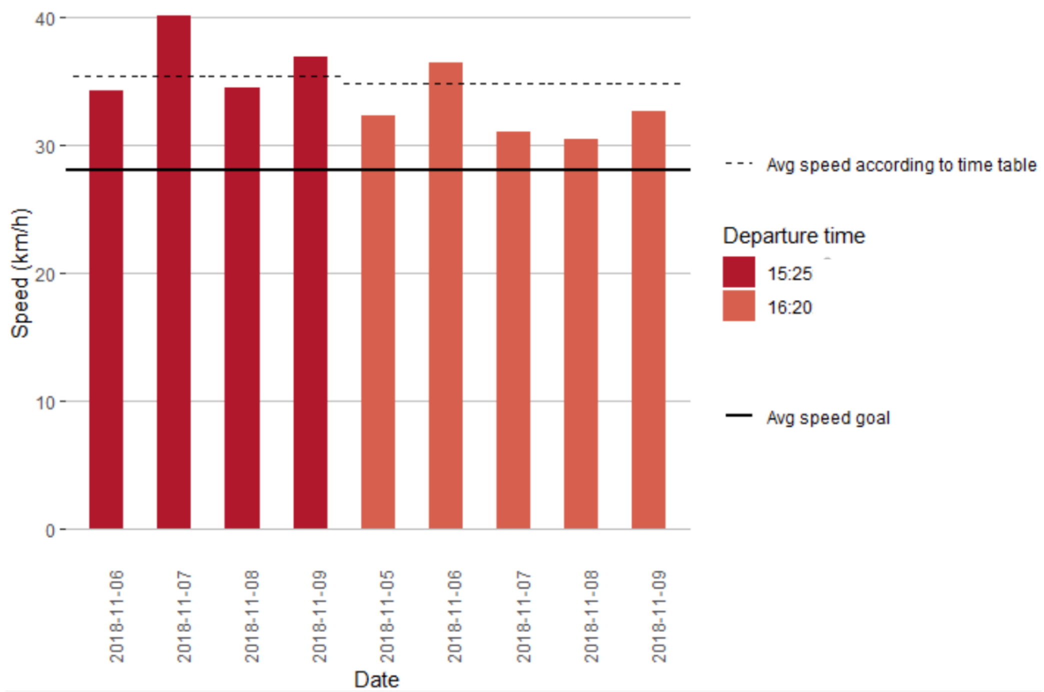

Figure 61 - Variation in average speed during afternoon peak in direction Mellangrind.

Figure 62 shows that the vehicles that have the worst RMSE during the morning peak in direction Norrköpings resecentrum, is still arriving almost on time to the last bus stop. It does not seem to be any big problems with LOS. Although, the trip that departure from Finspång at 07:40 is overrepresented, which indicates that during the morning peak in this direction this is the time period where LOS is the lowest. Figure 63 shows that there are not any problems with the LOS in this direction during the morning peak. The vehicles are following the timetable well.

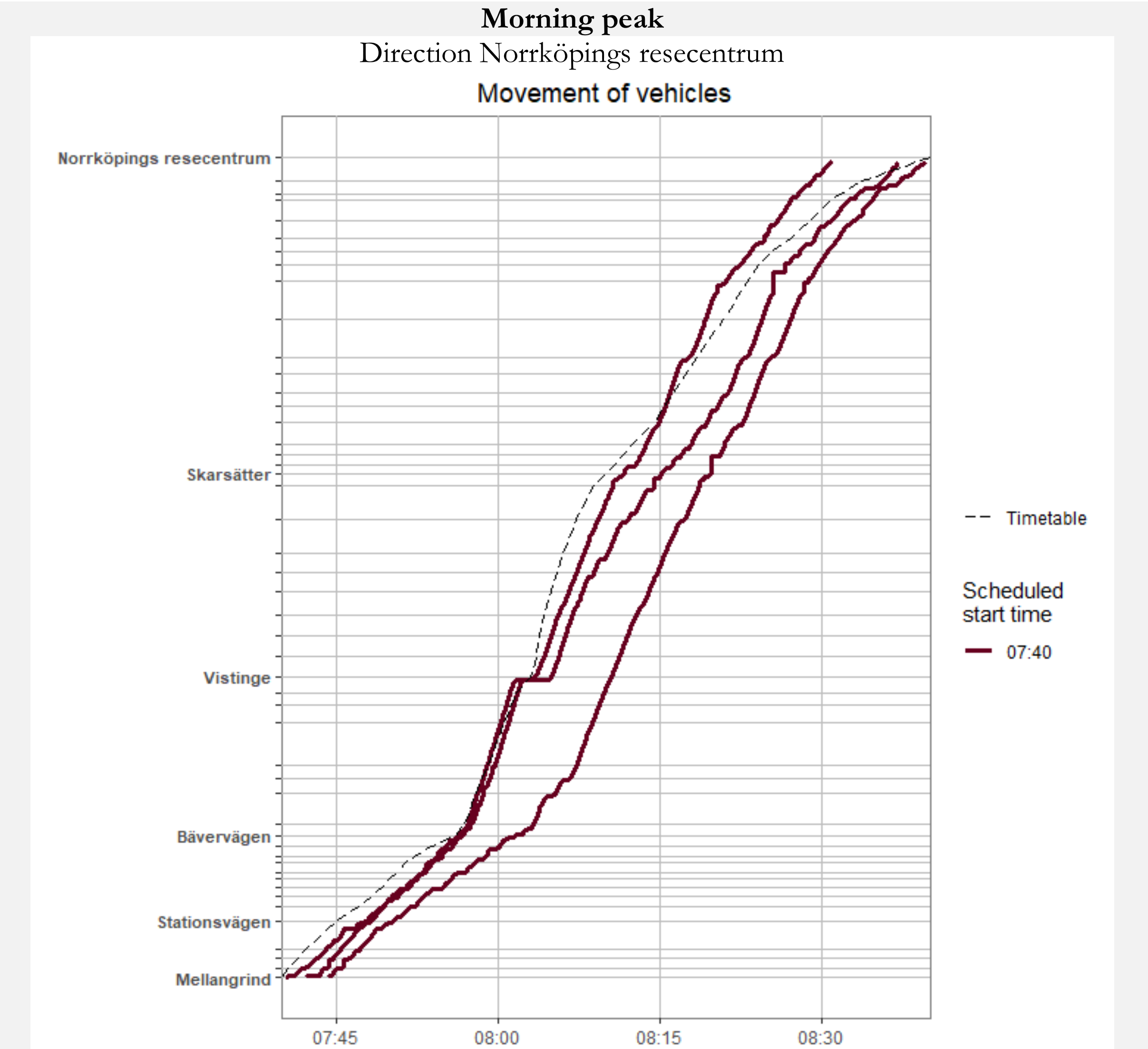

Figure 62 - Movement of vehicles during the morning peak in direction Norrköpings resecentrum.

Direction Mellangrind

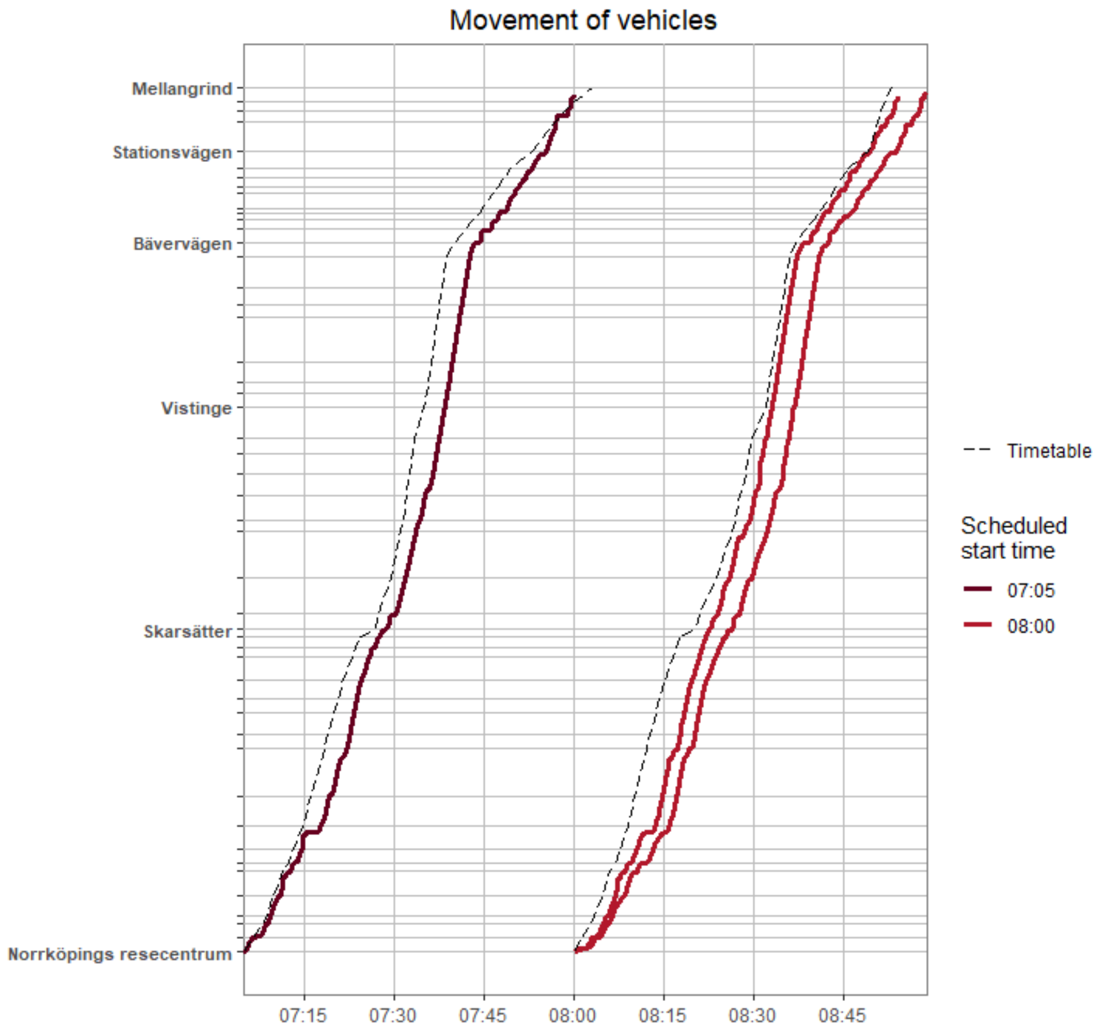

Figure 63 - Movement of vehicles during morning peak in direction Mellangrind.

Figure 64 and Figure 65 show that the LOS is decreased in the afternoon peak when comparing to the morning peak. It seems like the trips that are departing around 16:00 in both directions have problems with the LOS.

Afternoon peak

Direction Norrköpings resecentrum

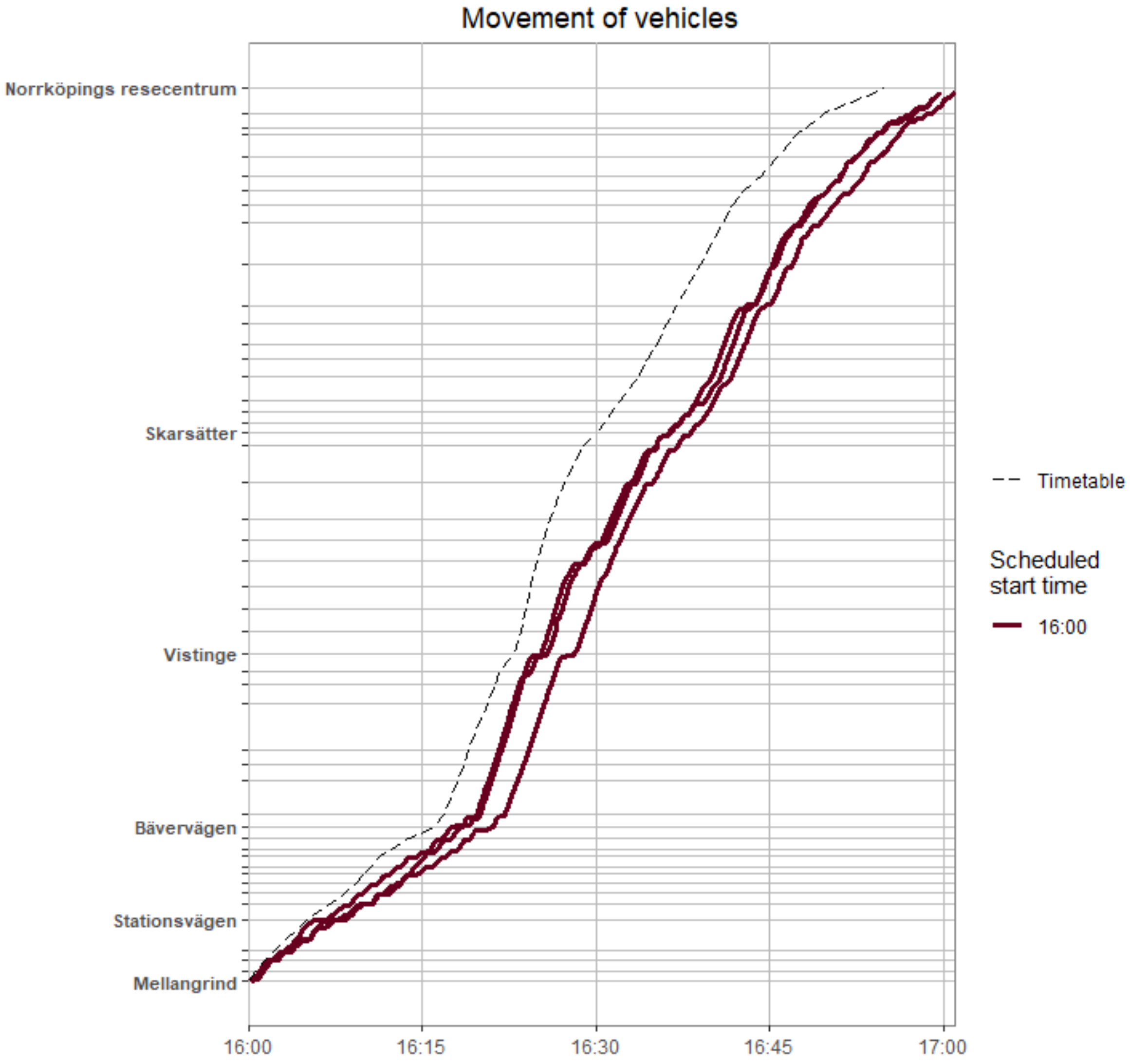

Figure 64 - Movement of vehicles during afternoon peak in direction Norrköpings resecentrum.

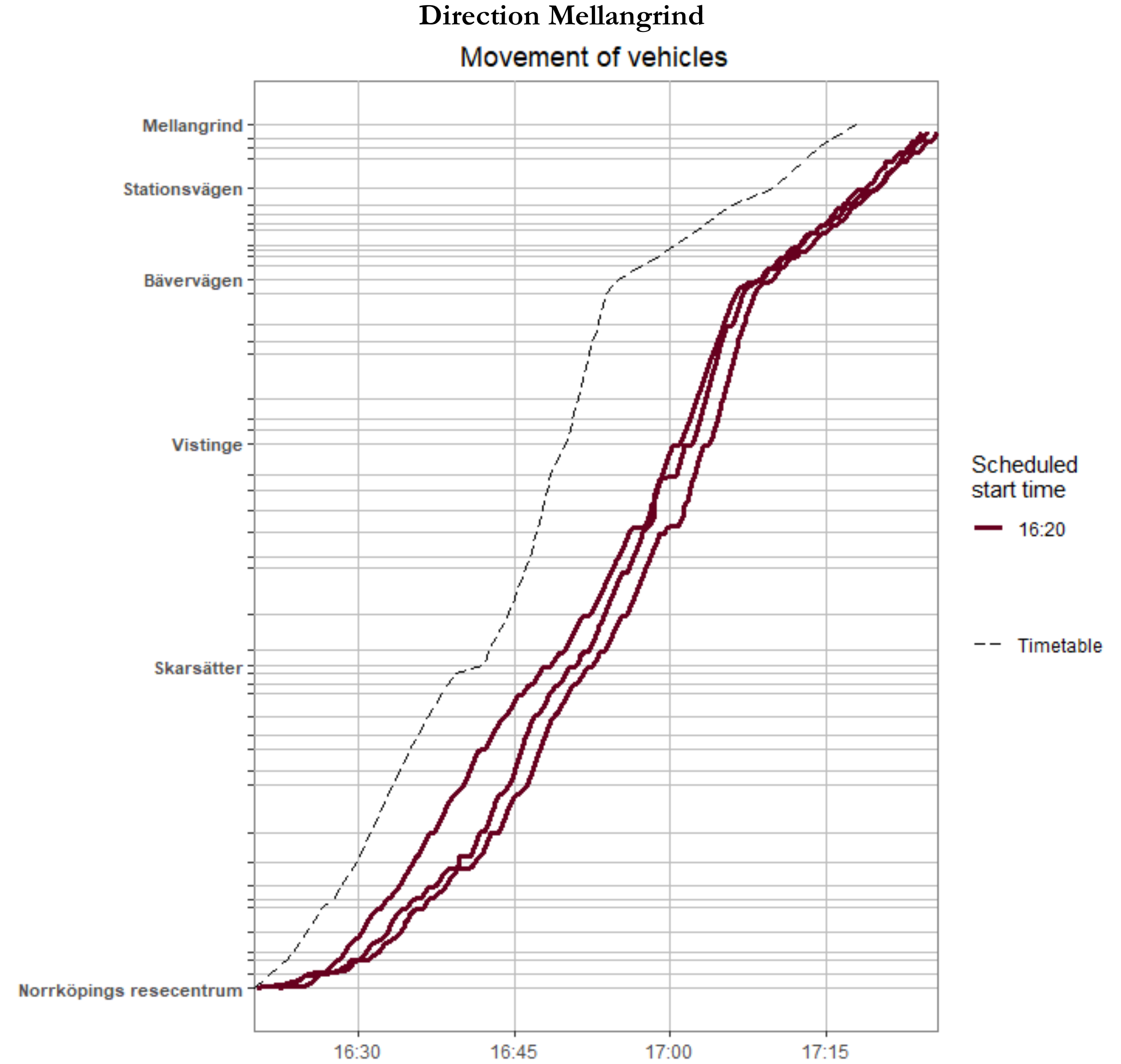

Figure 65 - Movement of vehicles during afternoon peak in direction Mellangrind.

Figure 66 and Figure 67 shows the delay at each regulation stop in direction Norrköpings resecentrum and Mellangrind during the morning peak. The number at the bottom of each bar shows how many trips that were delayed at each stop. The average delay is calculated before rounding down to whole minutes, hence the average delay at Vistinge is higher than the maximum delay. No trips were delayed to the last stop Norrköping resecentrum even though several trips were delayed during the trip and even started late. In the opposite direction, direction Mellangrind, three trips were delayed to the last stop Mellangrind. No trips started early although several trips got delayed during the trip.

Morning peak

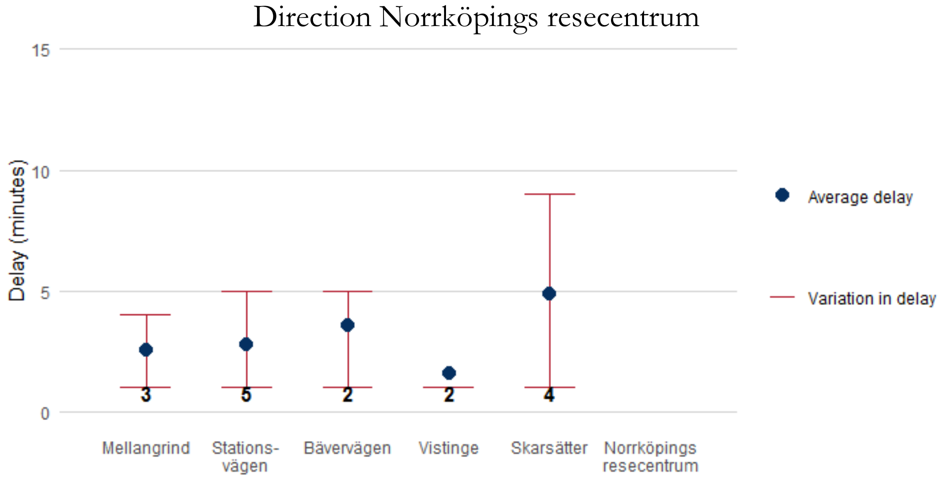

Figure 66 - Delays during the morning peak on bus line 410, direction Norrköpings resecentrum. The numbers below the bars describe how many trips that were delayed at each stop.

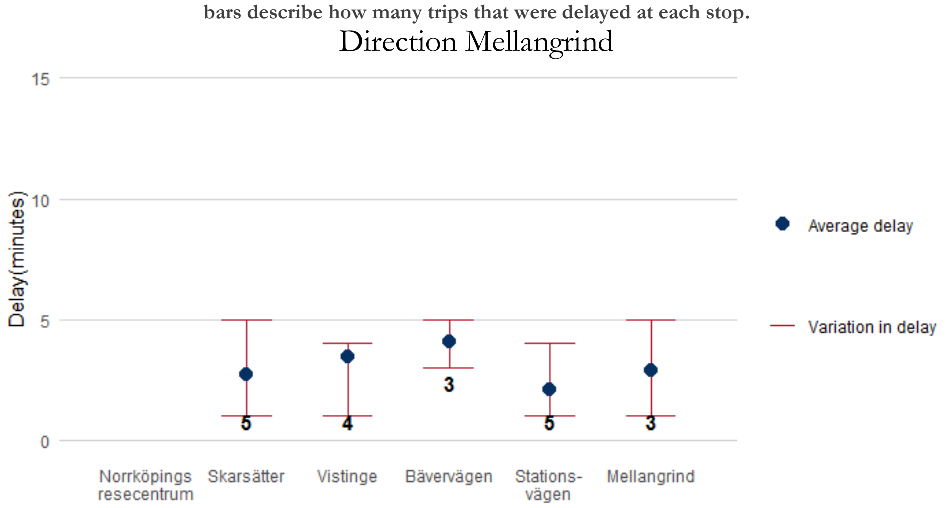

Figure 67 - Delays during the morning peak on line 410, direction Mellangrind. The numbers below the bars describe how many trips that were delayed at each stop.

In contrast to the result in Figure 66, Figure 68 shows that seven trips were delayed to Norrköping resecentrum during the afternoon peak. At the stop Skarsätter, all eleven trips were delayed at least one minute. In Figure 69, the delays at each stop in direction Mellangrind during the afternoon peak can be seen. In total, there were nine trips during this time period. Four of those nine trips were delayed at least one minute to the last stop Mellangrind. At three stops, the maximum delay was ten minutes or more.

Afternoon peak

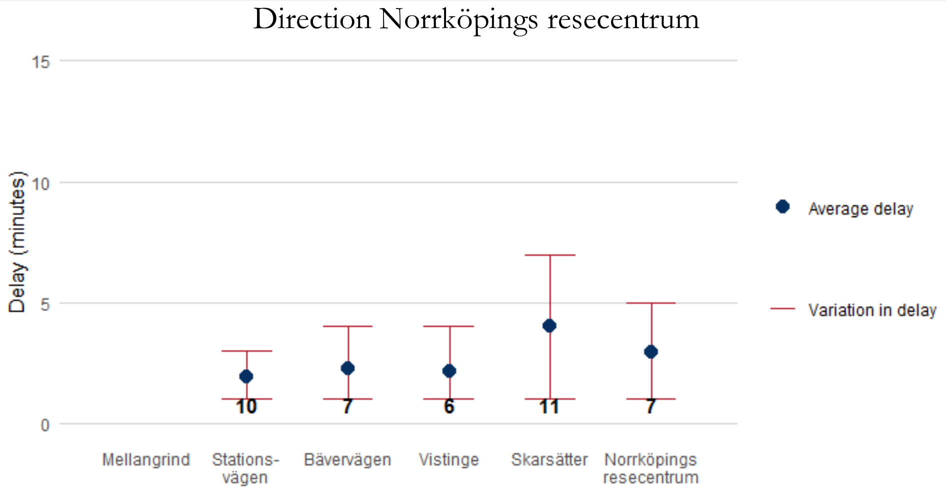

Figure 68 - Delays during the afternoon peak on bus line 410, direction Norrköpings resecentrum. The numbers below the bars describe how many trips that were delayed at each stop.

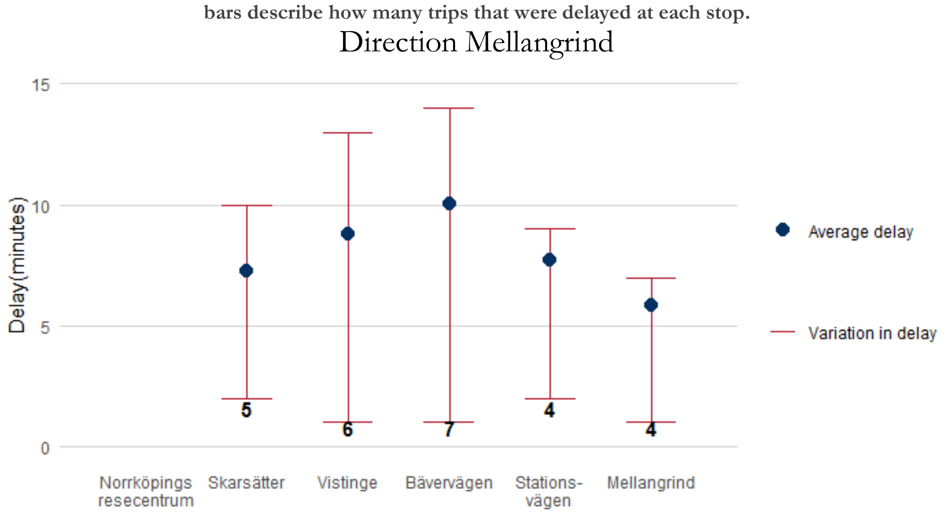

Figure 69 - Delays during the afternoon peak on bus line 410, direction Mellangrind. The numbers below the bars describe how many trips that were delayed at each stop.

The travel time distribution for the bus line 410 was about the same for the morning peak and afternoon peak, as Figure 70 and Figure 71 shows. However, when studying each direction for the two time-periods, more variations can be seen. In the afternoon, the dwell time is 10% of the total time in direction Mellangrind and only 4.6% in direction Norrköpings resecentrum. In direction Norrköpings resecentrum during the afternoon, the share of signalized intersection delay and traffic delay is higher than for direction Mellangrind.

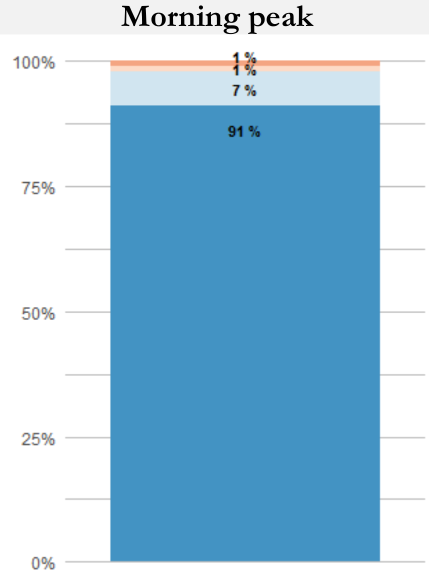

Figure 70 - Travel time distribution for bus line 410 during the morning peak, both directions.

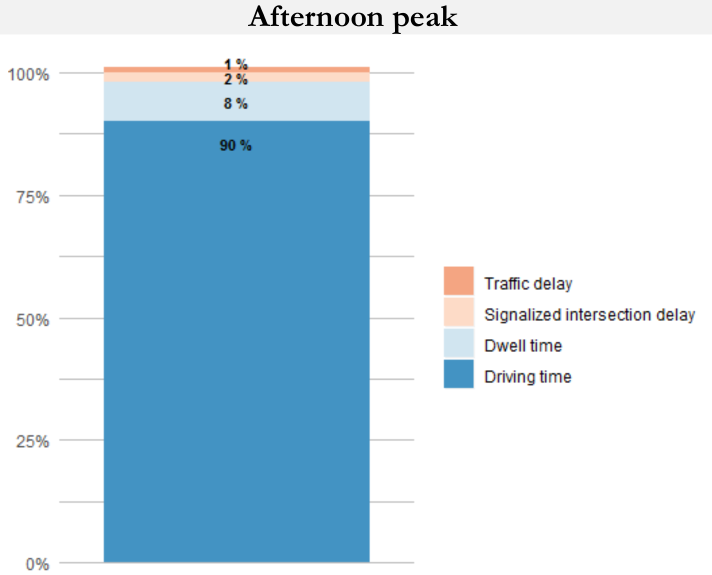

Figure 71 - Travel time distribution for bus line 410 during the afternoon peak, both directions.

Table 12 gives the overall results for bus line 410 for the morning and afternoon peak for both directions. The table shows the average, minimum and maximum of each KPI but low speed. As can be seen, there was more variations and generally worse results in the afternoon.

Table 12 - The values of each KPI measure for 410 for the examined week.

KPI measure	Morning peak	Afternoon peak
Low speed		
Nr obs. with low speed	10%	11%
Low speed (MM:SS/vehicle)	04:09	04:41
Average speed		
Average speed (km/h)	36.11	35.10
Minimum average speed(km/h)	28.84	30.40
Maximum average speed(km/h)	41.50	40.12
Average speed without dwell time (km/h)	38.80	37.92
Minimum average speed without dwell time (km/h)	30.54	31.63
Maximum average speed without dwell time (km/h)	44.26	41.76
Nr vehicles with speed > speed goal	100%	100%
Nr vehicles with speed > speed based on timetable	67%	30%
Delay		
Average delay per trip at the last stop (MM:SS)	01:24	02:24
Share of trips at least one minute delayed to a regulation stop	55 %	57 %
Average delay at a regulation stop (MM:SS)	02:37	04:11
Minimum delay at a regulation stop (MM:SS)	01:00	01:00
Maximum delay at a regulation stop (MM:SS)	09:00	14:00
Slack time		
Share of trips with slack time at a regulation stop	32 %	17 %
Average slack time at a regulation stop (MM:SS)	02:06	02:24
Minimum slack time at a regulation stop (MM:SS)	01:00	01:00
Maximum slack time at a regulation stop (MM:SS)	09:00	08:00
Early departure		
Share of trips that departed early from a regulation stop	9 %	15 %
Average early departure from a regulation stop (MM:SS)	01:00	01:53
Minimum early departure from a regulation stop (MM:SS)	01:00	01:00
Maximum early departure from a regulation stop (MM:SS)	01:00	08:00
Travel time distribution		
Number of trips	12	20
Shortest dwell time	4 %	3 %
Average dwell time	7 %	8 %
Longest dwell time	12 %	13 %
Shortest traffic delay	0 %	0 %
Average traffic delay	1 %	1 %
Longest traffic delay	3 %	4 %
Shortest signalized intersection delay	0 %	0 %
Average signalized intersection delay	1 %	2 %
Longest signalized intersection delay	2 %	4 %
Shortest driving time	85 %	84 %
Average driving time	91 %	90 %
Longest driving time	95 %	96 %

7.3.2 Further investigation – Bus line 410

When studying the tables and figures in subsection 7.3.1, they indicate that there is a problem with the LOS around 16:00 in both directions. It was therefore decided to perform a more detailed analysis of the trips that were operating during this time period. The trip that had the worst LOS from Finspång was departing 16.00 from Mellangrind, meanwhile, the trip that had the worst LOS from Norrköping was departing 16:20 from Norrköpings resecentrum.

Figure 72 describes how bus line 410 can be divided into subsegments based on the placement of the regulation stops. The colors represent the different subsegments.

Figure 72 - Bus line 410 divided into subsections based on regulation stops.

The deviation from the timetable compared to the reality is shown in Table 13. The trips that are studied are the trips that deviated the most from the timetable respectively the trip that deviated the least. The trips with departure time 16:00 on the 5th, 6th and 7th of November in Table 13 are those trips that deviated the most from the timetable. The trip departing at 17:00 the 9th of November was closest to the scheduled time between Vistinge and Skatsätter. The table shows that the subsegments where the actual time is deviating the most from the timetable is between Vistinge and Skarsätter.

Table 13 - Deviation from timetable (MM:SS) in each subsegment.

Departure day and time from Mellangrind	Mellangrind - Stationsvägen	Stationsvägen - Bävervägen	Bävervägen - Vistinge	Vistinge - Skarsätter	Skarsätter - Norrköping
5/11 16:00	+2:12	+1:55	-0:42	+3:18	-1:56
6/11 16:00	+1:32	-0:07	+0:30	+3:29	-0:54
7/11 16:00	+1:35	-0:17	-0:49	+4:26	-1:28
8/11 17:00	-0:45	+0:35	NA	+0:30	-1:55

Figure 73 shows how the travel time was distributed for the concerned trips where the different colors represents the different parts of the travel time. The dashed line represents the scheduled travel time and the numbers shows the percent of each part. As can be seen, none of the trips kept the time in the time table. The dwell time for the trip carried out on the 7th of November have a larger share of dwell time than the average dwell time.

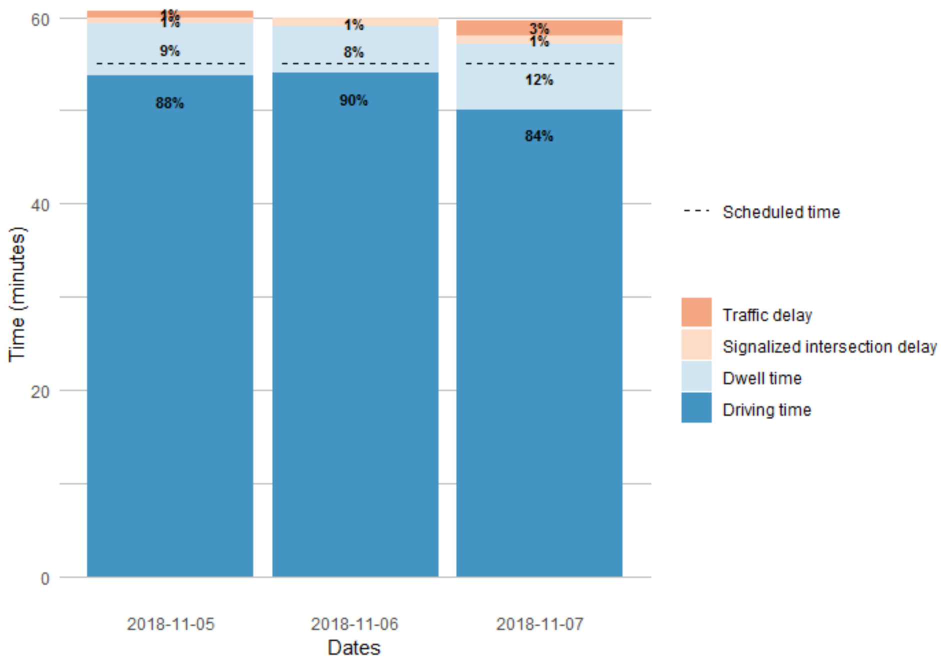

Figure 73 - Travel time distribution for the concerned trips.

Since the subsegment between Vistinge and Skarsätter deviated the most from the timetable, observations with low speed for this subsegment was examined, see Figure 74.

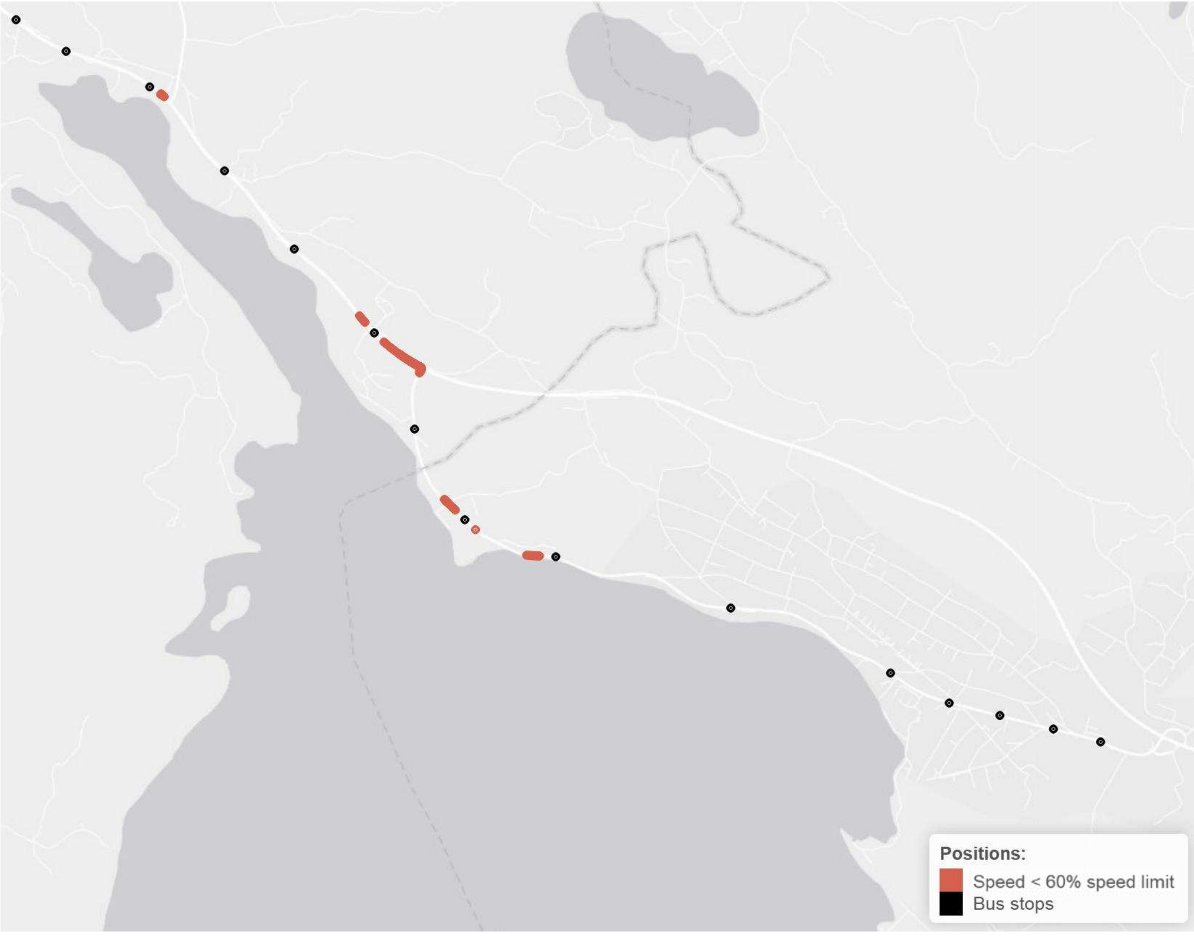

Figure 74 - Observations with low speed for the concerned trips.

To find a possible cause of the variations from the scheduled travel time at the sub section between Vistinge and Skarsätter, the average speed and the dwell time for the area was studied. As Table 14 shows, the average speed was significantly higher for the best trip at this part of the journey. The dwell time was a bit shorter than for the worst trips. However, the shorter dwell time cannot completely explain the variations in travel time.

Table 14 - Average speed and total dwell time for the investigated area for the concerned trips.

Date and time	Average speed (km/h)	Total dwell time in the area (MM:SS)
5/11 16:00	50.66	0:58
6/11 16:00	49.68	1:02
7/11 16:00	45.60	1:10
9/11 17:00	62.76	0:35

Then the same analysis was performed for the opposite direction, departing from Norrköping. The trips with departure time 16:20 and that was carried out the 5th, 7th and 8th of November deviated the most. The trip with the same departure time on the 6th of November was closest to the scheduled travel time in the subsegment. The travel time deviation compared to the timetable is presented in Table 15.

Table 15 - Deviation from timetable in each subsegment.

Departure day and time from Norrköping	Norrköping - Skarsätter	Skarsätter - Vistinge	Vistinge - Bävervägen	Bävervägen – Stationsvägen	Stationsvägen - Mellangrind
5/11 16:20	+7:46	+3:16	+1:12	-4:57	-2:20
6/11 16:20	+0:18	+3:36	+1:38	-6:54	-1:54
7/11 16:20	+9:58	+3:14	+1:02	-5:03	-3:04
8/11 16:20	+5:40	+4:25	+2:41	-3:62	-1:37

Figure 75 shows how the travel time was distributed for the concerned trips, that deviated the most from the timetable for this subsegment.

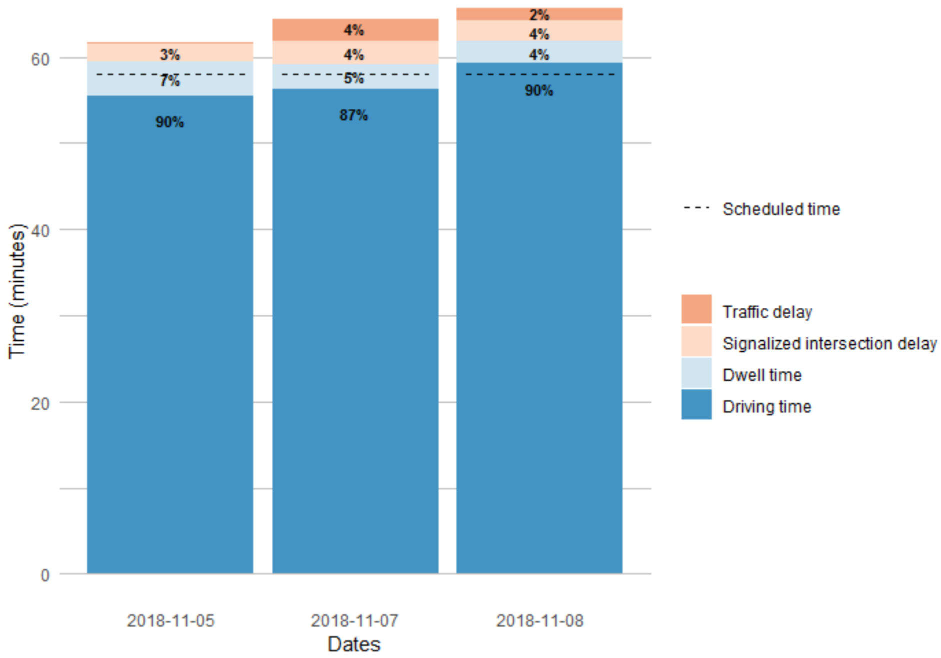

Figure 75 - Travel time distribution for the concerned trips.

In Figure 76 observations where the speed was lower than 50% of the speed limit on the road are displayed for the trips departing from Norrköping 16:20 5th, 7th and 8th of November 2018. This figure is indicating the road segments where the bus is driving at a speed lower than 50% of the speed limit on the road.

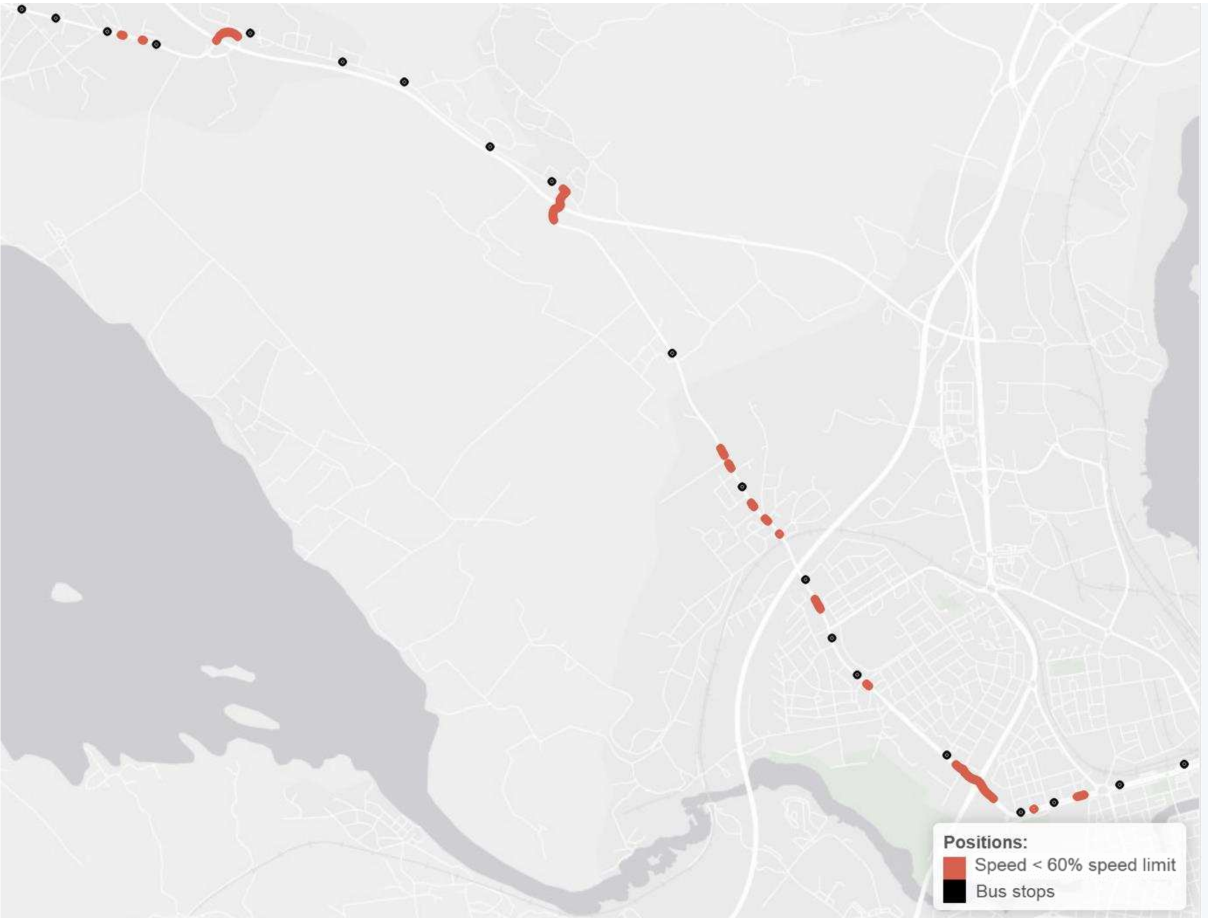

Figure 76 - Observations with low speed for the trips mentioned above.

Table 16 shows the average speed and dwell time at the segment between Norrköping resecentrum and Skarsätter since this part of the journey had the largest deviations from the scheduled travel time. The trip on the 6th of November had the shortest dwell time and a significantly higher average speed. The shorter dwell time cannot explain the total deviation which for one trip was almost 10 minutes. The main reason seems to be the average speed.

Table 16 - Average speed and total dwell time for the investigated area for the concerned trips.

Date and time	Average speed (km/h)	Total dwell time in the area (MM:SS)
5/11 16:20	26.40	2:07
6/11 16:20	33.58	0:40
7/11 16:20	23.46	1:20
8/11 16:20	26.73	1:18

Figure 77 and Figure 78 shows the delay per trip during the morning and afternoon peak for both directions. In contrast to the results in Figure 66-Figure 69 that shows the average delay per delayed trip, Figure 77 and Figure 78 shows the average delay per trip. During the morning peak, Skarsätter had the worst results for direction Norrköpings resecentrum, which was also shown in Figure 66. For direction Mellangrind, Bävervägen has the highest delay per vehicle which is not as obvious in Figure 67.

Morning peak

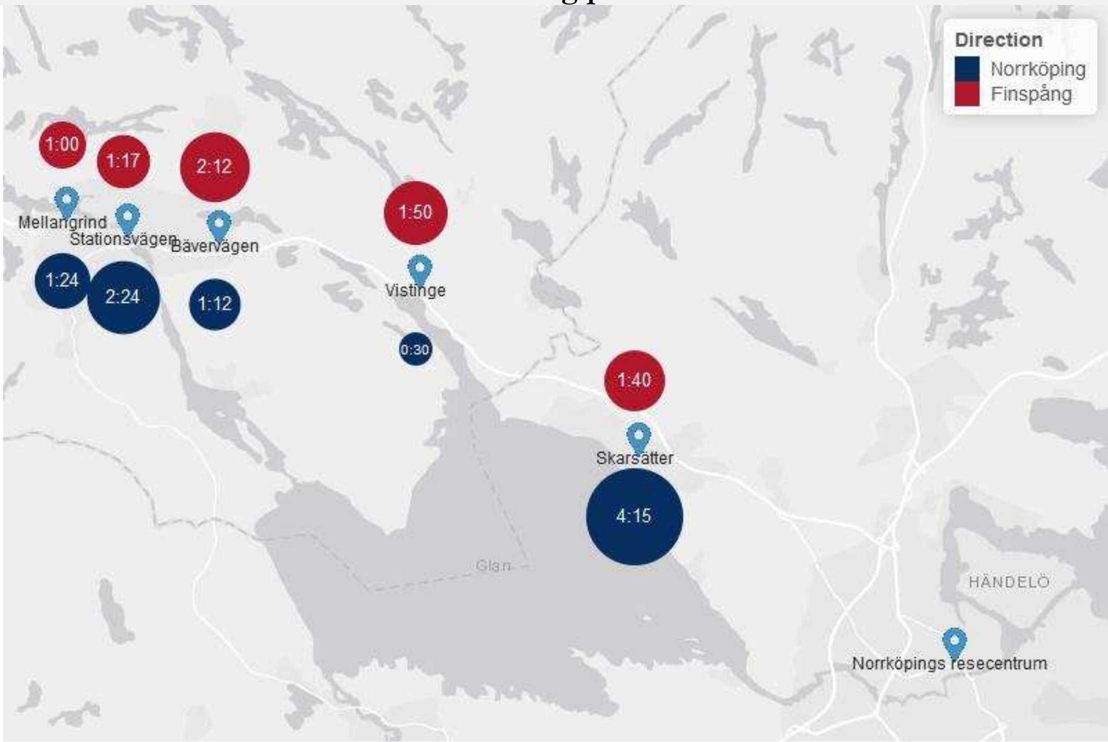

Figure 77 - Delay per trip (MM:SS) at each regulation stop of bus line 410, both directions during the morning peak.

Likewise, to the morning peak, Bävervägen and Skarsätter are the stops with the highest delay per trip during the afternoon peak. Similar results can be seen in Figure 68 and Figure 69.

Afternoon peak

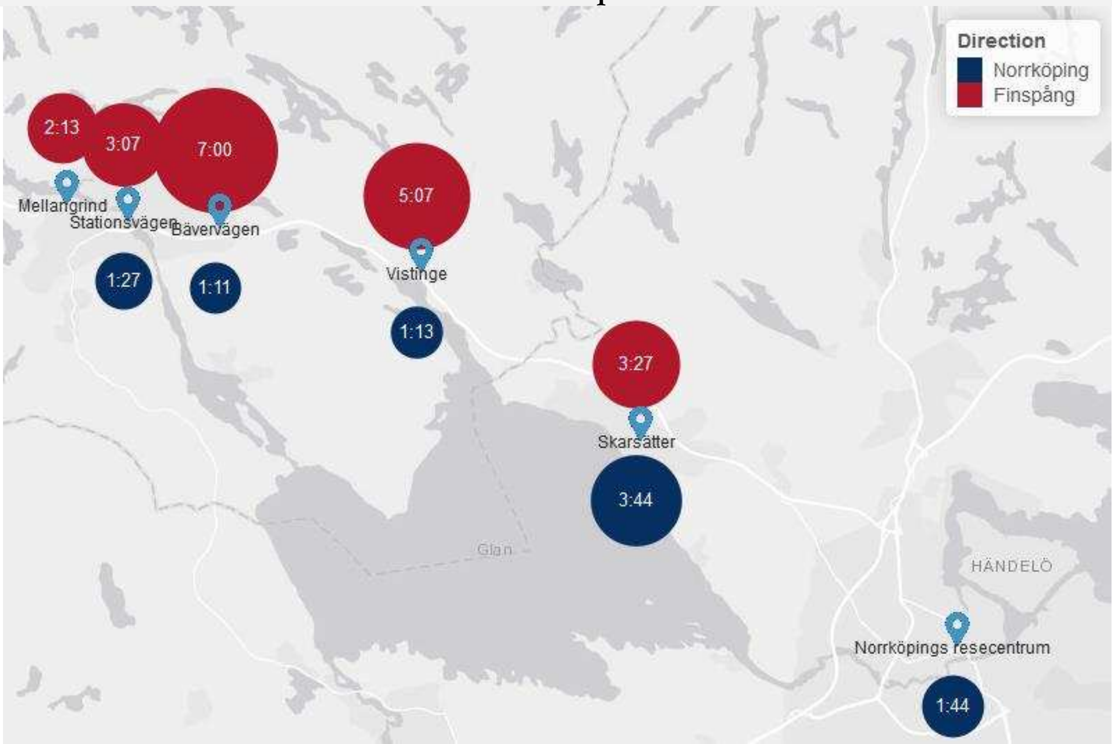

Figure 78 - Delay per trip (MM:SS) at each regulation stop of bus line 410, both directions during the afternoon peak.

7.4 Results for bus line 42

The subsections below include the overall LOS of the bus line 42 as well as a detailed investigation on specific parts of the bus line. In the morning peak, the trip departing at 07:05 from Söder tull is enhanced with two additional buses that departures from Norrköping resecentrum (07:15) and Norr tull (07:17). In total, three buses are heading towards Mellangrind from Norrköping during the same time. In this analysis, only the bus starting from Söder tull is considered.

7.4.1 Overall LOS of bus line 42

Table 17**Error! Reference source not found.** describes the overall LOS for bus line 42. Each KPI is calculated both for the morning and the afternoon peak. The detailed results for both directions can be found in Appendix 5. Figure 79 - Figure 81 show that there are not many occurrences of low speed in the area of Svärtinge. Low speed has mostly occurred in the urban areas that are within the route of bus line 42.

Morning peak

Norrköping

Figure 79 - Observations with low speed during morning peak in Norrköping.

Finspång

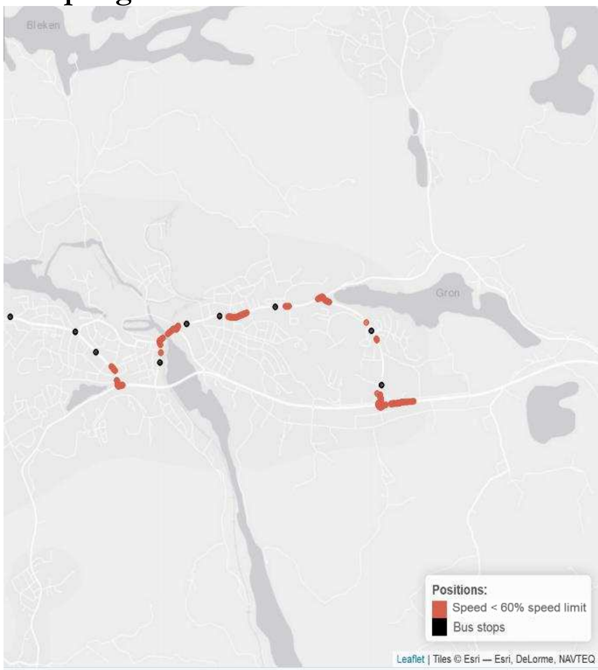

Figure 80 - Observations with low speed during morning peak in Finspång.

Svärtinge

Figure 81 - Observations with low speed during morning peak in Svärtinge.

The areas where low speed have occurred is in the urban areas in the afternoon peak as well, which can be seen in Figure 82 - Figure 84.

Afternoon peak

Norrköping

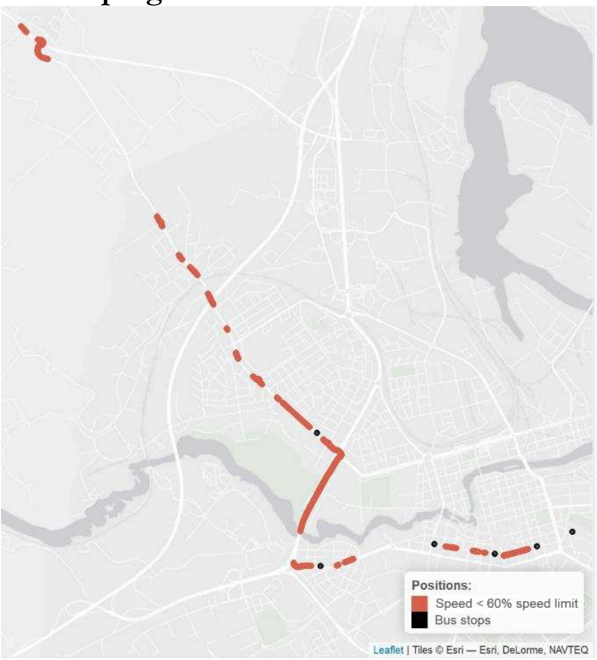

Figure 82 - Observations with low speed during morning peak in Norrköping.

Finspång

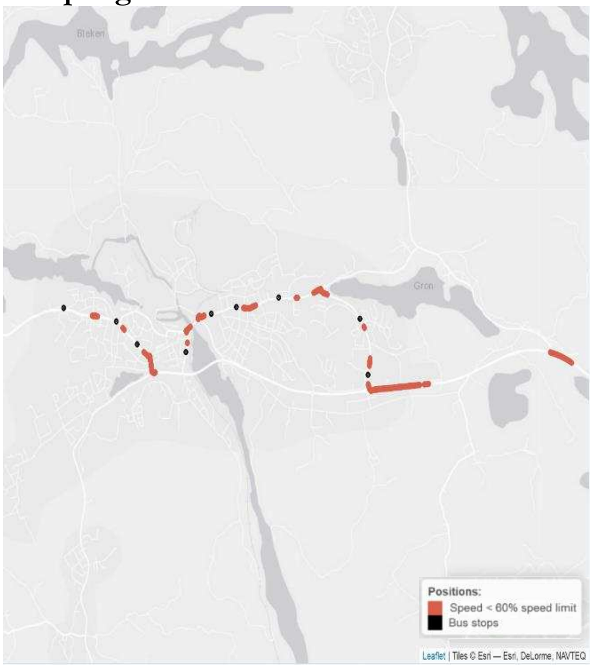

Figure 83 - Observations with low speed during morning peak in Finspång.

Svärtinge

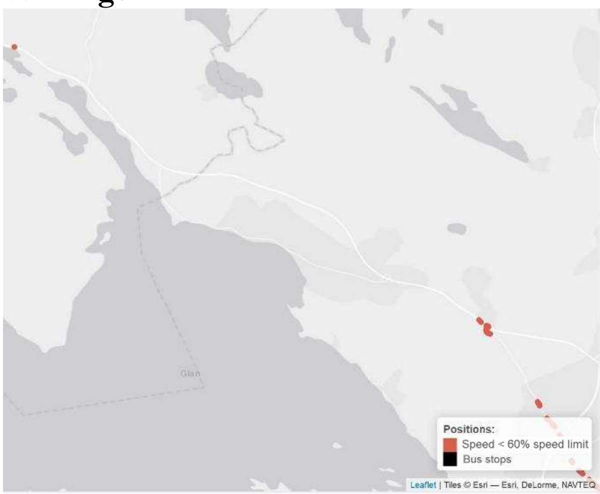

Figure 84 - Observations with low speed during morning peak in Svärtinge.

Figure 85 displays the variations in average speed in the morning peak for the different trips and the different days during the analyzed week. All of the trips have an average speed above the average speed goal of 28km/h. However, most of the trips have an average speed that is lower than what the average speed should be according to the timetable.

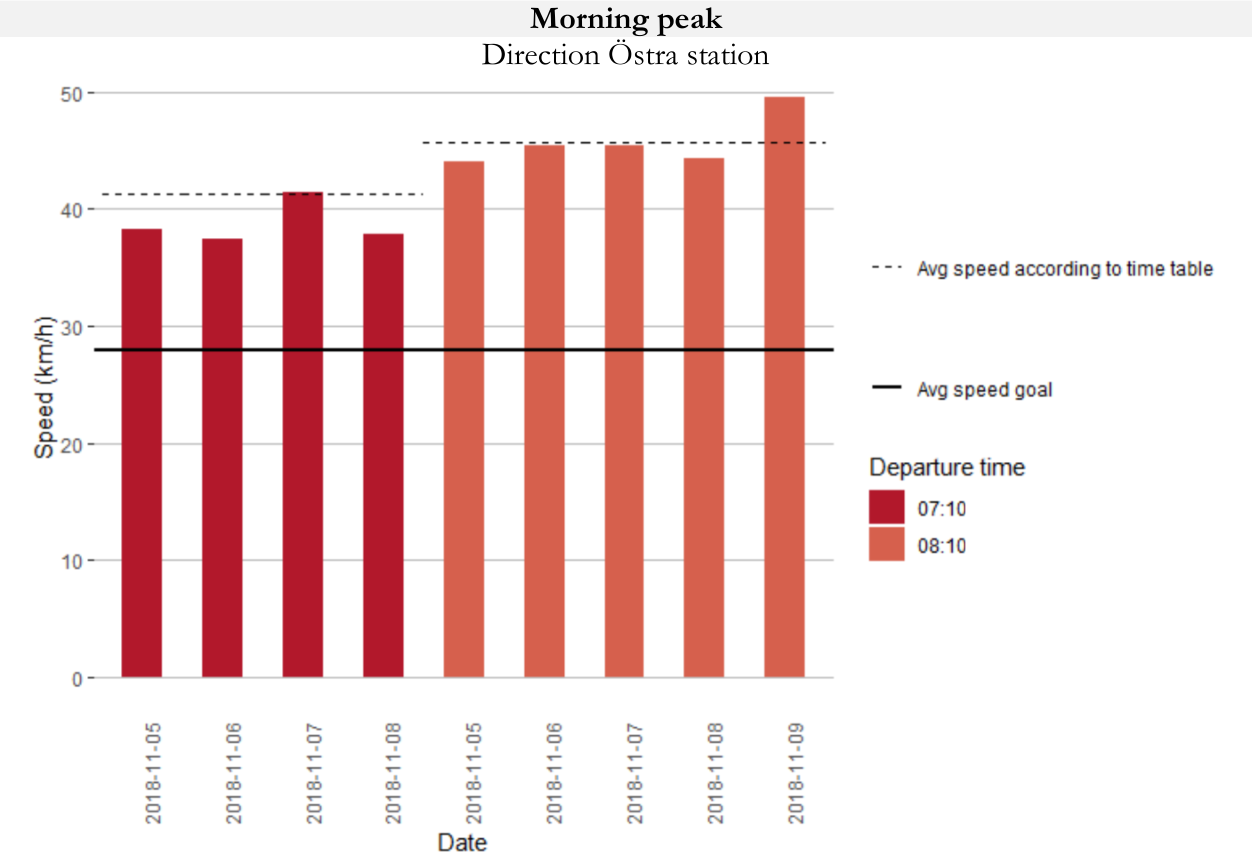

Figure 85 - Variation in average speed during morning peak in direction Östra station.

Figure 86 presents the variation in average speed for the afternoon peak during the examined week. There are more trips that have an average speed above the average speed according to what the speed should be according to the timetable in the afternoon than it was during the morning peak. All the trips have an average speed that is above the average speed goal of 28 km/h.

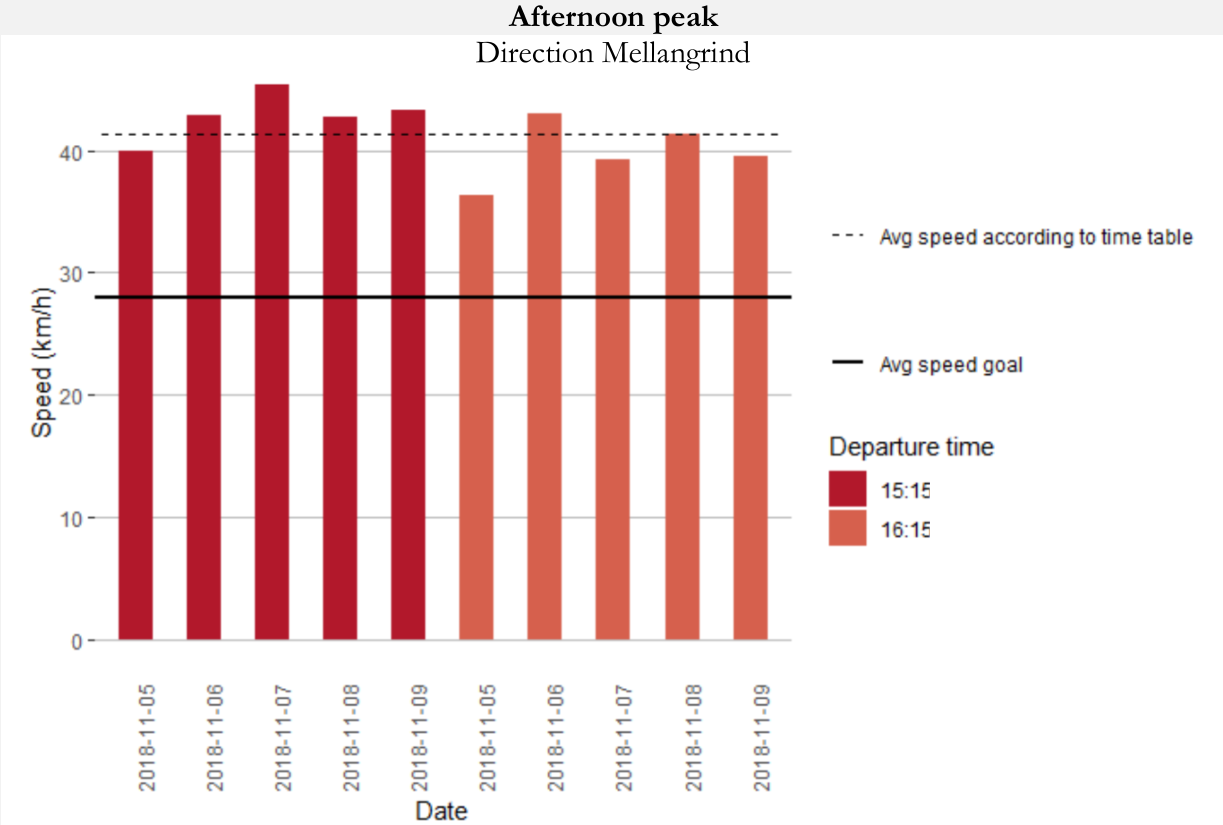

Figure 86 - Variation in average speed during morning peak in direction Mellangrind.

The three trips that had the worst RMSE during the week in the morning peak all depart from Mellangrind at 07:10, as can be seen in Figure 87. The delay is propagating throughout the route.

Morning peak

Direction Östra station

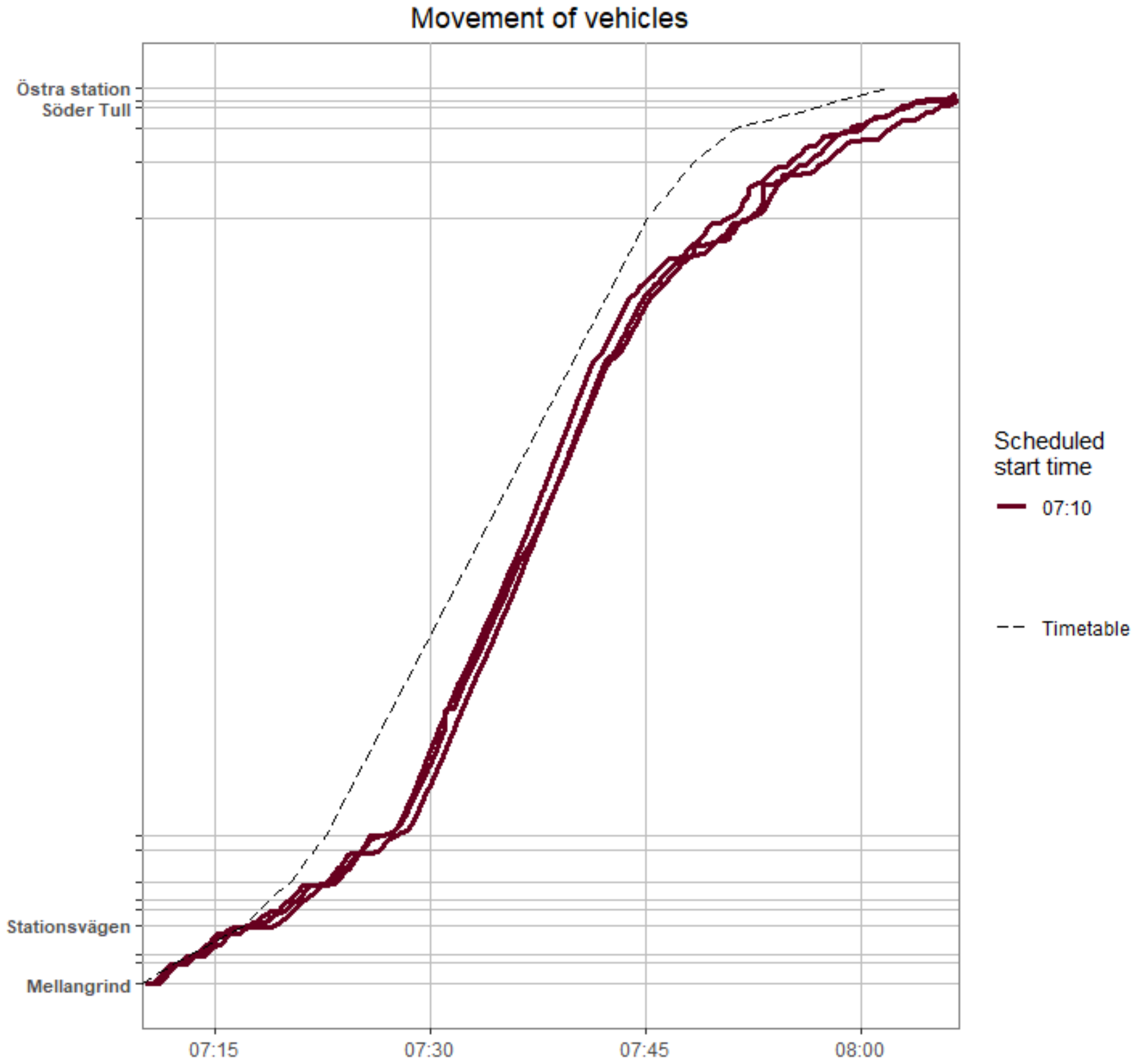

Figure 87 - Movement of vehicles during the morning peak in direction Östra station.

Figure 88 displays the trips that had the worst RMSE in the afternoon during the examined week. The three trips all depart from Östra station at 16:15. The delay is propagation throughout the route, as can be seen in Figure 88.

Afternoon peak

Direction Mellangrind

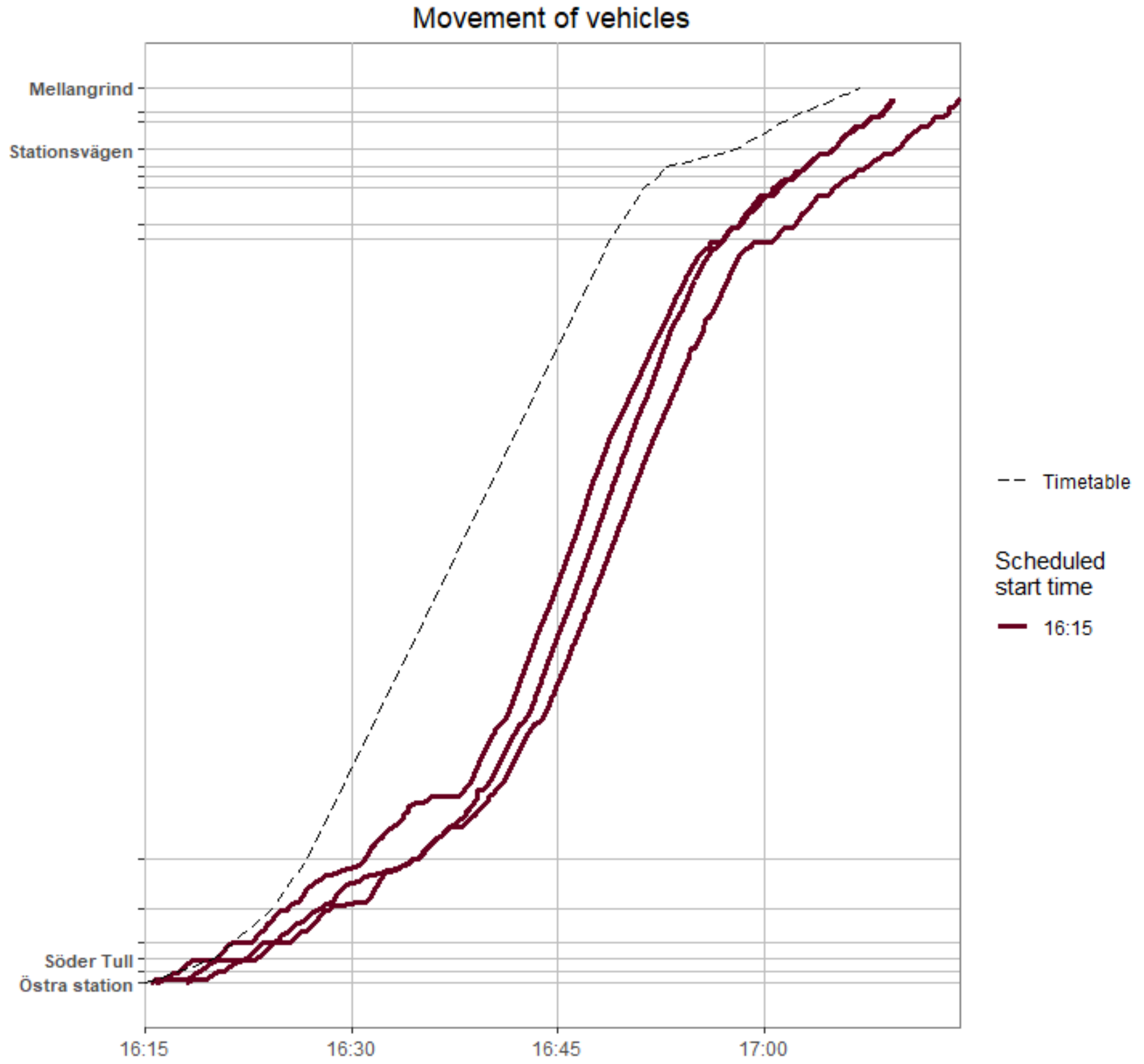

Figure 88 - Movement of vehicles during the morning peak in direction Mellangrind.

Figure 89 shows the delays at the regulation stops during the morning peak in direction Östra station. The numbers below the bars show the number of delayed trips at each stop. In total, nine trips were found for the time period. Seven of the nine trips were delayed to Söder tull with a minimum delay of two minutes and a maximum delay of six minutes. Five trips were delayed to the last stop Östra station. Two trips started late at the first stop Mellangrind.

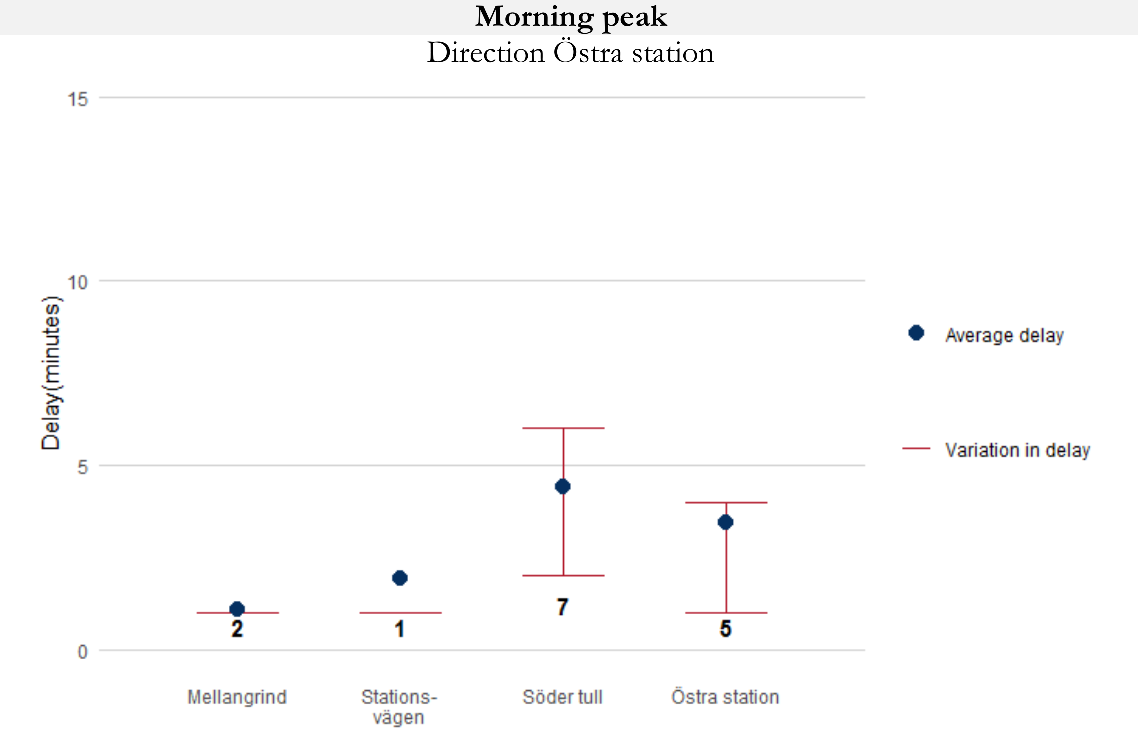

Figure 89 - Delay at regulation stops during the morning peak.

The variations in delay during the afternoon peak in direction Mellangrind is shown in Figure 90. The numbers below the bars indicate the number of delay trips at each stop. In total, ten trips were found for the time period. One of those trips started late at Östra station, eight were delayed to Stationsvägen and four to the last stop Mellangrind. The maximum delay at Stationsvägen was eleven minutes and the average five minutes. At Mellangrind the maximum delay was seven minutes and the average around 3 minutes.

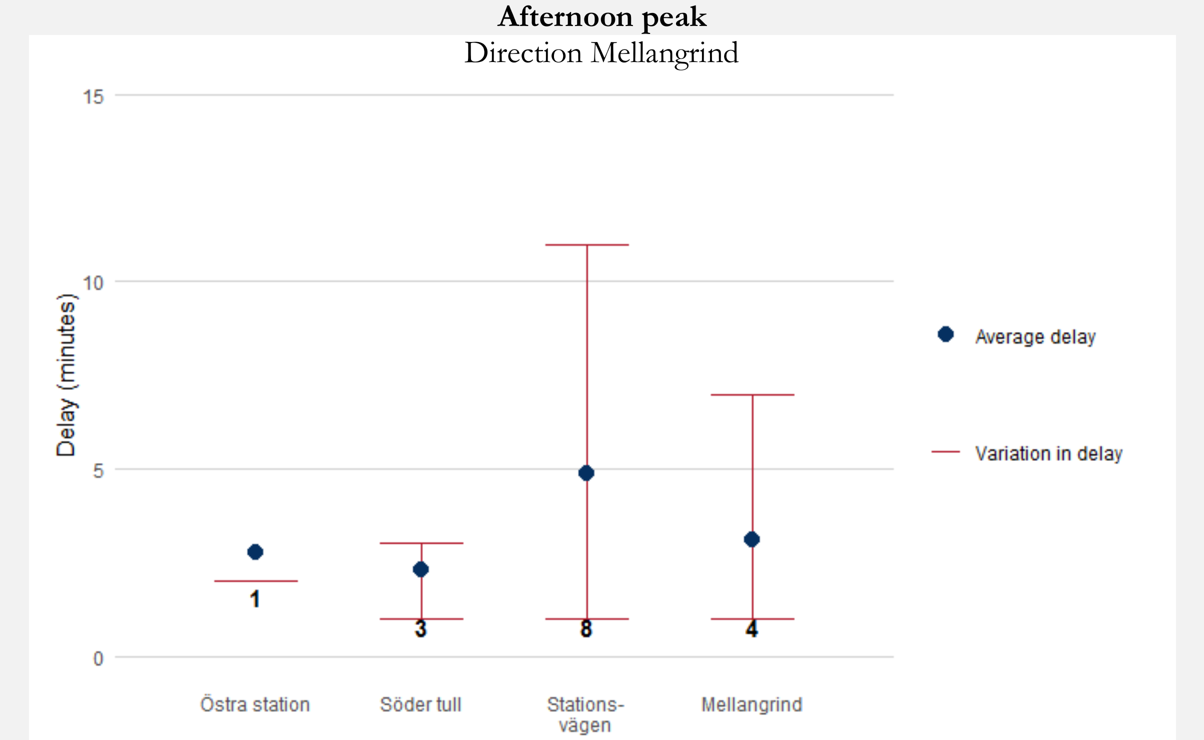

Figure 90 - Delay at regulation stops during the afternoon peak.

The travel time distribution for the morning peak is shown in Figure 91 and for the afternoon peak in Figure 92. There is not a big difference between the two time periods.

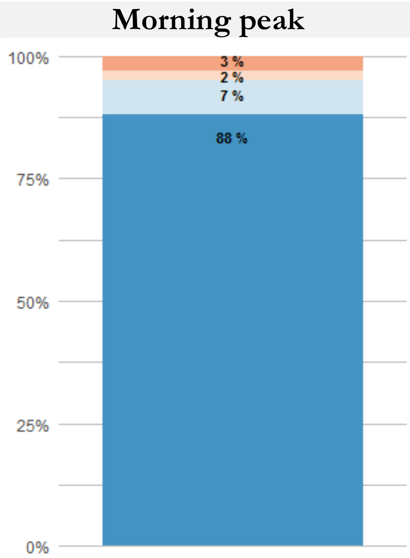

Figure 91 - Travel time distribution for bus line 410 during the morning peak, both directions.

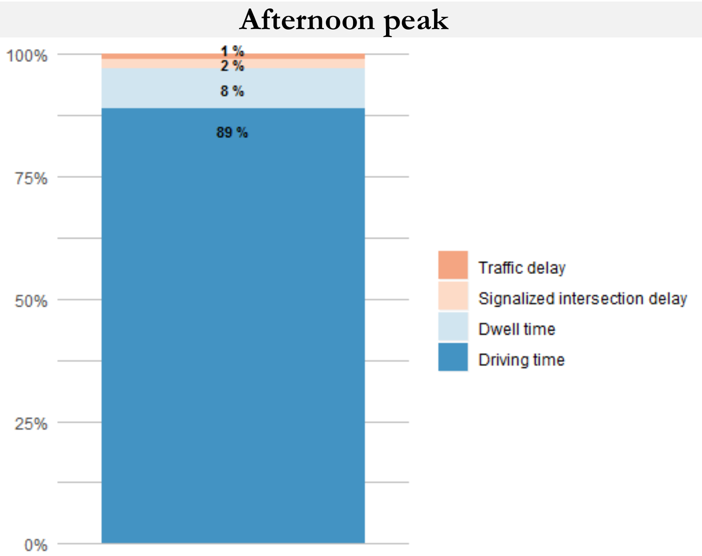

Figure 92 - Travel time distribution for bus line 410 during the afternoon peak, both directions.

The result for each KPI for bus line 42 is shown Table 17. There is not one of the time period that clearly have a worse reults than the other, for example the average speed is lower in the afternoon but more vehicles had a speed higher than the speed based on the time table.

Table 17 - The values of each KPI measure for bus line 42 for the examined week.

	Morning peak	Afternoon peak
Low speed		
Nr obs. with low speed	10%	13%
Low speed (MM:SS/vehicle)	04:43	06:02
Average speed		
Average speed (km/h)	42.62	41.35
Minimum average speed(km/h)	37.45	36.32
Maximum average speed(km/h)	49.54	45.34
Average speed without dwell time (km/h)	45.94	44.77
Minimum average speed without dwell time (km/h)	40.22	38.64
Maximum average speed without dwell time (km/h)	53.19	50.91
Nr vehicles with speed > speed goal	100%	100%
Nr vehicles with speed > speed based on timetable	11%	60%
Delay		
Average delay per trip at the last stop (MM:SS)	1:13	1:23
Share of trips at least one minute delayed to a regulation stop	42%	40%
Average delay at a regulation stop (MM:SS)	2:56	3:26
Minimum delay at a regulation stop (MM:SS)	1:00	1:00
Maximum delay at a regulation stop (MM:SS)	6:00	11:00
Slack time		
Share of trips with slack time at a regulation stop	28%	45%
Average slack time at a regulation stop (MM:SS)	2:06	1:37
Minimum slack time at a regulation stop (MM:SS)	2:00	1:00
Maximum slack time at a regulation stop (MM:SS)	3:00	4:00
Early departure		
Share of trips that departed early from a regulation stop	14%	13%
Average early departure from a regulation stop (MM:SS)	1:00	1:00
Minimum early departure from a regulation stop (MM:SS)	1:00	1:00
Maximum early departure from a regulation stop (MM:SS)	1:00	1:00
Travel time distribution		
Number of trips	9	10
Shortest dwell time	6%	4%
Average dwell time	7%	8%
Longest dwell time	9%	11%
Shortest traffic delay	1%	0%
Average traffic delay	3%	1%
Longest traffic delay	4%	4%
Shortest signalized intersection delay	0%	1%
Average signalized intersection delay	2%	2%
Longest signalized intersection delay	5%	4%
Shortest driving time	83%	86%
Average driving time	88%	89%
Longest driving time	91%	92%

7.4.2 Further investigation – Bus line 42

In the analysis of the overall LOS for bus line 42, the results showed that there are problems with a lot of delays during the examined week. The speed was therefore investigated further, in order to point out which places in the traffic system that most likely caused these delays.

The bus that departure 07:10 from Finspång 6th of November was delayed with 6 minutes and 54 seconds when it reached Söder tull. The speed of this bus was therefore examined for the complete journey, which can be seen in Figure 93. Meanwhile, the bus that departure 08:10 the 9th of November was one minute early when it reached Söder tull. The speed of this bus was also examined to be able to compare a good journey with a bad journey. The speed in km/h of this bus can be seen in Figure 96. Figure 94 and Figure 95 respectively Figure 97 and Figure 98 show a zoomed-in view of the two city centers that belong to the route of bus line 42.

Figure 93 - The speed (km/h) of bus line 42 to Östra station 07-10 the 6th of November.

Figure 94 - The speed (km/h) of bus line 42 to Östra station 07:10 the 6th of November, zoomed on Finspång.

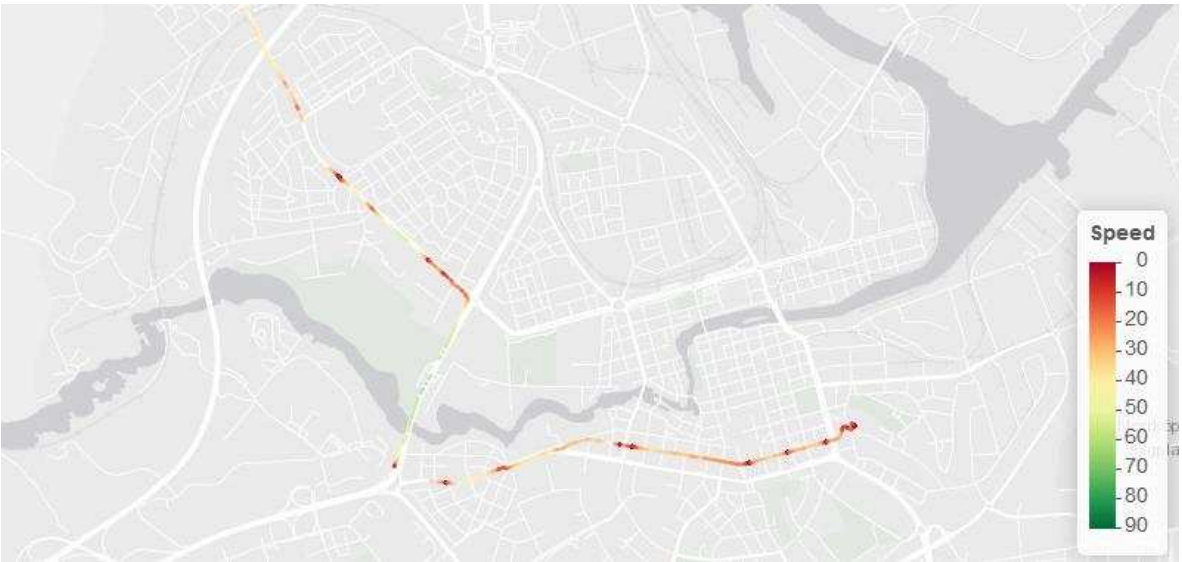

Figure 95 - The speed (km/h) of bus line 42 to Norrköping 07:10 the 6th of November, zoomed on Norrköping.

Figure 96 - The speed (km/h) of bus line 42 to Norrköping 8:10 the 9th of November.

Figure 97 - The speed (km/h) of bus line 42 to Östra station 08:10 the 9th of November, zoomed on Finspång.

Figure 98 - The speed (km/h) of bus line 42 to Östra station 08:10 the 9th of November, zoomed on Norrköping.

When comparing Figure 94 and Figure 97 it is clear that the LOS is worse on for example Bävervägen on the 6th of November than on the 9th of November. A clear difference between Figure 95 and Figure 98 is the number of observations where the speed was zero km/h. During the 9th of November, there were very few observations with a speed of zero km/h. One area that seems to be especially problematic is around the bus stop Hagagatan and outside of Eneby centrum.

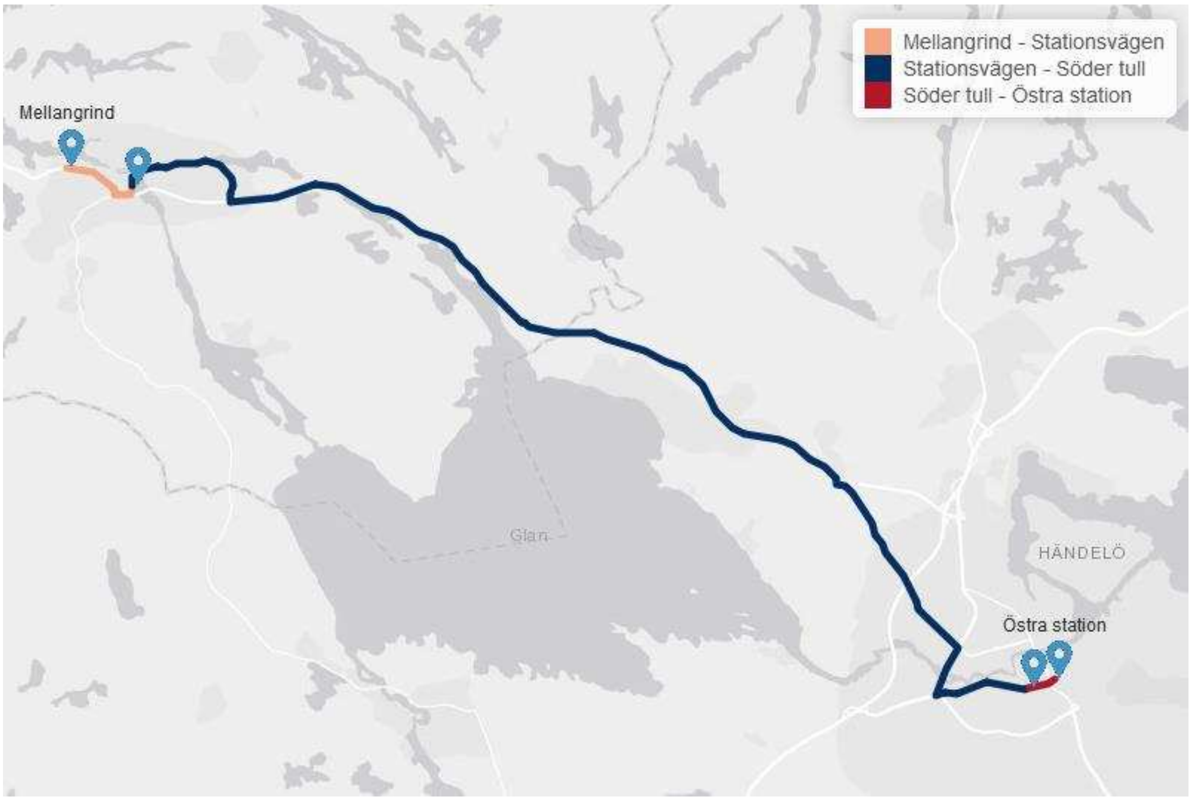

Figure 99 - Regulation stops and road sections for bus line 42.

Figure 99 shows the regulation stops for bus line 42 and the sections that are formed between them. Table 18 then describes the difference in travel time between those stops for the trip with the longest delay during the morning peak respectively the trip with the shortest delay during the morning peak.

Table 18 - Difference in travel time between regulation stops.

Departure day and time from Mellangrind	Mellangrind – Stationsvägen (MM:SS)	Stationsvägen – Söder tull (MM:SS)	Söder tull - Östra station (MM:SS)
6/11 7:10	05:21	46:17	02:39
9/11 8:10	04:54	34:59	02:13

The scheduled travel time between Stationsvägen and Södertull for the trip departing 7:10 was 40 minutes and for the trip departing 8:10 it was 36 minutes. The trip departing at 7:10 was 4 minutes and 33 seconds delayed to the last stop, the trip departing at 8:10 was not delayed to the last stop.

Figure 100 - The speed (km/h) of bus line 42 with departure time 16:16 time to Mellangrind the 5th of November.

Figure 101 - The speed (km/h) of bus line 42 departure time 16:15 to Mellangrind at the 5th of November zoom on Norrköping.

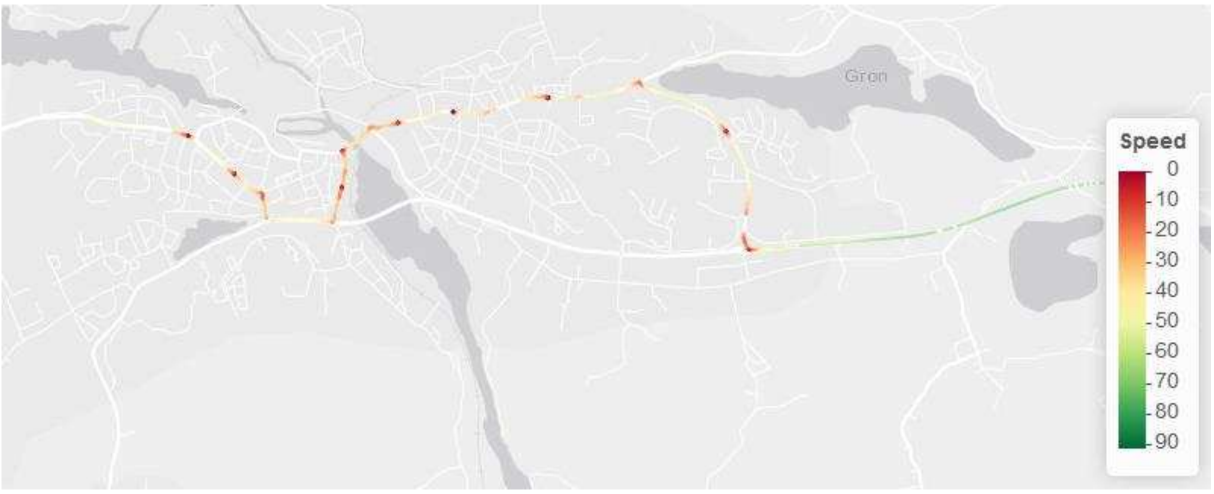

Figure 102 - The speed (km/h) of bus line 42 departure time 16:15 to Mellangrind at the 5th of November zoom on Finspång.

Figure 103 - The speed (km/h) of bus line 42 departure time 15:15 to Mellangrind at the 7th of November.

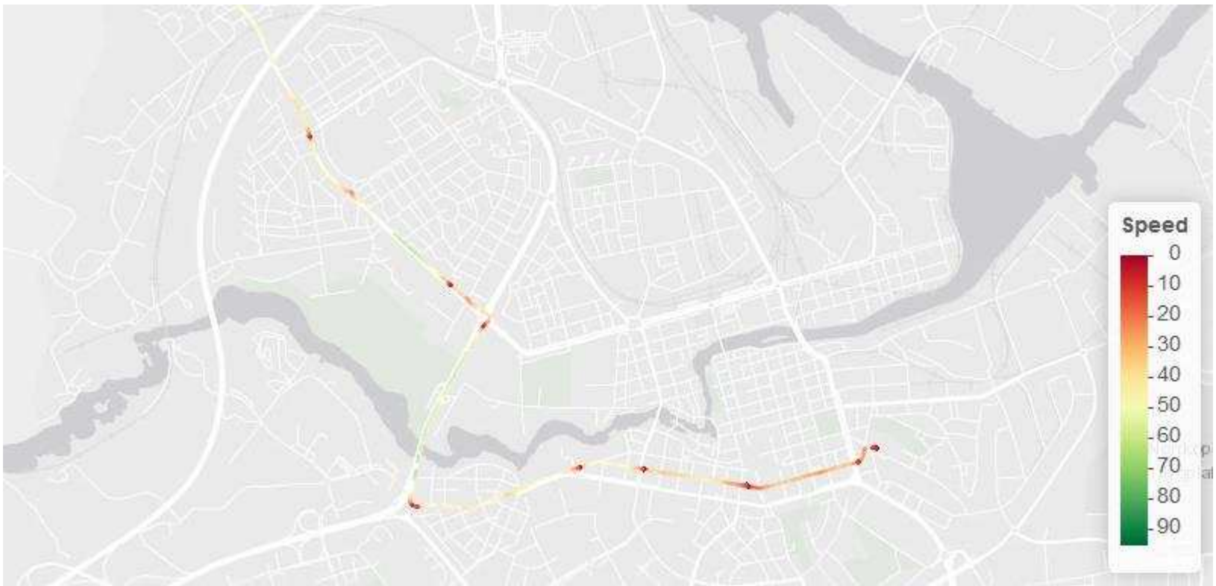

Figure 104 - The speed (km/h) of bus line 42 departure 15:15 to Mellangrind the 7th of November zoom on Norrköping.

Figure 105 - The speed (km/h) of bus line 42 departure 15:15 to Mellangrind the 7th of November zoom on Finspång.

When comparing Figure 101 and Figure 104 it is clear that there are more problems with the LOS at 16:15 than 15:15. The roundabout to Finspångsvägen from Riksvägen, is still the area where the LOS is the worst, as it was during the morning peak. When comparing Figure 102 and Figure 105 there is not that much difference in the LOS. Figure 100 and Figure 103 shows that outside of the cities the speed is high, and the LOS is good.

Table 19 describes the travel times in the afternoon peak on the areas between the regulations stops. The travel times are measured for the trips that hade the longest delay respectively the trip that had the shortest delay.

Table 19 - Difference in travel time between regulation stops.

Departure day and time from Östra station	Östra station – Söder tull (MM:SS)	Söder tull – Stationsvägen (MM:SS)	Stationsvägen – Mellangrind (MM:SS)
5/11 16:15	6:27	46:42	4:57
7/11 15:15	2:56	36:56	4:53

The trip departing at 16:15 from Östra station was 7 minutes delayed to the last stop Mellangrind. The trip departing at 15:15 from Östra station was not delayed at the last stop Mellangrind. The scheduled travel time for all sections was the same for both departure times.

Figure 106 shows the delay per trip at each stop. In contrast to Figure 89, this figure displays the average delay for all trips and not only the trips that were delayed. When arriving at Söder tull, the trips were on average delayed by three minutes. At the last stop Östra station, the delay was 1 minute and 33 seconds on average.

Morning peak

Figure 106 - **Delay per trip (MM:SS) at each regulation stop of line 42 during the morning peak.**

In Figure 107, the average delay for all trips at each stop in the afternoon peak can be seen. On average, the trips were 3 minutes and 30 seconds late to Stationsvägen. At the last stop Mellangrind, the average delay for all vehicles were one minute and twelve seconds.

Afternoon peak

Figure 107 - **Delay per trip (MM:SS) at each regulation stop of line 42 during the afternoon peak.**

7.5 Results for tram line 2

The subsections below include the overall LOS of tram line 2 as well as a detailed investigation on specific parts of the tram line.

7.5.1 Overall LOS of tram line 2

Table 20 and Figure 108-Figure 123 show the overall result of the KPI measures for tram line 2. All of the results are based on data from the 5th to 9th of November and the morning and afternoon peak are defined as Table 8. The detailed results for both directions of tram line 2 can be found in Appendix 6.

Figure 108 and Figure 109 describe where in the route low speed have been observed when comparing to the speed of the road. On the roads where the tram is driving in a separate lane, it is assumed that the speed limit is the same as adjacent roads. When comparing Figure 108 and Figure 109 there is not an evident difference between the morning peak and the afternoon peak. The observations with low speed have occurred in similar places.

Morning peak **Afternoon peak**

Figure 108 - Observations where a vehicle drove at a low speed during the morning peak for both directions.

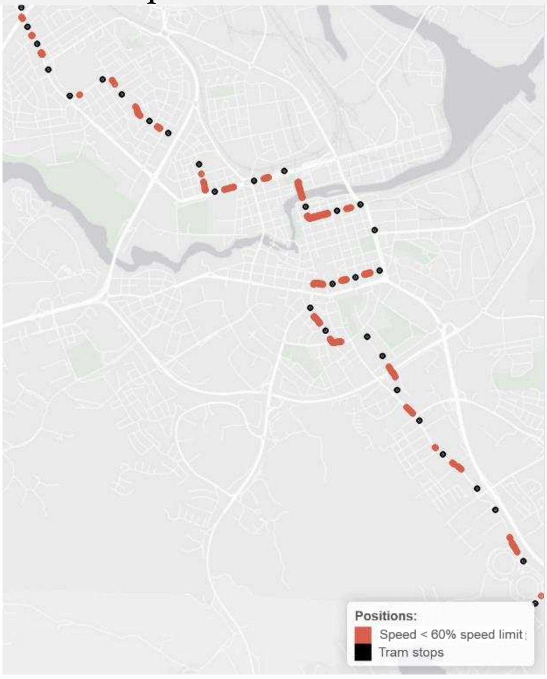

Figure 109 - Observations where a vehicle drove at a low speed during the afternoon peak for both directions.

Figure 110-Figure 113 show the average speed during morning peak and afternoon peak in both directions. The average speed is not diverging much in any of these figures, it is rather constant. There are almost none of the vehicles that have an average speed that is above the average speed goal of 20 km/h.

Morning peak

Direction Fridvalla

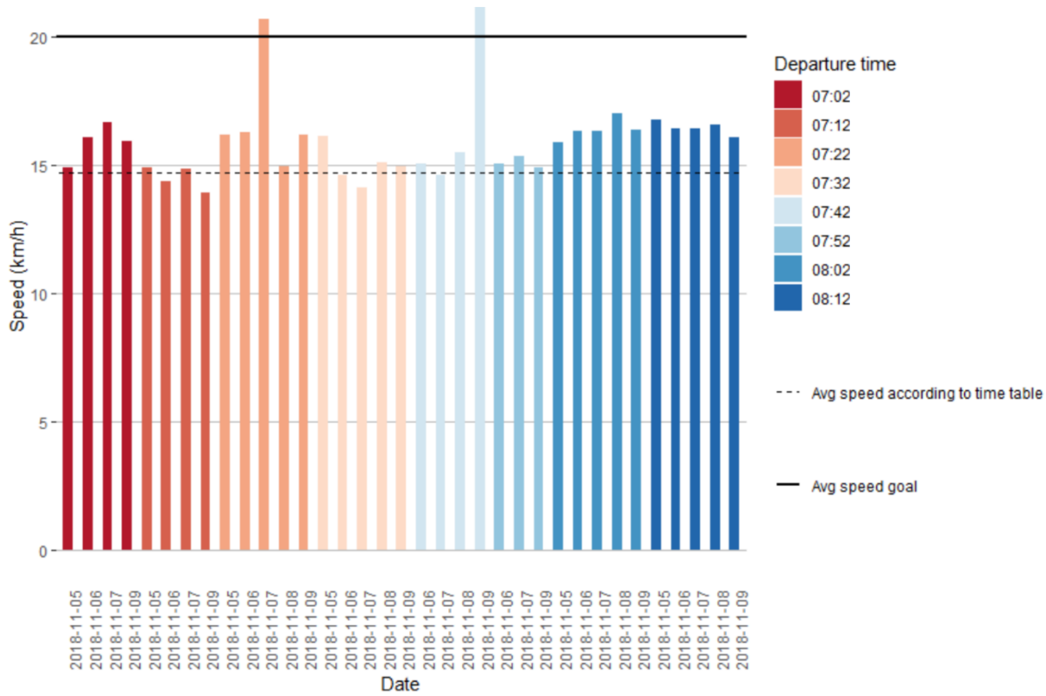

Figure 110 - Variation in average speed during morning peak in direction Fridvalla.

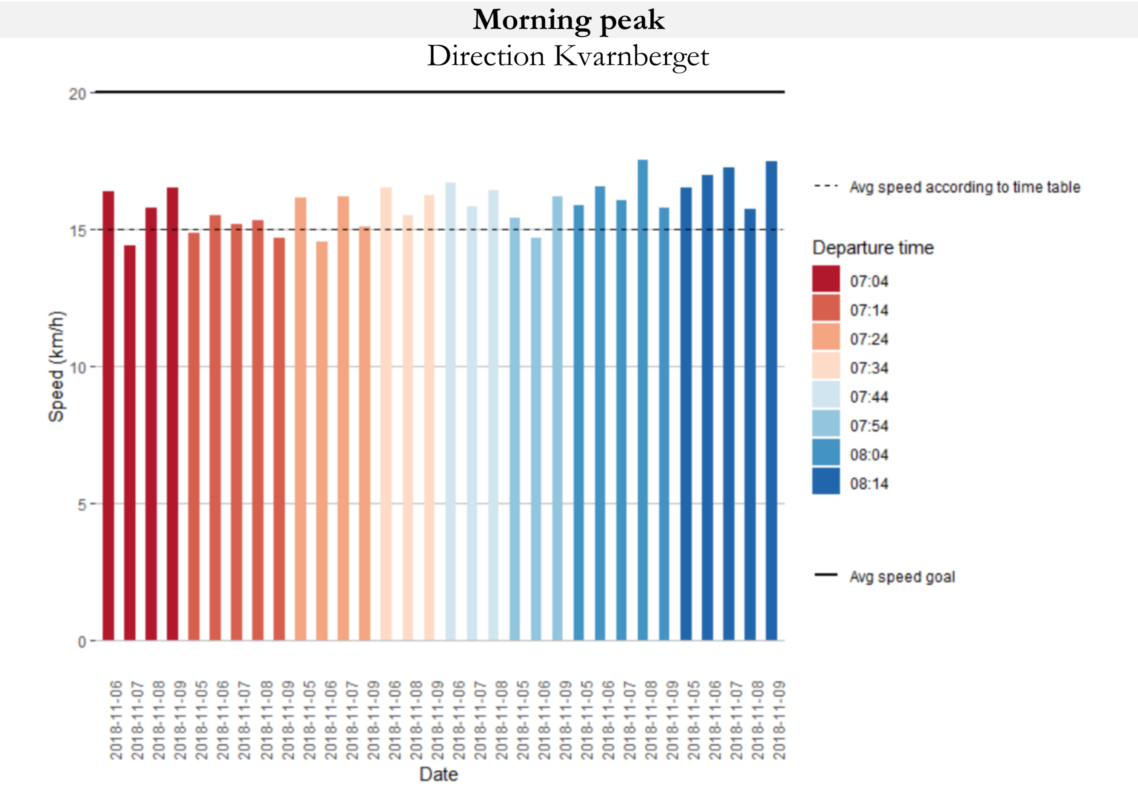

Figure 111 - Variation in average speed during morning peak in direction Kvarnberget.

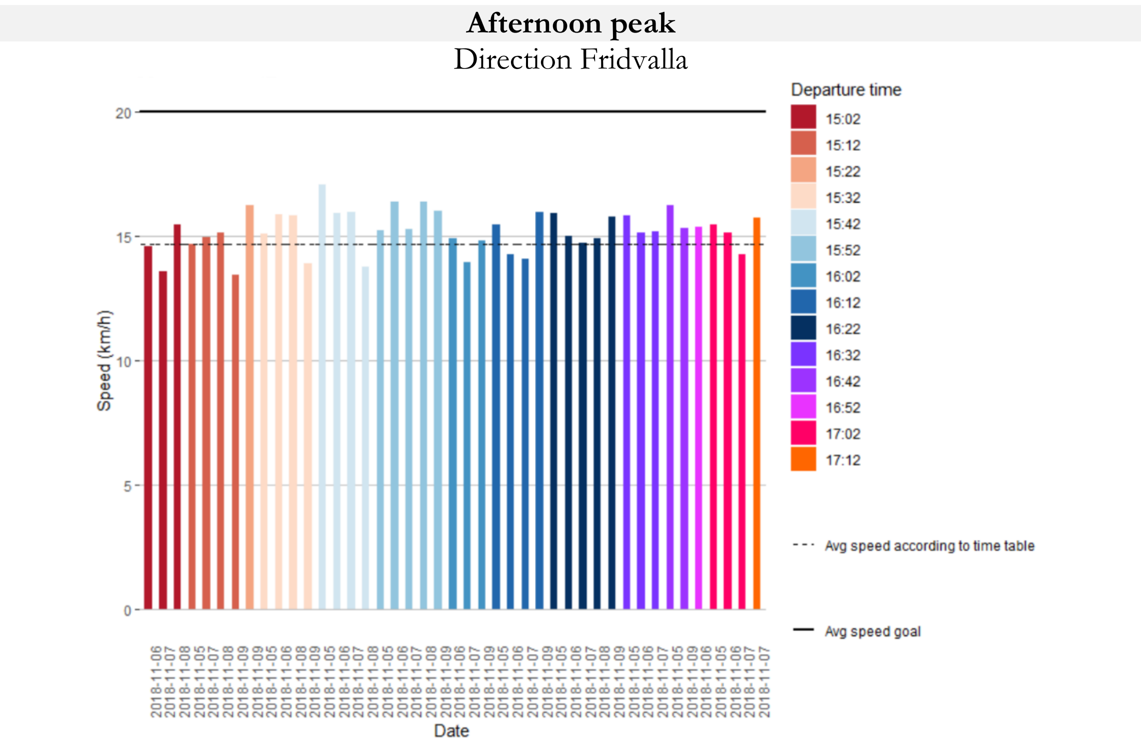

Figure 112 - Variation in average speed during afternoon peak in direction Fridvalla.

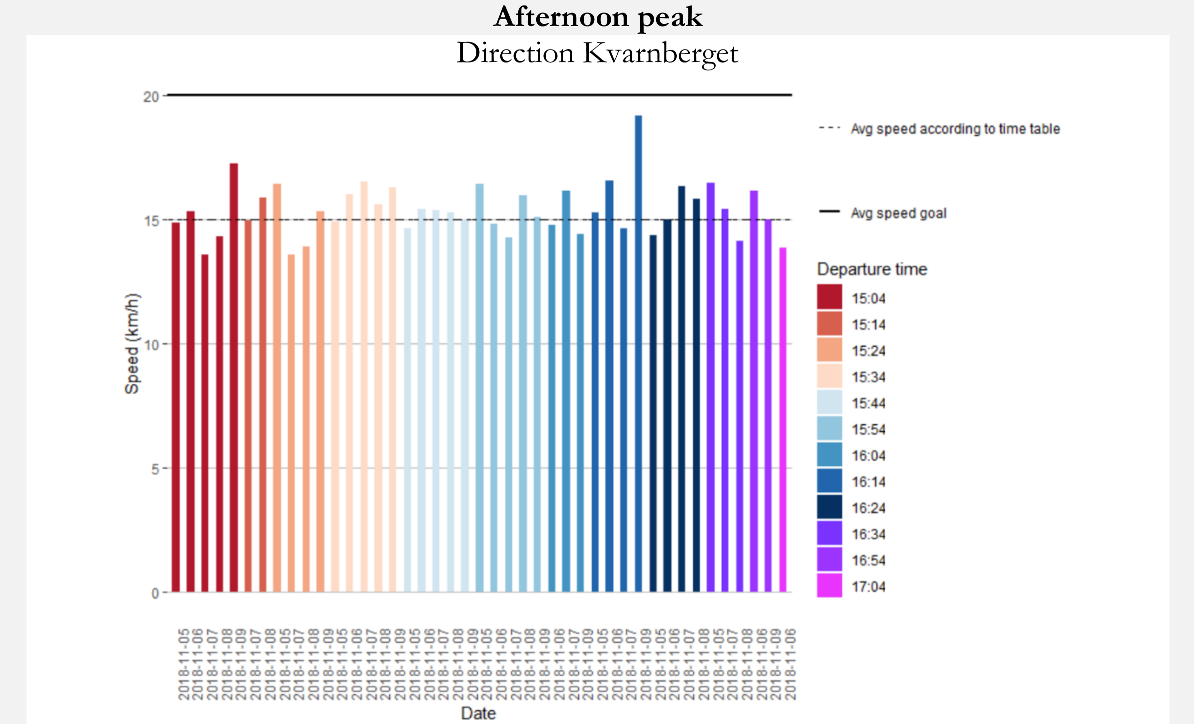

Figure 113 - Variation in average speed during afternoon peak in direction Kvarnberget.

Figure 114 indicates that during the morning peak in direction Fridvalla, even the worst trips are following the timetable quite well. It is also clear that delays usually start at Söder tull.

Morning peak

Direction Fridvalla

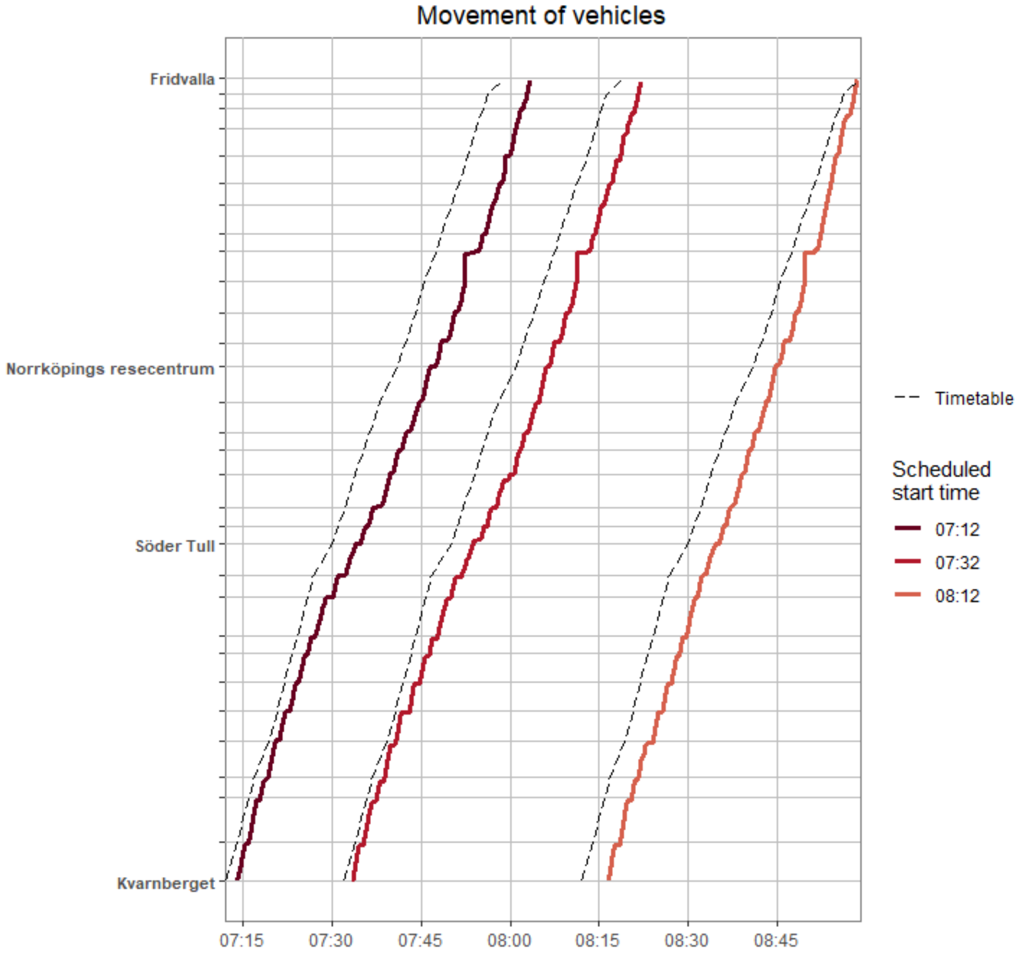

Figure 114 - Movement of vehicles during the morning peak in direction Fridvalla.

Figure 115 shows that in direction Kvarnberget, it is not as evident as in Figure 114, that delays arise at Söder tull. In this figure, the delay is constantly getting worse but almost arrive on time to the last stop.

Morning peak

Direction Kvarnberget

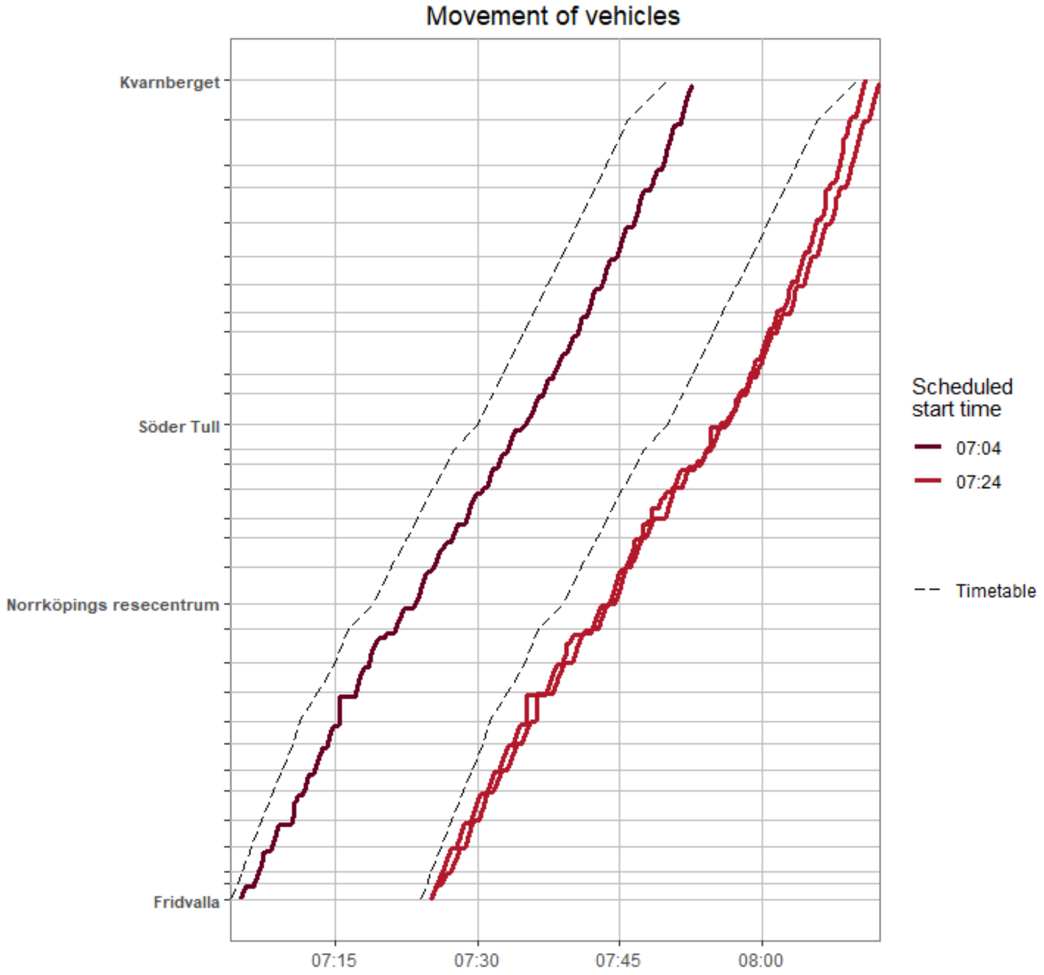

Figure 115 - Movement of vehicles during the morning peak in direction Kvarnberget.

Figure 116 shows that the delay is getting worse after Söder tull similar to during the morning peak. The difference between the morning peak and the afternoon peak is that the worst three trips were diverging more from the timetable than during the morning peak.

Afternoon peak

Direction Fridvalla

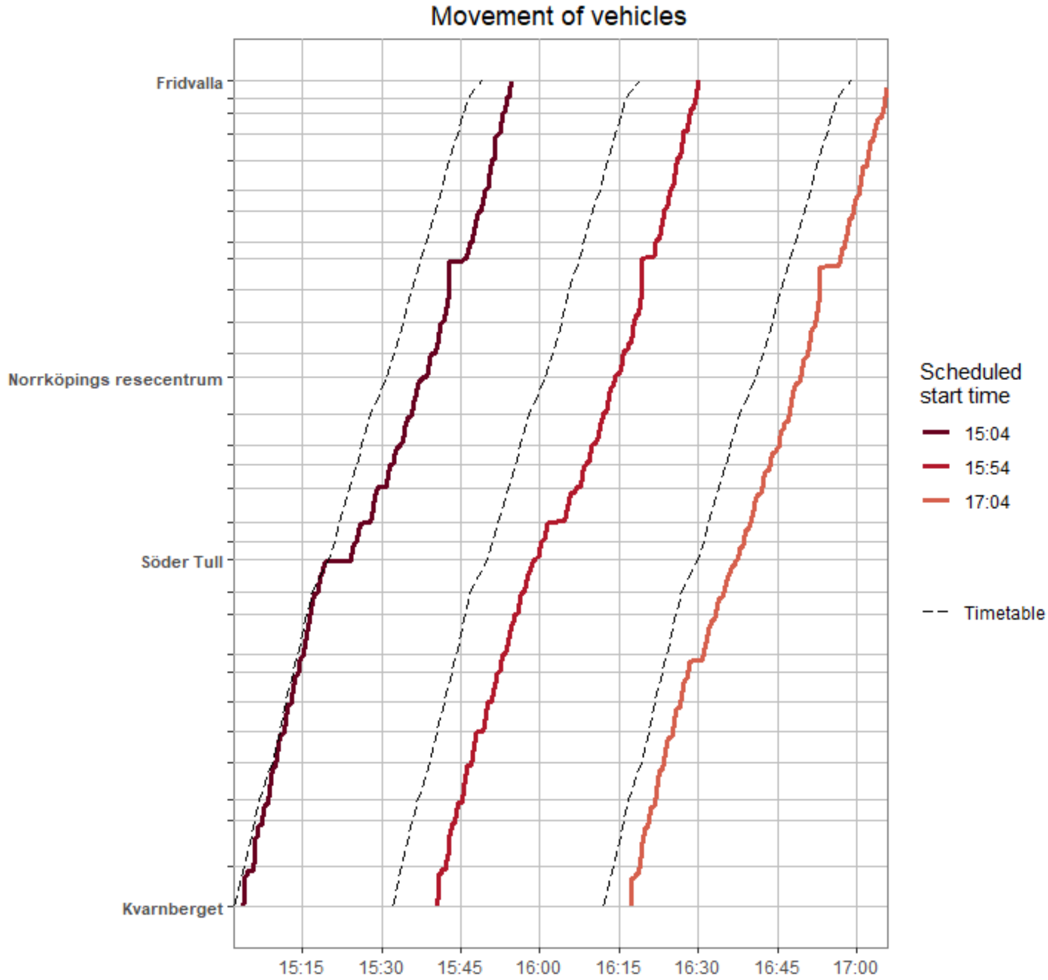

Figure 116 - Movement of vehicles during the afternoon peak in direction Fridvalla.

Figure 117 shows that during the afternoon peak in direction Kvarnberget, there were not as much delays as it was during the morning peak.

Afternoon peak

Direction Kvarnberget

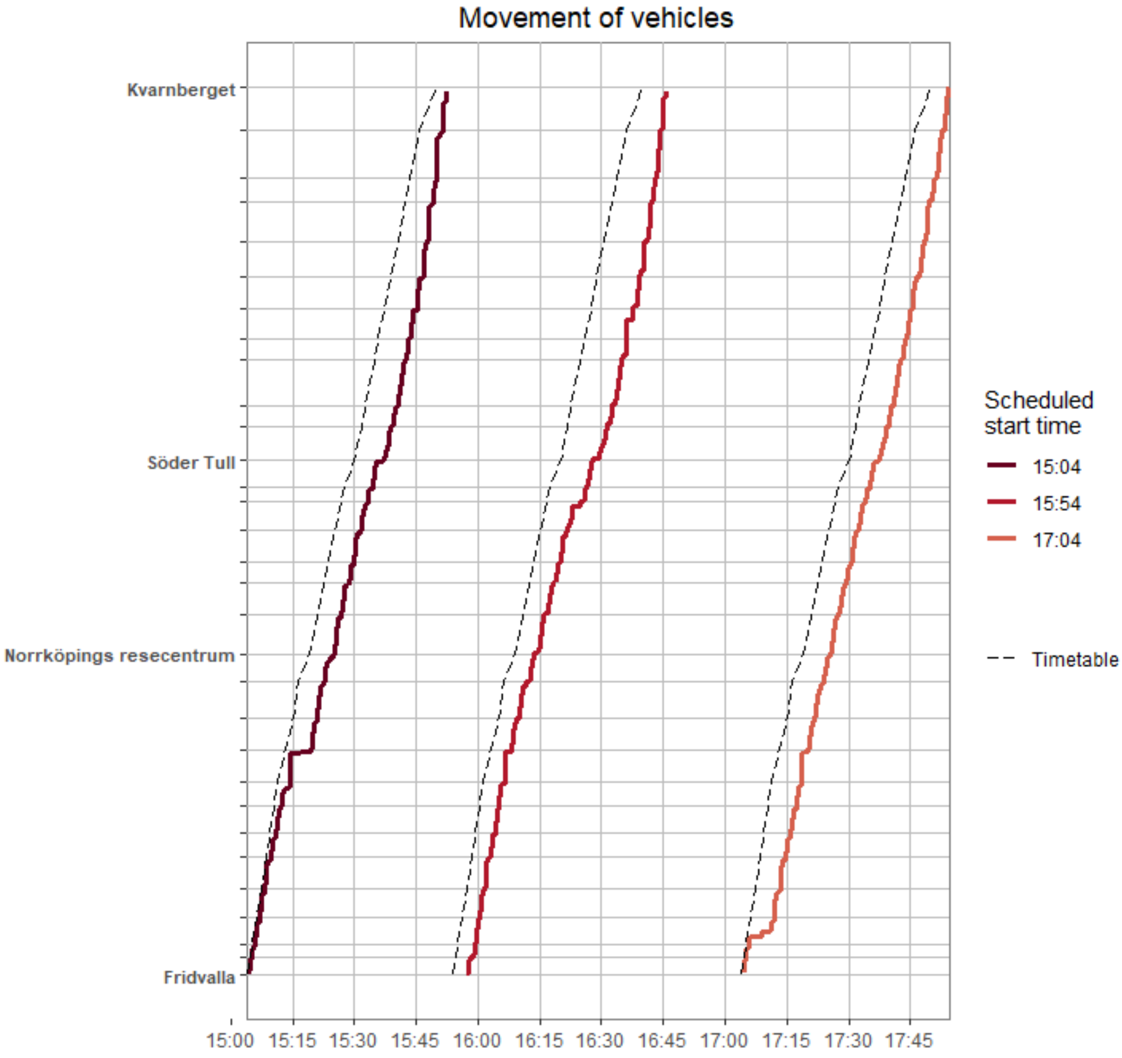

Figure 117 - Movement of vehicles during the afternoon peak in direction Kvarnberget.

Figure 118 shows the variation of delay at the regulation stops of tram line 2. In total 35 trips were found for the morning peak in this direction during the studied week. The numbers below the bars show the number of delayed trips at each stop. In the middle of the journey, more than half of the vehicles were delayed to the regulation stops Söder tull and Norrköpings resecentrum. At the last stop Fridvalla, only three trips were still delayed with an average around three minutes. Five trips started late at the first stop Kvarnberget.

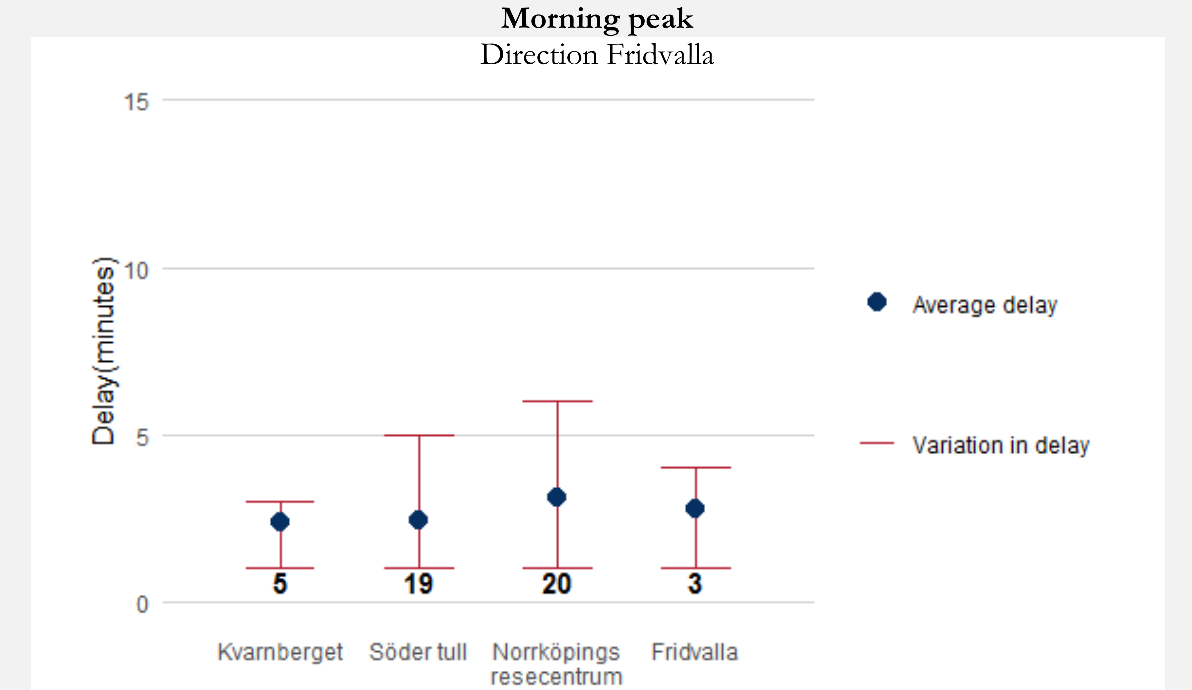

Figure 118 - Delay at a regulation stop during the morning peak direction Fridvalla. The numbers below the bars describe how many trips that were delayed at each stop.

The variation in delays at regulation stops during the morning peak in direction Kvarnberget can be seen in Figure 119. 32 trips were found for the time period. The numbers below the bars shos how many trips that were delayed to each stop. At Norrköping resecentrum and Söder tull, almost all of the trips were delayed, at most five respective six minutes. At the end of the route, only four trips were delayed to the last stop Kvarnberget. One trip started late from the first stop Fridvalla.

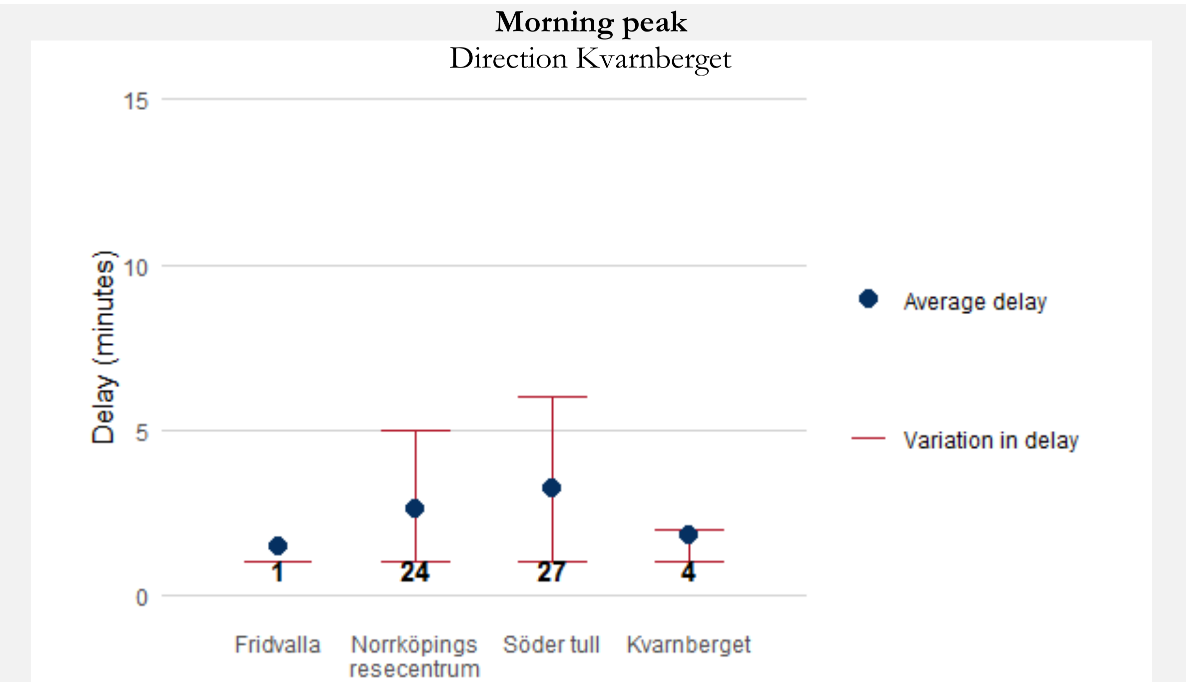

Figure 119 - Delay at a regulation stop during the morning peak direction Kvarnberget. The numbers below the bars describe how many trips that were delayed at each stop.

Figure 120 shows the variation in delays in the afternoon peak in direction Fridvalla. In total, 47 trips were found in the direction and time period. As can be seen, there were more delays at the first and last stop in the afternoon peak for direction Fridvalla compared to the morning peak. At Norrköping resecentrum the maximum delay was 14 minutes. However, the average delay was around four minutes. At the other stops, the maximum delay was also high although the average delay was under five minutes at all stops.

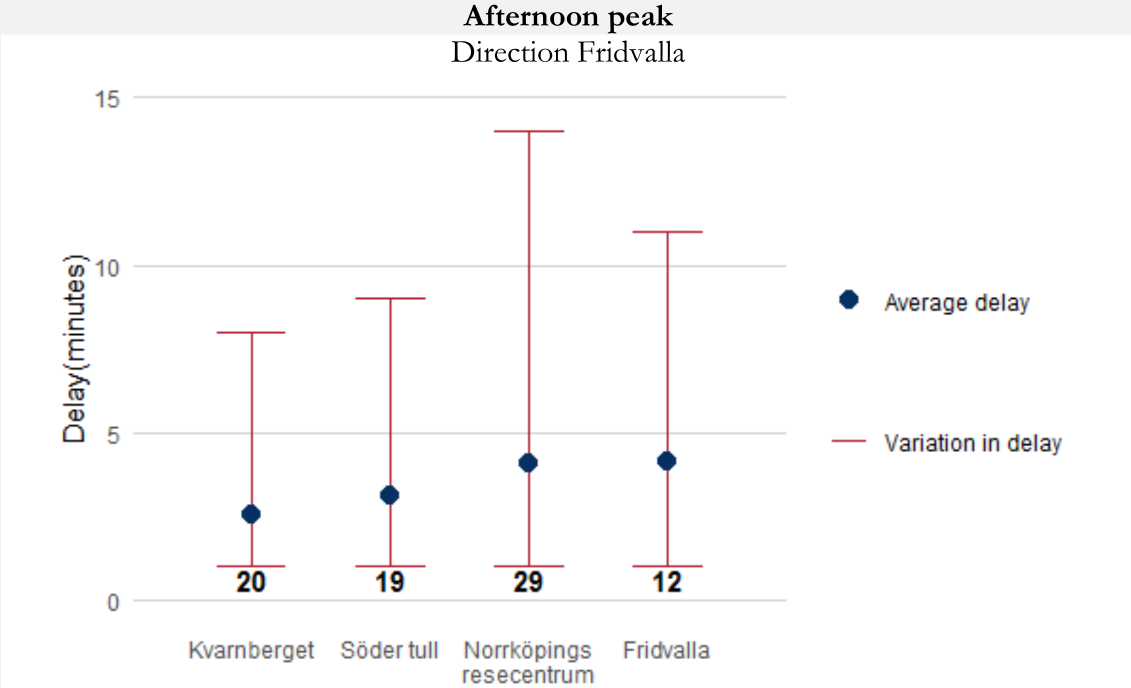

Figure 120 - Delay at a regulation stop during the afternoon peak direction Fridvalla. The numbers below the bars describe how many trips that were delayed at each stop.

The variation in delays in direction Kvarnberget during the afternoon peak can be seen in Figure 121, 43 trips were found for the direction and time period. At Söder tull, the maximum delay was nine minutes and about 80% of the trips were delayed to this stop. At the last stop, 14 trips were delayed with an average around four minutes.

Afternoon peak

Direction Kvarnberget

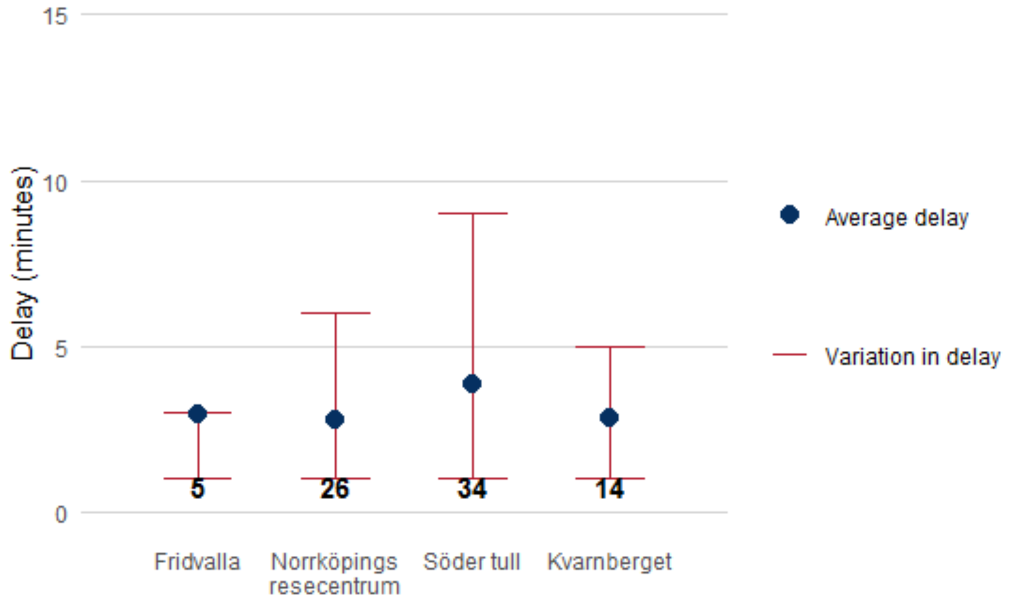

Figure 121 - Delay at a regulation stop during the afternoon peak direction Kvarnberget. The numbers below the bars describe how many trips that were delayed at each stop.

The average travel time distribution for tram line 2 during the morning and afternoon peak can be seen in Figure 122 and Figure 123. For both peaks, the results are similar.

Morning peak

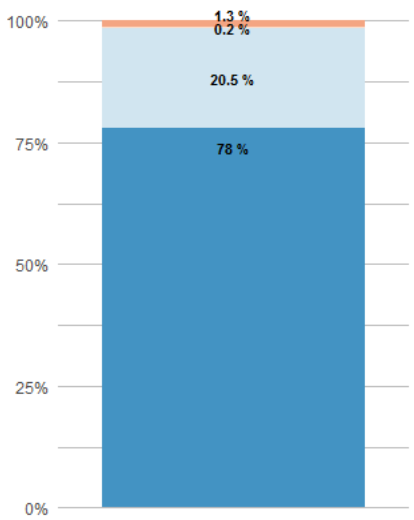

Figure 122 - Travel time distribution for tram line 2 during the morning peak, both directions.

Afternoon peak

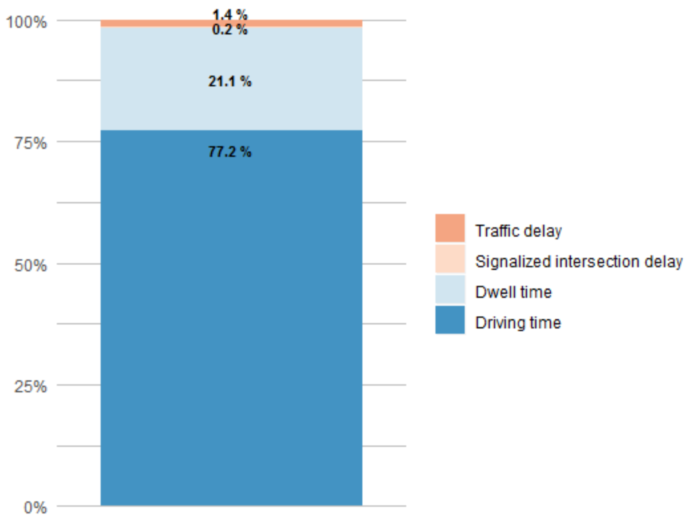

Figure 123 - Travel time distribution for tram line 2 during the afternoon peak, both directions.

Table 20 shows the overall results of the KPIs for tram line 2 during the morning and afternoon peak. The results for each direction are summarized in the table. Generally, the results are worse in for the afternoon peak. For example, the average speed is lower, and the travel time distribution has a higher variance than during the morning peak.

Table 20 - Overall result of tram line 2.

	Morning peak	Afternoon peak
Low speed		
Nr obs. with low speed	4%	3%
Low speed (MM:SS/vehicle)	01:16	01:10
Average speed		
Average speed (km/h)	15.92	15.28
Minimum average speed(km/h)	13.94	13.46
Maximum average speed(km/h)	21.37	19.16
Average speed without dwell time (km/h)	20.04	19.41
Minimum average speed without dwell time (km/h)	17.67	17.20
Maximum average speed without dwell time (km/h)	27.71	23.69
Nr vehicles with speed > speed goal	3%	0%
Nr vehicles with speed > speed based on timetable	85%	66%
Delay		
Average delay per trip at the last stop (MM:SS)	0:55	1:21
Share of trips at least one minute delayed to a regulation stop	38%	46%
Average delay at a regulation stop (MM:SS)	2:22	2:55
Minimum delay at a regulation stop (MM:SS)	1:00	1:00
Maximum delay at a regulation stop (MM:SS)	6:00	14:00
Slack time		
Share of trips with slack time at a regulation stop	26%	25%
Average slack time at a regulation stop (MM:SS)	2:56	1:58
Minimum slack time at a regulation stop (MM:SS)	1:00	1:00
Maximum slack time at a regulation stop (MM:SS)	17:00	6:00
Early departure		
Share of trips that departed early from a regulation stop	2%	7%
Average early departure from a regulation stop (MM:SS)	01:00	01:03
Minimum early departure from a regulation stop (MM:SS)	01:00	01:00
Maximum early departure from a regulation stop (MM:SS)	01:00	02:00
Travel time distribution		
Number of trips	67	86
Shortest dwell time	10%	10%
Average dwell time	20%	21%
Longest dwell time	28%	30%
Shortest traffic delay	0%	0%
Average traffic delay	1%	1%
Longest traffic delay	5%	9%
Shortest signalized intersection delay	0%	0%
Average signalized intersection delay	0%	0%
Longest signalized intersection delay	2%	3%
Shortest driving time	72%	67%
Average driving time	78%	77%
Longest driving time	87%	86%

7.5.2 Further investigation - Tram line 2

Tram line 2 had an average dwell time around 20% of the total travel time which is a significantly bigger part than for all of the other lines investigated. The average dwell time at each stop was, therefore, studied closer. In Figure 124 and Figure 125 shows the average dwell time at each stop in direction Fridvalla respective Kvarnberget during the morning peak. In both directions, the longest average dwell time was at Söder tull. A possible cause could be that Söder tull is a regulation stop and the tram often arrives early to this stop. The second longest dwell time in direction Fridvalla was 2 minutes and 41 seconds at Norr tull closely followed by Hageby vårdcentral with an average dwell time of 2 minutes and 40 seconds. However, both these stops are located close to signalized intersections and the dwell time can, in reality, be signalized intersection delay.

Morning peak

Figure 124 - Average dwell time at each stop during the morning peak in direction Fridvalla.

Figure 125 - Average dwell time at each stop during the morning peak in direction Kvarnberget.

Afternoon peak

Direction Fridvalla

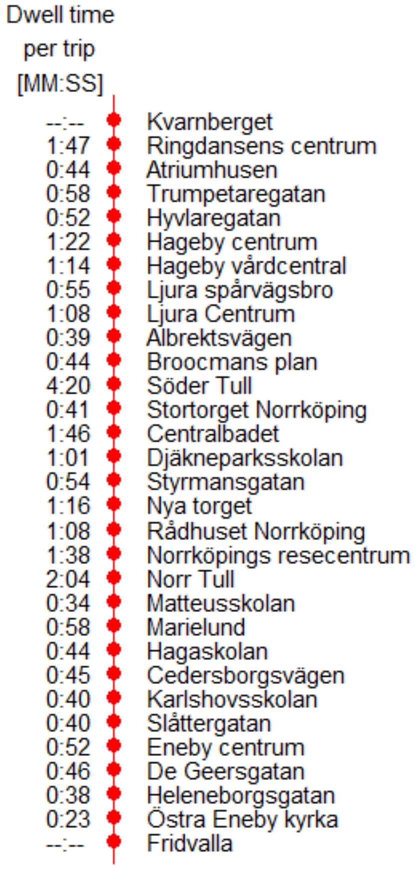

Figure 126 - Average dwell time at each stop during the afternoon peak in direction Fridvalla.

Direction Kvarnberget

Figure 127 - Average dwell time at each stop during the afternoon peak in direction Kvarnberget.

Figure 128 - Sections between the stops in the center of Norrköping.

The figures where the movement of vehicles were visualized showed that the delays usually increase after Söder tull in direction Fridvalla. Therefore, further investigations regarding average speed were performed. The investigated sections are presented in Figure 128. It is evident in Table 21 that the section with the lowest average speed is between Söder tull and Stortorget. Meanwhile, the average speed is quite high on Östra promenaden.

Table 22 shows that it is a similar pattern of where the average speed is high respectively low during the afternoon peak as during the morning peak.

Table 21 - Shows the average speed for the sections in the central parts of Norrköping during the morning peak.

Section	Average speed(km/h) Morning peak -Kvarnberget	Average speed(km/h) Morning peak - Fridvalla
Södertull-Stortorget	7.48	5.15
Stortorget-Centralbadet	15.78	13.57
Centralbadet-Djäkneparksskolan	9.05	15.22
Djäkneparksskolan-Styrmansgatan	11.62	9.28
Styrmansgatan-Nya torget	16.23	16.52
Nya torget-Rådhuset	13.83	14.05
Rådhuset-Norrköpings resecentrum	12.22	13.93

Table 22 - Shows the average speed for the sections in the central parts of Norrköping during the afternoon peak.

Section	Average speed(km/h) Afternoon peak - Kvarnberget	Average speed(km/h) Afternoon peak - Fridvalla
Södertull-Stortorget	6.49	4.57
Stortorget-Centralbadet	13.65	13.83
Centralbadet-Djäkneparksskolan	9.08	16.13
Djäkneparksskolan-Styrmansgatan	11.78	8.59
Styrmansgatan-Nya torget	16.57	16.32
Nya torget-Rådhuset	13.69	13.18
Rådhuset-Norrköpings resecentrum	12.33	13.47

8. Discussion

In the subsections below, the different subjects in this thesis are discussed. Firstly, the errors that could be caused by the chosen methods in this thesis are discussed. Secondly, adjustments of the thresholds are presented. Thirdly, how to interpret the KPIs and their shortages are discussed as well as the different levels of aggregation used, followed by the evaluation of the LOS for the investigated lines and a discussion on what was found during the further investigations. Lastly, how to implement the general process in ÖGTs processes is discussed.

8.1 Sources of error

The choice of method to calculate the distances could have affected the results. However, Haversine distance is a commonly used method and simple to use. The accuracy of the distance must not be perfect for the calculations carried out in this thesis and the effect of the method will be equal for all of the calculations.

Moreover, removal of outliers can cause errors in the calculations. For example, if a lot of observations of a trip are defined as erroneous and excluded, the calculations of the KPIs will be based on a small amount of data which could lead to misleading values of the KPIs. The analysis of the KPIs should, therefore, be done with caution to be able to point out unreasonable values.

8.2 Adjustments of thresholds

To identify the erroneous data, the processes described in section 6 was used. When applying the general process to the different lines, some problems with the definitions of the thresholds used in the filtrations where encountered. Adjustments of the thresholds were therefore applied to fit the different lines properly. One adjustment done was the allowed distance from the shape line to the vehicle's position. For all lines except bus line 42, this threshold was set to five meters. When filtering the positions of bus line 42, a lot of observations were considered erroneous and therefore the allowed distance was increased to ten meters to include more observations. Bus line 410, that has a similar route and operates in the same areas as bus line 42, did not have too few observations with the original threshold of five meters. Further investigations of why the threshold of five meters did not work for bus line 42 was not made. In the future, the allowed distance could be evaluated more. Furthermore, stops have different geographical layouts, especially the first and last stop. A fixed radius for these stops was therefore not possible to use, and the radius was adapted for each first and last stop. For the remaining stops, a fixed radius of 20 meters functioned well, except from the analysis of the tram line. Since the trams used by ÖGT is longer than their buses, and the AVL transmitter is placed in one end of the vehicle that can drive in both directions, a radius of 20 meters was not enough to position a tram at a stop correctly. Therefore, the radius of a tram stop was set to 50 meters to not miss a tram that passed/stopped at a stop.

8.3 Usage of the KPIs

This section will discuss the advantages and shortcomings of the KPIs used in this thesis, as well as how they should be interpreted. Moreover, the aggregation levels and the limitations of aggregation is discussed.

In previous studies, on-time performance is mainly based on punctuality and lack the aspect of how delayed the trips were, how much early the trips departed and the amount of slack time. The on-time performance in this thesis gives information about the average, minimum and maximum delay, slack time and early departure as well as how many trips that were delayed, had slack time or departed early. Moreover, the on-time performance developed is measured for all regulation stops for a trip, and not only for the last stop. As discussed earlier, there is a trade-off between minimizing the delay and slack time. To decrease the risk of delays, more slack time needs to be added to the schedule. If the slack time is reduced, the planning is less robust and more sensitive to delays. With increasing slack time, the travel time and production costs increase as well. Since early departures affect the travelers not yet on the vehicle negative, this too should be considered when evaluating the LOS.

The travel time distribution should be different for different type of lines. For example, an express line with few stops should have a larger share of driving time and a smaller share of dwell time compared to a city line with many stops. If all the traffic lights are programmed to give priority to public transport, the share of signalized intersection delay should be smaller than if they are not. The share of traffic delay depends on the time of the day, the traffic volume in the city and the infrastructure. To summarize, there is not one correct distribution to strive for, but the ideal levels will depend on the type of line, the traffic situation in the city and the setup of the traffic lights.

When calculating the number of minutes that a vehicle is driving at a low speed, it is assumed that there is one observation for each second. However, that might not be the case if there are a lot of erroneous observations. It is therefore important to check that the time a vehicle has driven at a low speed and when the vehicle has not used a low speed is summarized to the time the trip is supposed to take. If the summarized time is diverging a lot the value might not be trustworthy, since too many observations are missing to give a reasonable value.

It is not evident that the average speed should be above the same specific threshold for all different types of modes. The average speed can vary a lot depending on where the line is operating, the design of the route (for example if there are many or few stops), the infrastructure in the area where the line is operating, etc. It is therefore important to evaluate what a reasonable speed is for the investigated line.

To evaluate the level of service for the investigated lines, a time period of one week was chosen. Hence, the results in this thesis only show the traffic situation for one week and which is not necessarily representative for the general level of service for the line. To find problems in the system, the KPIs were aggregated on several levels. In the further investigations, each line has been analyzed with different KPIs and level of aggregation to show the different possibilities. Examples of ranges of the aggregation levels can be from one stop to the whole system, from one hour to one year. However, if a high level of aggregation (the whole system) is chosen the analysis gets complex and is time consuming; there is a trade-off between the amount of data to include and the time to perform the analysis. Furthermore, in this thesis, no limitations in levels of aggregation have been found other than time consumption. The LOS was investigated for one line at a time to discover problems in the system affecting the LOS. If several lines would have been analyzed together, deviations and problems could have been more difficult to identify. Although, evaluating the LOS for the whole system could also be beneficial for a public transport provider.

8.4 Level of Service of bus line 4

When analyzing the results of bus line 4 for the KPI measure low speed the bus line is considered to have a good LOS regarding this aspect. Figure 26 and Figure 27 show that there were quite many places where positions of low speed have been measured. One of the reasons for this could be the number of bus stops. For example on Boställsgatan, it was not possible to reach the speed limit of the road since there were so many stops.

The average speed for bus line 4 during the examined week was generally good. Although, there were many vehicles that do not reach the average speed goal set by the board, possibly due to the average speed according to the time table which was lower than the goal. Furthermore, there were many vehicles that did not reach the average speed set in the timetable, but many of them were close to the goal. The results also show that there was a tendency that the average speed was generally lower during the afternoon peak than during the morning peak which indicates that the LOS was lower during the afternoon peak.

The average time the buses were delayed to the last stop was generally low, although around 50% of the trips were delayed to a regulation stop which is bad for the LOS. The average delay was quite long, and many trips were delayed to some of the regulation stops, which is affecting the LOS negatively. This should, therefore, be studied further to be able to improve the promise made to the customer in the timetable. For example, the bus was almost always late to the regulation stop Isberget in the direction Landbogatan. The average delay of the delayed trips for this stop was almost four minutes which is believed to be too long.

When analyzing how well the trips were following the timetable it is evident that the trips were following quite well even when they were a bit delayed. If they were delayed, they were not that delayed to the last stop, which means that they were able to catch up. Although, the situation was worse during the afternoon peak than during the morning peak. This is strengthening the indication that the LOS was worse during the afternoon peak.

The buses mainly waited at the regulation stops until departure time which results in an acceptable LOS. However, the regulation stops with the highest number of early departures were US södra entren in direction Linköpings resecentrum. Since this stop was overrepresented, ÖGT should investigate whether this is due to ignorance of the drivers or if it is problematic to stand still at this stop.

There were a lot of trips that had slack time at the first stop, this is probably to have a margin for delays. Generally, there were few buses that had slack time in the middle of the trip as well as at the last stop. This confirms the there are problems with delays since buses rarely wait at regulation stops during a trip or at least indicates that there is not too much slack time in the time table.

The distribution of travel time seems to have diverged more during the afternoon peak than during the morning peak. The travel time distribution was generally reasonable between the different factors, which implies that the LOS is good in this aspect. The factor that could be improved is the signalized intersection delay.

In Figure 129 an attempt to evaluate the overall LOS for bus line 4 has been made. Every KPI have been graded as either good, acceptable or bad. Even though the LOS regarding speed was good, the bad LOS considering on-time performance was valued as more important for the customers. Hence, the overall LOS for bus line 4 was considered acceptable.

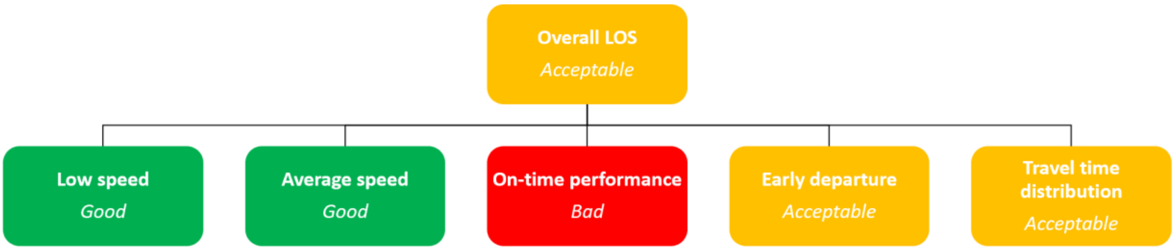

Figure 129 - The overall LOS for bus line 4.

8.5 Level of Service of bus line 410

For bus line 410 the LOS concerning low speed is quite bad since a high part of the observations had a speed lower than 60% of the speed limit and the average speed was low. The average speed varied for different times of the day, probably depending on the traffic and was generally lower during the afternoon peak. In the afternoon, only 30% of the trips could keep the speed according to the timetable which could lead to delays and unreliability. The LOS of the average speed was therefore bad. Either the timetable could need adjustments or actions to improve the traffic situation is needed. However, the average speed was always over ÖGT's speed goal of 28 km/h though this could imply that the goal should be set higher for this kind of traffic.

Regarding the on-time performance, the LOS is bad for the studied time period. During the morning peak, no trips heading towards Norrköping was late to the last stop Norrköping resecentrum. Norrköping resecentrum is an important stop since the passengers can change to other buses, trains and trams there. Hence, no delays to this stop result in a good LOS. Among the trips heading to Mellangrind during the morning peak, some of them were delayed to the last stop. In the afternoon, several trips were delayed to Norrköping resecentrum, as well as to Mellangrind. Especially the trips to Mellangrind suffers from delays, at Bävervägen the average delay among the delayed trips was ten minutes during the afternoon peak (Figure 69) which results in a bad LOS for these trips.

Mainly, there was slack time at the first and last stop for both directions and time periods and this does not affect the customers in a bad way. Slack time at the first or last stop foremost gives a robust timetable. Delayed vehicles from earlier trips will have some margins in the schedule before starting the next trip and some extra time in the end to catch up with delays that build up during the journey. With much slack time in the middle of a trip, passengers could be annoyed if the vehicle is standing still for a longer time. More scheduled slack time for this bus line could however decrease the delays; though it would also result in longer travel times when there is less traffic. In conclusion, it is difficult to say what the LOS is concerning the slack time for bus line 410.

The LOS regarding early departures is good for bus line 410, a few trips left some seconds early from the regulation stops. To improve the LOS further in this aspect, ÖGT could stress how important it is to not leave early from regulation stops to their drivers. Potentially, it is not possible for the buses to stop and wait at some regulation stops, which should be kept in mind when deciding which stops that are regulation stops.

The travel time distribution shows that on average the bus was driving around 90% of the time. Even though bus line 410 has many stops, the average dwell time was not that high. The LOS regarding the travel time distribution is therefore good.

When looking at the movements of vehicles, the results strengthen that the LOS is lower in the afternoon.

In Figure 130 an attempt to summarize the overall LOS for bus line 410 has been made. Average speed and on-time performance are higher valued in a customer perspective than early departure and travel time distribution. This result in that the overall LOS for this line is bad. The number of stops results makes it difficult to plan a well functioning timetable and this could be a reason for the poor on-time performance and average speed. However, this type of line is supposed to have many stops to reach many passengers in the rural areas and if the number of stops is decreased the clientele will change.

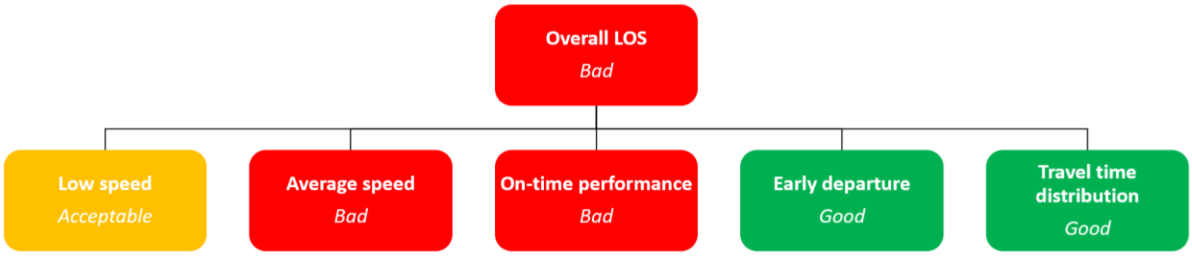

Figure 130 – The overall LOS for bus line 410.

8.6 Level of Service of bus line 42

There were a high proportion of positions where vehicles were driving at a low speed for bus line 42, this induces that vehicles were driving at a low speed for many minutes. The observations where a low speed was used are mainly concentrated in the city centers included in the route which indicates that the LOS is worse in the central part of the cities than in the rural areas of the route.

The average speed was acceptable, although it was diverging quite much. There were many vehicles that did not reach what the average speed should be according to the timetable. This indicates that there is either problem with the amount of traffic or that the timetable needs to be improved. The investigation of this line was however based on quite a few trips, which makes it difficult to determine the root cause of the problem. All of the vehicles had an average speed that was above the average speed goal of 28km/h but as earlier mentioned the average speed goal needs to be reformulated.

There were fewer trips that were delayed on bus line 42 than 410, this could be due to the fact that there are fewer stops on bus line 42. Moreover, bus line 42 was not diverging as much as 410 between the morning and afternoon peak in average time the buses were delayed. Although bus line 42 was almost always late to the second to last regulation stop and the average delay of the delayed trips to this bus stop was five minutes. The LOS is therefore considered bad in this aspect.

Bus line 42 usually had slack time at its bus stops, however, it was not as long as for bus line 410. During the morning peak, there was only slack time in the beginning and at the end of the route.

Meanwhile, during the afternoon peak, the results showed that there was slack time in the regulation stops in the middle of the route as well.

The LOS regarding early departures is considered to be acceptable. At least one bus had left early on each regulation stop though all early departures were less than one minute. This should be monitored to prevent an increase in early departures. If the early departures would increase, it might be a good idea to emphasize the operator that they need to decrease the early departures both in time and occurrences.

The travel time distribution for bus line 42 looked good and nothing was standing out that needs to be analyzed. This means that the LOS regarding travel time should be considered good.

When studying the movement of the vehicles that were diverging the most to the timetable, it is evident that the bus was getting more delayed as the bus progresses throughout the route. This could indicate that the timetable is too optimistic since there are problems in both directions and during both of the examined peaks.

An attempt to summarize the overall LOS for bus line 42 can be seen in Figure 131. When adding the LOS for each KPI, the overall LOS was considered to be acceptable.

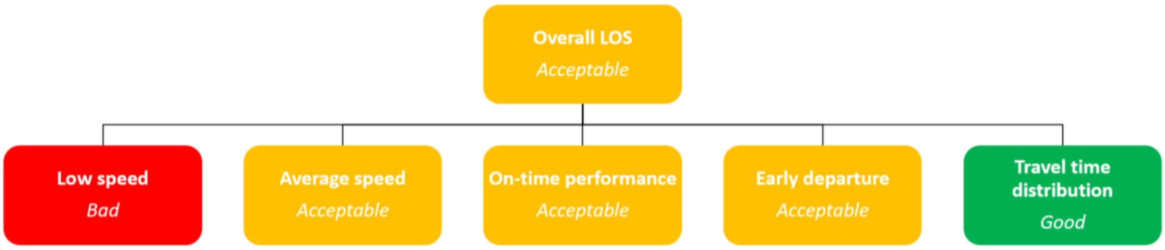

Figure 131 - Overall LOS for bus line 42.

8.7 Level of Service of tram line 2

Since the speed limit of trams probably is not the same as for the nearest road at all places, the KPI low speed could be misleading. However, low speed of tram line 2 was comparable to low speed of bus line 4 and the LOS is considered good.

The average speed was quite low considering that the tram often has its own lane, a separate signal system with priority and should therefore not be affected much by the car traffic. The low average speed probably derives from the number of stops for the line. The average speed without dwell time was significantly higher. Moreover, the tram has a longer breaking distance than buses and accelerates slower as well. Therefore, unnecessary stops should be eliminated when planning a tram line to achieve a higher average speed. Table 21 and Table 22 shows that the tram at some parts had a speed equivalent to walking. Overall, the LOS for the average speed is acceptable to low.

During the morning peak, many trips were delayed during the journey but only a few were delayed to the last stop. Probably, most of the passengers do not travel from the first stop to the last stop. Consequently, the on-time performance for the stops Norrköpings resecentrum and Söder tull should be more important than to Fridvalla and Kvarnberget for the customers. For example, about 80% of the trips were at least one minute delayed to Söder tull during the afternoon peak in direction Kvarnberget. Additionally, more trips were delayed to the last stop and started late at the first stop during the afternoon. To summarize, the LOS is acceptable during the morning peak and bad in the afternoon.

Regarding the slack time for tram line 2, it seems to be some errors in the data affecting the maximum slack time at some stops. About half of the trips had slack time at the last stop, and some trips had slack time at Norrköpings resecentrum and Söder tull. Since some trips had problems with delay and some had excess time, different travel times could be considered for different times of the day since all of the trips had the same scheduled travel time (46 minutes in direction Kvarnberget and 47 minutes in direction Fridvalla) during the studied time period.

The LOS considering early departures from regulation stops is good for tram line 2. Especially in the morning, very few trips departed early and only a few seconds. In the afternoon more trips departed early but still not remarkable early.

Compared to the other lines, tram line 2 had a significantly larger part of dwell time. The higher share of dwell time could be due to the many stops and passengers. Moreover, many of the stops are in the area of a signal, which means that signalized intersection delay could have been interpreted as dwell time. The traffic delay could too, in reality, be signalized intersection delay since there are few places where the tram could be interrupted by other traffic. The dwell time was varying between 10% and 30% which leads to larger variations in driving time as well. The LOS considering the travel time distribution is therefore acceptable, but the dwell time should be looked at more closely.

When looking at the movement of vehicles, the trips with the worst RMSE were still quite good. Only in the afternoon peak in direction Fridvalla the worst trips varied a lot from the timetable. For example, the trams in those trips seem to have spent a lot of time at stops near schools.

Figure 132 shows an attempt to summarize the overall LOS for tram line 2. Even though two KPIs got a good LOS, the overall LOS was only considered to be acceptable since the on-time performance was bad. As described before, the on-time performance is the KPI affecting the customers most and was therefore valued high.

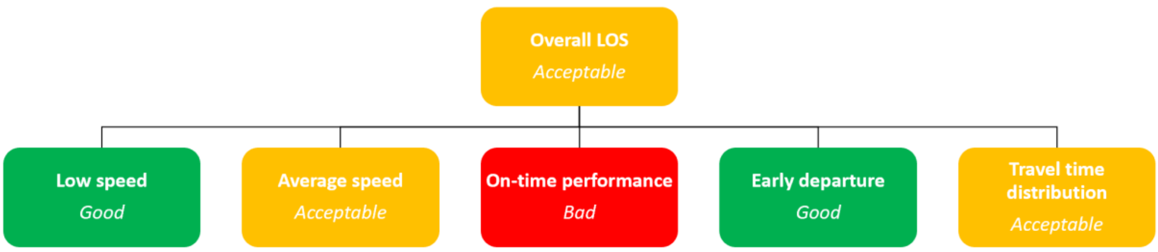

Figure 132 - Overall LOS for tram line 2.

8.8 Further investigations of the lines

Generally, when low speeds and low average speeds were observed, the further investigations found the cause to be either traffic jams or the layout of the road. For example, the low speed on Kunskapslänken was assumed to be mainly due to that the road is curvy, and buses cannot drive with full speed there. For line 410, the further investigation showed that the trips that deviated much from the timetable had a lower average speed that the line in total. To exclude the possibility that longer dwell times caused the lower speed, the dwell times were computed and compared. Even though these trips had longer dwell times, it was not enough to explain the total delay. Therefore, the delays were assumed to be due to the traffic in the peak hours.

For bus line 42, the further investigation showed that there were problems with congestion in the roundabout crossing Riksvägen and Finspångsvägen in both the inbound and outbound direction. Probably, this leads to delays for bus line 42 and other lines that pass this part of the system.

The average dwell time on each stop was further investigated for tram line 2. This showed that there were stops that did not have a dwell time at all in a specific direction during the examined week. If a stop does not have any dwell time at all this is a strong indication that the stop is unnecessary. The number of stops makes it impossible for the tram to drive with a high speed since it needs to deaccelerate often due to stops. However, some of the dwell time could, in reality, be time waiting for green light since there is often traffic signals in close connection to the tram stops. If some of the stops are removed, possibly some of the traffic signals could be removed as well.

8.9 Incorporation of the general process in ÖGTs operational management

The KPIs and the general process formulated in this thesis can be incorporated into ÖGTs working progress in different ways. One example is to use the general process when constructing timetables. In this way, it would be easier to make improvements to the timetable since critical aspect can be discovered with visualizations or measures. It is then possible for ÖGT to eliminate problems before a customer complains about them. Additionally, this will result in more satisfied customers and also a better LOS overall. Another example is to use the KPIs to measure if the goals set up by the board of Region Östergötland are fulfilled. The only goals in the steering document set up by the board of Region Östergötland that is formulated numerically are regarding average speed. Therefore, it is suggested that ÖGT formulate more goals to strive for concerning on-time performance and travel time. Moreover, the existing average speed goals are formulated as earlier mentioned: average speed in the city center should be at least 20km/h and in the outer parts the speed should be 28km/h. It would be better to rewrite these goals and divide them it into city lines and rural lines instead since the central and outer parts of a city are vague and can be interpreted in different ways. If it would be divided into city and rural lines it would also be easier to calculate the measure as the KPI described in this thesis and it is possible that the average speed goal for the rural lines could be increased. Based on the results in this thesis, a suggested goal for the rural lines is an average speed of 45 km/h. The goal of an average speed of 20km/h in the city center is considered to be an accomplishable goal for the city lines. However, in order for ÖGT to achieve this goal they must start to plan their timetables according to the goal. For example, only a few trips of bus line 4 had an average speed according to the time table that was higher than 20 km/h. If this is not changed, the goal an average speed of 20km/h for city lines will never be fulfilled.

To increase the efficiency of a line, ÖGT should aim to increase the share of driving time. If the share of driving time is high, the vehicle spends little time standing still at stops, intersections and in a traffic jam. However, some lines will naturally have a higher share of dwell time and a smaller share of driving time to reach more customers, there is a trade-off between pleasing the customers already in the vehicle and potential customers along the route. Concerning the share of traffic delay and signalized intersection delay, ÖGT should strive to minimize these parts to offer a reliable service to the customers. With less disturbance from traffic and signals, ÖGT will gain a system that is more robust and some of the sources of delays are removed.

The goal of the on-time performance should be the same irrespective of if the type of line. To measure the on-time performance of a line, ÖGT should define intervals where the on-time performance is good, bad and very bad. Moreover, ÖGT then need to set a goal of the proportions for the three intervals. A common strategy when planning public transport is to have a tight schedule in the first and middle part of the trip and add extra time in the end. Therefore, the interval for good on-time performance must not be too narrow as some delays will always occur with this planning strategy. On the contrary, if the customers do not travel from the first to the last stop of the line, they will often experience delays, and this should be considered as well.

The KPI measuring early departure makes it possible for ÖGT to claim the operator to pay a quality deductive penalty if they leave a regulation stop too early. One requirement that ÖGT have on their operator is that they should not leave regulation stops earlier than the time set in the timetable. When studying the results of the investigated lines they show that there are many occurrences where the operator leaves a regulation stop too early even though most of the early departures are less than one minute.

9. Conclusion

The aim of this thesis was to develop a general process to identify and remove erroneous data as well as to evaluate the LOS based on AVL data from vehicles in a public transport system. The process that was developed proposes five steps to detect and remove outliers and three main KPIs to evaluate the LOS. Examples of how to find possible improvements can be seen in the sections regarding further investigations of each line in section 7. The formulated research questions in section 1.2 are answered below.

The following errors in the AVL data were identified and removed with the stated methods. Observations that were not following the route of a line was considered erroneous. To determine erroneous observations the distance from the observations to the route was calculated. If the distance was higher than a threshold value (5 and 10 meters were used in this thesis), the observation was considered erroneous. Observations with too high speed were also removed, the speed in each observation was compared to the speed limit at the closest road and if the speed in the observation was 20% higher than the speed limit, the observation was excluded from the data set. Moreover, duplicated rows in the data were removed, rows containing the exact same data was removed and only the first occurring row was kept in the data set. If several trip IDs were assigned to the same vehicle ID during the same time point, the number of occurrences of those trip IDs were calculated. The trip ID that had the most occurrences was saved and the observations belonging to the other trip IDs are considered erroneous. When several observations during the same timestamp was registered to the same trip ID, all of the observations belonging to that trip ID were removed. Trips with deviating travel times were removed; ÖGTs system to collect the data already handled unfinished trips and therefore, the developed process only identified and removed trips with too short travel times. The travel time for each trip was compared to the scheduled duration and all observations associated with a trip was removed if the travel time for that trip was less than 75% of the scheduled travel time.

There are several possible KPIs that can be used when evaluating the LOS. However, the data available limits which KPIs that are appropriate to use. The data provided in this thesis resulted in the usages of the following main KPIs: on-time performance, travel time distribution and speed. No limitations regarding the level of aggregation were found for the KPIs used in this thesis. It is rather a trade-off between time and purpose that determines what level of aggregation that should be used. Since the processing was found to be time-consuming, a well-defined time period and geographical area of interest are important to not analyze unnecessary data. Examples of different levels of aggregation can be found in section 7.

The thresholds in this thesis should not be seen as fixed values, they should be adjusted to the geographical area and type of public transport mode. Before an analysis is performed, it is important to evaluate the suitability of the values of each threshold, otherwise, the results could be based on unrepresentative data. The chosen threshold for each line in this thesis is stated in section 5 and 6.

The general process should be structured in the following steps. The first step in the process should be to identify and remove erroneous data. The second step is to calculate the KPIs and the third step is to analyze the results. In the process, there is a fourth and fifth step which is not carried out in this thesis but should be implemented in reality. Step one is divided into five sub-steps, where each step identifies and removes the different kind of outliers described in question one in this section.

For the studied time period the investigated lines were considered to have the following LOS. The LOS for each line could be valued differently depending on how the different KPIs are weighted.

- Bus line 4: Acceptable.
- Bus line 410: Bad.
- Bus line 42: Acceptable.
- Tram line 2: Acceptable.

As an improvement of this work, thresholds that state the status of the KPIs should be implemented. For example, what average speed is good, acceptable or bad for different types of public transport modes, how much slack time should a trip have, etc. to evaluate the LOS objectively. Since only AVL data is used in this thesis, it is difficult to determine the real cause of bad LOS. To find the root cause of a problem, other data such as passenger, weather and cellular data could be added to the analysis. A deeper analysis could then be executed, and the real cause of a problem is more likely to be found.

Bus line 410 had a bad LOS during the examined week, it is therefore suggested that ÖGT should investigate this line further to improve the LOS. Moreover, ÖGT should define goals regarding on-time performance and travel time, re-define the average speed goals and clarify how the goals should be measured. To continue to improve the LOS to the customers, ÖGT should strive to implement the developed general process in their existing processes. The advantages of implementing the process are many; decrease in costs and travel times, high LOS to their customers; the results could be used as support to decision making and to enforce changes in the infrastructure.

Not only a public transport provider can benefit from using the general process to analyze the public transport system, but it is also of interest for stakeholders such as the municipality and county council. The socioeconomic benefit could increase if all the parties would collaborate to define mutual goals and strategies to increase the LOS.

References

Adelsköld, A. & Ejder, M. (2018). *Linje 6 - En lyckad satsning på Stockholms nya stomlinje*. Stockholm: Keolis. (http://www.stockholm.se/PageFiles/1587700/utvardering-stombusslinje-6-en-lyckad-satsning-pa-stockholms-nya-stomlinje.pdf)

Barabino, B., Di Francesco, M., Mozzoni, S. (2017). *An Offline Framework for the Diagnosis of Time Reliability by Automatic Vehicle Location Data*. IEEE Transactions on Intelligent Transportation Systems. 18(3): 583-594 March, 2017 (https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7519088)

Büchel, B., Corman, F. (2018). *Modelling probability distributions of public transport travel time components*. 18th Swiss Transport Research Conference. Ascona, Switzerland 16-18 May 2018. (http://hdl.handle.net/20.500.11850/263929)

Camus, R., Longo, G., Macorini, C. (2005). Estimation of Transit Reliability Level-of-Service Based on Autimatic Vehicle Location Data. Transportation Research Record Journal of the Transportation Research Board 1927(1):277-286 January, 2005.
DOI: 10.1177/0361198105192700131
(https://journals.sagepub.com/doi/10.1177/0361198105192700131)

Cathy, F.W. & Dailey, D.J. (2003). *A prescription for transit arrival/departure prediction using automatic vehicle location data*. Transportation Research Part C: Emerging Technologies. 11(3-4): 241-264. doi: 10.1016/S0968-090X(03)00023-8 (https://ac-els-cdn-com.e.bibl.liu.se/S0968090X03000238/1-s2.0-S0968090X03000238-main.pdf?_tid=0ed8bae9-0c40-4b5d-aa70-e836de28495a&acdnat=1548689924_d1d968537103bf1e0ee3c5964bb9f7db)

Christofa, E. & Skabardonis, A. (2010). *Traffic Signal Optimization with Conditional Transit Signal Priority for Conflicting Transit Routes*. In proceeding of 12:th World Conference on Transport Research. Lisbon, Portugal 11-15 July 2010. (https://www.researchgate.net/publication/272718821_Traffic_Signal_Optimization_with_Application_of_Transit_Signal_Priority_to_an_Isolated_Intersection)

Cronemyr, P. (2015). Six Sigma -Reducera oönskad variation för att kunna styra processerna. *Supply chain effect*. (3):34-39.

Gilmore, Stephen. & Reijsbergen, D. (2015). *Validation of Automatic Vehicle Location Data in Public Transport Systems Twenty-ninth and thirtieth Annual UK Performance Engineering Workshops (UKPEW)*, Electronic Notes in Theoretical Computer Science 25 November 2015 318:31-51. doi: 10.1016/j.entcs.2015.10.018 (https://ac-els-cdn-com.e.bibl.liu.se/S1571066115000596/1-s2.0-S1571066115000596-main.pdf?_tid=eee0a484-ba58-4633-9371-7d1b13e19a3f&acdnat=1548676467_00e6a498d71b80c46a5b468e4cf73d03)

Google, Inc. (2018). *GTFS Realtime Overview*. (https://developers.google.com/transit/gtfs-realtime/) [2019-01-30]

GTFS.org. (n.d.). *General Transit Feed Specification*. (https://gtfs.org/) [2019-01-30]

Gunnarsson, A. System integrator at Östgötatrafiken (2019). Personal communication, 28th January 2019.

Kieu, L. M., Bhaskar, A., Chund, E. (2015). *Public transport travel time variability definitions and monitoring.* ASCE Journal of Transportation Engineering, 141(1). doi: 10.1061/(ASCE)TE.1943-5436.0000724

Klasander, J. Traffic and society strategist at Östgötatrafiken (2019a). Meeting regarding traffic planning, Östgötatrafiken headquarters, 24th of January 2019.

Klasander, J. Traffic and society strategist at Östgötatrafiken (2019b). Personal communication, 20th March 2019.

Klasander, J. Traffic and society strategist at Östgötatrafiken (2019c). Personal communication, 3th April 2019.

Ma, Z., Ferreira, L., Mesbah, M. (2014). *Measuring Service Reliability Using Automatic Vehicle Location Data.* Mathematical Problems in Engineering. Volume 2014, Article ID 468563 (http://dx.doi.org/10.1155/2014/468563)

Van Oort, N. & Van Nes, R. (2007). *Improving reliability in urban public transport in strategic and tactical design*. Transportation research board 87th annual meeting. Washington DC, United States 13-17 January 2008. (https://www.researchgate.net/profile/Niels_Oort/publication/237238196_IMPROVING_RELIABILITY_IN_URBAN_PUBLIC_TRANSPORT_IN_STRATEGIC_AND_TACTICAL_DESIGN_Prepared_for_the_87th_Annual_Meeting_of_the_Transportation_Research_Board_2008/links/551ee0b00cf29dcabb083fc7/IMPROVING-RELIABILITY-IN-URBAN-PUBLIC-TRANSPORT-IN-STRATEGIC-AND-TACTICAL-DESIGN-Prepared-for-the-87th-Annual-Meeting-of-the-Transportation-Research-Board-2008.pdf)

Matulin, M., Mrvelj, Š., Jelušić, N. (2011). *Two-Level evaluation of public transport performances.* Promet – Traffic & Transportation. 23(5): 329-339. doi:10.7307/ptt.v23i5.151(https://traffic.fpz.hr/index.php/PROMTT/article/view/151/58)

OpenStreetMap (n.d). *OpenStreetMap förser tusentals webbsidor, mobilappar, och fysiska apparater med kartdata* (https://www.openstreetmap.org/about) [2019-04-15]

Pearson, R. K. (2002). *Outliers in Process Modeling and Identification.* IEEE Transactions on Control Systems Technology IEEE Trans. Contr. Syst. Technol. Control Systems Technology, IEEE Transactions on. 10(1):55-63 Jan, 2002.

Predic, B., Rancic, D., Milosavljevic, A. (2010). *Impacts of Applying Automated Vehicle Location Systems to Public Bus Transport Management.* Journal of Research and Practice in Information Technology, 42(2). (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.644.4036#?)

Region Östergötland (2016). *Regionalt trafikförsörjningsprogram för Östergötland 2030.* (https://wssext.regionostergotland.se/Politiska%20dokument/Trafik%20och%20samh%C3%A4llsplaneringsn%C3%A4mnden/Regionalt%20trafikf%C3%B6rs%C3%B6rjningsprogram%202030.pdf)

R Foundation (n.d). *What is R?* (https://www.r-project.org/about.html) [2019-05-29]

SCB (2019). *Folkmängd i riket, län och kommuner 31 december 2018 och befolkningsförändringar 1 oktober–31 december 2018.* (https://www.scb.se/hitta-statistik/statistik-efteramne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/kvartals--och-halvarsstatistik--kommun-lan-och-riket/kvartal-4-2018/) [2019-03-21]

Svensk kollektivtrafik (2019). *Kollektivtrafikbarometern Årsrapport 2018.* (https://www.svenskkollektivtrafik.se/globalassets/svenskkollektivtrafik/dokument/verktyg-och-system/kollektivtrafikbarometern/kollektivtrafikbarometern-arsrapport-2018.pdf) [2019-05-09]

Trafiklab (n.d). *GTFS Sverige 2.* (https://www.trafiklab.se/api/gtfs-sverige-2/dokumentation) [2019-01-30]

Trafikverket (2015). *Reviderade prognoser for person- och godstransporter 2040*. Borlänge: Trafikverket. ISBN: 978-91-7725-376-1. (https://www.trafikverket.se/contentassets/7e1063efbcfd4b34a4591b0d4e00f855/2018/reviderade_prognoser_for_person_godstransporter_2040_trafikverkets_basprognoser_20180401_ver_181115.pdf)

Trompet, M., Liu, X. and Graham, D. J. (2011). *Development of Key Performance Indicator to Compare Regularity of Service between Urban Bus Operators.* Transportation Research Record, 2216(1): 33–41. doi: 10.3141/2216-04 (https://journals.sagepub.com/doi/pdf/10.3141/2216-04)

Upadhyay, A (2019) *Haversine Formula – Calculate geographic distance on earth* (https://www.igismap.com/Haversine-formula-calculate-geographic-distance-earth/) [2019-03-06]

Yang, F et al. (2018). *Measuring temporal and spatial travel efficiency for transit route system using low-frequency bus automatic vehicle location data*. Advances in mechanical engineering.10(10): 1-11 doi: 10.1177/1687814018802128(https://journals.sagepub.com/doi/pdf/10.1177/1687814018802128)

Wahlstedt, J. (2014). *Evaluation of bus priority strategies in coordinated traffic signal systems.* Lic.-avh. KTH. (https://www.diva-portal.org/smash/get/diva2:715636/FULLTEXT01.pdf)

Östgötatrafiken (2019a). *Medvind för kollektivtrafiken under 2018.* (https://www.ostgotatrafiken.se/info/nyhetsarkiv/medvind-for-kollektivtrafiken-under-2018/) [2019-03-21]

Östgötatrafiken (2019b). Årsredovisning 2018. (https://www.ostgotatrafiken.se/globalassets/media/regionen/arsredovisningar/arsredovisning-2018-ab-ostgotatrafiken_.pdf) [2019-05-08]

Östgötatrafiken (2019c). Hållbarhetsredovisning 2018. (https://www.ostgotatrafiken.se/globalassets/media/regionen/arsredovisningar/hallbarhetsredovisning-2018-ab-ostgotatrafiken.pdf) [2019-05-08]

Östgötatrafiken (2018a). *Vår trafik.* (https://www.ostgotatrafiken.se/info/var-trafik/) [2019-03-21]

Östgötatrafiken (2018b). *Tillgängligt, bekvämt och tryggt.* (https://www.ostgotatrafiken.se/info/vi-och-vart-uppdrag/tillgangligt-bekvamt-och-tryggt/) [2019-03-21]

Östgötatrafiken (2018c). *Tidtabeller*. (https://www.ostgotatrafiken.se/reseinfo/planera-din-resa/tidtabeller/) [2019-03-21]

Appendix 1 – Pseudocode to calculate the KPIs

In Figure 1, the pseudocode for the calculation of the dwell time can be found. It was assumed that the number of observations with a speed equal to zero and within a stop area was close enough to the real dwell time in seconds.

```
# A set of observations with a speed of 0 m/s
data_zero <- data which(data$speed == 0)

# Find which observations with a speed of 0 m/s is within a stop area
data_dwell <- data_zero which distanceToStop ≤ D_stop

# Calculate the dwell time as number of observations in data_dwell
T_dwell= numberOfRows(data_dwell)
```

Figure 1– Pseudocode for calculation of dwell time.

The pseudocode in Figure 2 describes how the data set with observations with a speed equal to 0 m/s, within a signalized intersection area but excluding observations within a stop area is constructed.

```
# A set of observations with a speed of 0 m/s
data_zero <- data which(data$speed == 0)

# Find which observations with a speed of 0 m/s is within a signalized
intersection area
data_signal <- data_zero which distanceToSignalizedIntersection ≤ D_sign

# Exclude observations within a stop area
data_signal <- exclude data_dwell from data_signal

# Calculate the signalized intersection delay as the number of
observations in data_signal
T_sign.delay= numberOfRows(data_signal)
```

Figure 2 – Pseudocode for calculation of the signalized intersection delay.

The traffic delay in seconds was calculated as the number of observations with a speed equal to 0 m/s neither in a stop area or a signalized intersection area. The pseudocode for the calculation of the traffic delay can be seen in Figure 3.

```
# A set of observations with a speed of 0 m/s
data_zero <- data which(data$speed == 0)
# Find which observations with a speed of 0 m/s is due to traffic delay
data_traffic <- exclude data_signal and data_dwell from data_zero
# Calculate the traffic delay as the number of observations in data_traffic
T_traf.delay=numberOfRows(data_traffic)
```

Figure 3 - Pseudocode for calculating the traffic delay.

The average speed is calculated by the Equation (6) in the KPI section. The other KPIs that are based on the average speed were calculated based on the pseudocode in Figure 4.

```
N_{veh.A>T}  = which(A_{speed.actual} > A_{speed.timetable})

N_{veh.A>G}  = which(A_{speed.actual} > A_{speed.goal})

A_{speed-min}  = min(A_{speed})

A_{speed-max}  = max(A_{speed})
```

Figure 4 - Pseudocode for the KPIs based on average speed.

The visualization that shows the movement of vehicles is performed using the pseudocode in Figure 5.

```
for all i:
    VehiclePositions$RMSE=RMSE(T_{time.actual}, T_{time.timetable})


Order(VehiclePositions$RMSE, decending)
Print(T_{actual}  & D) for(VehiclePositions$RMSE[[1]] &
                          VehiclePositions$RMSE[[2]] &
                          VehiclePositions$RMSE[[3]])

Hold on

Print(T_{timetable} & D_{timetable})
                    for(VehiclePositions$trip_id[[1]] &
                        VehiclePositions$trip_id[[2]] &
                        VehiclePositions$trip_id[[3]] )
```

Figure 5 - Pseudocode for visualization of the movement of a vehicle.

The calculations of the $N_{veh.low}$ is in pseudocode done as in Figure 6. $T_{veh.low}$ is then calculated as in Equation (9) described in the KPI section.

```
for all i :
    VehiclePositions$DistanceTL = min(dist(i, Trafficlights))

for all i :
    VehiclePositions$DistanceBS = min(dist(i,BusStop))


N_{veh.low} = which(VehiclePositions$speed< V_{low}·SpeedTrafikverket$speed

                & VehiclePositions$DistanceTL<= D_{TL}

                & VehiclePositions$DistanceBS<= D_{BS})
```

Figure 6 - Pseudocode for $N_{veh.low}$.

The visualization of low speeds is displayed by the pseudocode in Figure 7.

```
Print(InMap( if (VehiclePositions$speed <
                 Speed_low·SpeedTrafikverket$speed
                 & VehiclePositions$DistanceTL<D_TL
                 & VehiclePositions$DistanceBS<= D_BS)))
```

Figure 7 - Pseudocode to visualize low speeds.

Appendix 2 – Pseudocode to remove outliers

To remove the general errors that have been found in the AVL data, the pseudocode in Figure 8 was used.

```
#removes duplicates in entity ID
[!duplicated(VehiclePositions$entity.id)]

#removes rows where a trip id have multiple transmits each second
if(VehiclePositions$trip_id & VehiclePositions$timestamp)
    remove rows

#if multiple trip_id use the same vehicle.id, only save the trip_id with
#the largest amount of observations
for all trip_id which vehicle.id == multiple
        save trip_id which nrow(trip_id) == Largest
```

Figure 8 - Pseudocode to remove general errors.

To remove all of the observations with an invalid position the pseudocode in Figure 9 was used.

```
Shapecoord = (Shapes$shape_pt_lat, Shapes$shape_pt_lon)
AVLcoord = (VehiclePositions$latitude, VehiclePositions$longitude)

distance = distToLine(AVLcoord, Shapecoord, distfun=distHaversine)

valid_Positions = which(VehiclePositions$distance <=
                                                  D_ToLine)
invalid_Positions = which(VehiclePositions$distance >
                                                  D_ToLine)
```

Figure 9 - Pseudocode to remove all observations with invalid positions.

There might be observations where unreasonable speeds have been measured. These outliers are removed by using the pseudocode in Figure 10.

```
VehiclePositions <- round(VehiclePositions$longitude,
                          VehiclePositions$latitude, Digits  = 4)
SpeedTrafikverket <- round(SpeedTrafikverket$longitude,
                          SpeedTrafikverket$latitude, Digits  = 4)


if((VehiclePositions$longitude & VehiclePositions$latitude)==
   (SpeedTrafikverket$longitude & SpeedTrafikverket$latitude))
         save speed from SpeedTrafikverket in VehiclePositions


valid_Speed <-which(VehiclePositions$speed <=
                    SpeedTrafikverket$speed·V_outlier  )
```

Figure 10 - Pseudocode to remove outliers in speed.

The pseudocode to filter abnormal trip length can be seen in Figure 11.

```
valid_trips <- trips which(trips$trip_length ≥ T_outlier ·
trips$scheduled_length)
```

Figure 11 - Pseudocode to find vaild trips.

Appendix 3 – Detailed results for bus line 4

In the sections below the detailed results for the KPIs regarding low speed and average speed for bus line 4 is presented.

Low speed morning peak, 2018-11-05 - 2018-11-09

The result of the investigations of the KPI low speed for the morning peak are shown for both directions in Table 1, during the specified time period.

Table 1 - Low speed investigations bus line 4, both directions, morning peak.

		Landbogatan		Linköpings resecentrum	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	4	202/11 303	0.34 min/vehicle	211/ 11 671	0.35 min/vehicle
2018-11-06	4	283/11 122	0.52 min/vehicle	370/12 480	0.56 min/vehicle
2018-11-07	4	395/14 721	0.55 min/vehicle	362/14 357	0.55 min/vehicle
2018-11-08	4	439/14 770	0.61 min/vehicle	399/15 909	0.55 min/vehicle
2018-11-09	4	346/12 333	0.58 min/vehicle	354/13 164	0.54 min/vehicle

Low speed afternoon peak, 2018-11-05-2018-11-09

The result of the investigations of the KPI low speed for the afternoon peak are shown for both directions in Table 2, during the specified time period.

Table 2 - Low speed investigations, both directions, afternoon peak.

		Landbogatan		Linköpings resecentrum	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	4	787/18 448	0.87 min/vehicle	655/21 122	0.73 min/vehicle
2018-11-06	4	691/19 469	0.77 min/vehicle	471/17 384	0.56 min/vehicle
2018-11-07	4	694/20 578	0.83 min/vehicle	515/18 291	0.57 min/vehicle
2018-11-08	4	721/22 758	0.71 min/vehicle	743/21 664	0.73 min/vehicle
2018-11-09	4	687/22 887	0.67 min/vehicle	534/21 384	0.52 min/vehicle

Average speed in direction Linköpings resecentrum during morning peak, 2018-11-05 – 2018-11-09

Table 3 shows the measures of the KPIs concerning average speed for the morning peak in direction Linköpings resecentrum for the given time period. The average speed for each day in Table 3 is based on all of the trips that day. Therefore, the average speed in the overall performance is based on all trips during the week. Due to this the summation of the week in average speed will not be equal to the average speed in the overall performance of bus line 4. The same applies for all of the tables concerning average speed in the Appendices.

Table 3 - Average speed investigations for bus line 4, direction Linköpings resecentrum, morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	4	2/6	4/6	19.05
2018-11-06	4	1/6	0/6	18.84
2018-11-07	4	3/8	7/8	19.41
2018-11-08	4	2/7	6/7	18.81
2018-11-09	4	0/6	6/6	19.21

Average speed in direction Linköpings resecentrum during afternoon peak, 2018-11-05-2018-11-09

Table 6 shows the measures of the KPIs concerning average speed for the afternoon peak in direction Linköpings resecentrum for the given time period.

Table 6 - Average speed investigations for bus line 4, direction Linköpings resecentrum, afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	4	0/9	2/9	17.72
2018-11-06	4	1/9	5/9	18.37
2018-11-07	4	1/10	7/10	18.84
2018-11-08	4	1/11	6/11	18.37
2018-11-09	4	3/12	9/12	19.24

Average speed in Landbogatan during morning peak, 2018-11-05 – 2018-11-09

Table 4 shows the measures of the KPIs concerning average speed for the morning peak in direction Landbogatan for the given time period.

Table 4 - Average speed investigations for bus line 4, direction Landbogatan, morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	4	3/5	3/5	20.23
2018-11-06	4	1/5	2/5	19.40
2018-11-07	4	2/7	4/7	19.80
2018-11-08	4	3/7	4/7	19.56
2018-11-09	4	1/5	0/5	19.41

Average speed in direction Landbogatan during afternoon peak, 2018-11-05-2018-11-09

Table 5 shows the measures of the KPIs concerning average speed for the afternoon peak in direction Landbogatan for the given time period.

Table 5 - Average speed investigations for bus line 4, direction Landbogatan, afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	4	1/9	3/9	18.12
2018-11-06	4	2/9	4/9	18.74
2018-11-07	4	2/11	5/11	18.89
2018-11-08	4	2/12	5/12	19.06
2018-11-09	4	4/9	4/9	19.21

Average speed without dwell time, both directions during morning peak, 2018-11-05-2018-11-09

Table 7 shows the average speed when the dwell time is excluded from the total time of a trip. The average speed was higher in direction Landbogatan than in direction Linköpings resecentrum for all of the examined days.

Table 7 - Average speed without dwell time for both direction during morning peak.

		Linköpings resecentrum	Landbogatan
Date	Line	Avg speed without dwell time (km/h)	Avg speed without dwell time (km/h)
2018-11-05	4	21.76	22.51
2018-11-06	4	21.09	21.65
2018-11-07	4	21.72	21.93
2018-11-08	4	21.00	22.27
2018-11-09	4	21.57	22.36

Average speed without dwell time, both directions during afternoon peak, 2018-11-05-2018-11-09

The detailed result of the average speed when dwell time was excluded is shown in Table 8.

Table 8 – Average speed without dwell time for both direction during afternoon peak.

		Linköpings resecentrum	Landbogatan
Date	Line	Avg speed without dwell time (km/h)	Avg speed without dwell time (km/h)
2018-11-05	4	20.12	20.47
2018-11-06	4	20.39	21.02
2018-11-07	4	21.26	21.07
2018-11-08	4	20.55	21.14
2018-11-09	4	21.34	21.18

Travel time distribution

In this section, the travel time distribution for the trips completed during the morning and afternoon peak are presented. The results are categorized after direction and time period of the day. The data used was collected during the 5th to 9th of November 2018.

In Table 9, it can be seen how the travel time is distributed over the concerned week. It is divided by 26 and 28 minutes due to the fact that different trips are planned to be different lengths in time.

Table 9 – Bus line 4, direction Landbogatan, morning peak.

Scheduled travel time	26 minutes	28 minutes	Summary (%)
Shortest dwell time	2.1	2.0	7%
Average dwell time	2.9	3.0	11%
Longest dwell time	4.4	6.0	20%
Shortest traffic delay	0.0	0.0	0%
Average traffic delay	0.4	0.1	1%
Longest traffic delay	0.9	0.5	3%
Shortest signalized intersection delay	0.5	0.1	0%
Average signalized intersection delay	1.4	1.5	5%
Longest signalized intersection delay	2.5	3.1	11%
Shortest driving time	20.1	20.5	75%
Average driving time	22.3	22.6	83%
Longest driving time	25.3	24.8	91%
Number of trips	9	20	29

In Table 10, the travel time distribution in the other direction (direction Linköpings resecentrum) for the morning peak hour is shown. The length of the planned trips is diverging in time for this direction as well, therefore it is divided by 26 and 28 minutes.

Table 10 – Bus line 4, direction Linköpings resecentrum, morning peak.

Scheduled travel time	26 minutes	28 minutes	Summary (%)
Shortest dwell time	2.2	2.4	8%
Average dwell time	2.7	3.1	11%
Longest dwell time	3.7	5.0	16%
Shortest traffic delay	0.0	0.0	0%
Average traffic delay	0.0	0.1	0%
Longest traffic delay	0.3	0.7	2%
Shortest signalized intersection delay	0.4	0.8	2%
Average signalized intersection delay	1.3	1.8	6%
Longest signalized intersection delay	2.1	2.9	10%
Shortest driving time	20.1	20.2	77%
Average driving time	21.6	23.2	83%
Longest driving time	23.1	26.5	87%
Number of trips	9	24	33

In Table 11, the travel time distribution for the afternoon peak in direction Linköpings resecentrum is presented. In the table trips that are scheduled to take 26 respectively 28 minutes are shown separate.

Table 11 – Bus line 4, direction Linköpings resecentrum, afternoon peak.

Scheduled travel time	26 minutes	28 minutes	Summary (%)
Shortest dwell time	1.9	1.2	5%
Average dwell time	2.9	3.1	11%
Longest dwell time	4.4	4.8	16%
Shortest traffic delay	0.0	0.0	0%
Average traffic delay	0.4	0.1	1%
Longest traffic delay	1.7	0.7	6%
Shortest signalized intersection delay	0.3	0.4	1%
Average signalized intersection delay	1.7	1.8	6%
Longest signalized intersection delay	2.4	3.5	12%
Shortest driving time	20.6	18.5	74%
Average driving time	22.6	23.5	82%
Longest driving time	24.7	26.1	92%
Number of trips	12	39	51

The travel time distribution for the afternoon peak is diverging a bit from the same analysis during the morning peak.

In Table 12, the travel time distribution for the other direction (direction Landbogatan) is shown. In this direction all of the trips were scheduled to take 28 minutes.

Table 12 – Bus line 4, direction Landbogatan, afternoon peak.

Scheduled travel time	28 minutes	Summary (%)
Shortest dwell time	1.5	5%
Average dwell time	3.1	9%
Longest dwell time	13.7	38%
Shortest traffic delay	0.0	0%
Average traffic delay	0.2	1%
Longest traffic delay	1.1	4%
Shortest signalized intersection delay	0.2	1%
Average signalized intersection delay	1.5	4%
Longest signalized intersection delay	4.4	14%
Shortest driving time	19.8	61%
Average driving time	23.7	68%
Longest driving time	27.4	91%
Number of trips	50	50

Delay at regulation stops

In Table 13 the delays for each regulation stops for bus line 4 in direction Linköpings resecentrum during the morning peak is shown.

Table 13 – Bus line 4, delays in direction Linköpings resecentrum during morning peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Landbogatan	1	33	5	1.6	1	3
Isberget	6	33	16	1.2	1	4
US Södra entrén	14	33	17	1.8	1	5
Linköpings resecentrum	19	21	4	1	1	2

Table 14 shows the delays in the other direction (direction Landogatan). When comparing the result of direction Linköpings resecentrum and direction Landbogatan it can be seen that there are more delayed trips in direction Landobgatan than in the opposite direction. The maximum delay time at the regulation stops is higher or equal, in direction Landbogatan compared to direction Linköpings resecentrum.

Table 14 – Bus line 4, delays in direction Landogatan during morning peak.

Stop name	Stop sequence	Numbe r of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Linköpings resecentrum	1	29	6	1.7	1	3
US Södra entrén	6	29	26	2.6	1	5
Isberget	13	29	24	3.2	1	6
Landbogatan	18	29	13	2.2	1	4

Table 15 shows the delays for the afternoon peak.

Table 15 – Bus line 4, delays in direction Linköpings resecentrum during the afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Landbogatan	1	51	2	1	1	1
Isberget	6	51	20	1	1	2
US Södra entrén	14	49	26	2.2	1	4
Linköpings resecentrum	19	31	15	2	1	5

Table 16 shows the delays for direction Landbogatan in the afternoon peak. It can be seen that the number of delayed trips is worse in direction Landbogatan compared to direction Linköpings resecentrum.

Table 16 – Bus line 4, delays in direction Landbogatan during the afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Linköpings resecentrum	1	50	8	1.6	1	4
US Södra entrén	6	50	44	2	1	5
Isberget	13	50	44	3.4	1	7
Landbogatan	18	50	24	2.2	1	5

Slack time at regulation stops

In Table 17, the slack time at each regulation stop is shown during the morning peak in direction Linköpings resecentrum.

Table 17 – Bus line 4, slack time in direction Linköpings resecentrum during morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Landbogatan	1	33	26	1.6	1	2
Isberget	6	33	0	-	-	-
US Södra entrén	14	33	4	1	1	1
Linköpings resecentrum	19	21	12	1.8	1	3

Table 18 show the slack time in direction Landbogatan during the morning peak. It can be seen when comparing the two directions that the result is similar.

Table 18 – Bus line 4, slack time in direction Landogatan during morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Linköpings resecentrum	1	29	24	1.8	1	2
US Södra entrén	6	29	0	-	-	-
Isberget	13	29	1	1	1	1
Landbogatan	18	29	6	1.67	1	3

Table 19 show the slack time in direction Linköpings resecentrum during the afternoon peak.

Table 19 – Bus line 4, slack time in direction Linköping resecentrum during afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Landbogatan	1	51	36	1	1	2
Isberget	6	51	0	-	-	-
US Södra entrén	14	49	6	1.3	1	2
Linköpings resecentrum	19	31	6	2	1	5

Table 20 show the slack time in direction Landbogatan during the afternoon peak. When comparing the two directions it can be seen that the result is similar during the afternoon peak as well.

Table 20 – Bus line 4, slack time in direction Landbogatan during the afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Linköpings resecentrum	1	50	44	1.4	1	2
US Södra entrén	6	50	0	-	-	-
Isberget	13	50	1	1	1	1
Landbogatan	18	50	10	2.2	1	4

Early departure from regulation stops

Table 21 shows measures of early departure from a regulation stop in direction Linköpings resecentrum during morning peak.

Table 21 – Bus line 4, early departure from regulation stops in direction Linköpings resecentrum during morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Landbogatan	1	33	0	-	-	-
Isberget	6	33	1	-1	-1	-1
US Södra entrén	14	33	5	-1	-1	-1
Linköpings resecentrum	19	21	0	-	-	-

Table 22 show the early departure from regulation stop in direction Landbogatan during morning peak. It can be seen that there are generally few trips that have an early departure.

Table 22 – Bus line 4, early departure from regulation stops in direction Landbogatan during morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Linköpings resecentrum	1	29	4	1	1	2
US Södra entrén	6	29	1	1	1	1
Isberget	13	29	2	1	1	1
Landbogatan	18	29	0	-	-	-

In Table 23 the early departures from regulation stops in direction Linköpings resecentrum during afternoon peak is shown.

Table 23 – Bus line 4, early departure from regulation stops in direction Linköpings resecentrum during afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Landbogatan	1	51	7	1.25	1	2
Isberget	6	51	2	1	1	1
US Södra entrén	14	49	11	1.33	1	3
Linköpings resecentrum	19	31	0	-	-	-

In Table 24 the early departures from regulation stops in direction Landbogatan during afternoon peak is shown. It can be seen when comparing the two directions that there are more early departures in direction Linköpings resecentrum than in direction Landbogatan.

Table 24 – Bus line 4, early departure from regulation stops in direction Landbogatan during afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Linköpings resecentrum	1	50	1	1	1	1
US Södra entrén	6	50	0	-	-	-
Isberget	13	50	3	1	1	1
Landbogatan	18	50	0	-	-	-

Appendix 4 – Detailed results for bus line 410

Detailed results of analysis of bus line 410 is presented below.

Low speed in both directions' morning peak, 2018-11-05 – 2018-11-09

The detailed result of the investigations of the KPI low speed for bus line 410 in the morning peak are shown for both directions in Table 25 during the specified time period. It can be seen in the table that no conclusions regarding difference in low speed depending on direction can be drawn.

Table 25 - Low speed calculations for both directions during morning peak.

		Mellangrind		Norrköpings resecentrum	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	410	231/2210	3.85	199/2691	3.32
2018-11-06	410	163/2524	2.72	182/2254	3.03
2018-11-07	410	465/4960	3.88	394/2620	6.57
2018-11-08	410	335/2334	5.58	153/2631	2.55
2018-11-09	410	519/4536	4.33	341/2421	5.68

Low speed in both directions' afternoon peak, 2018-11-05 – 2018-11-09

The detailed result of the investigations of the KPI low speed for bus line 410 in the afternoon peak are shown for both directions in Table 26, during the specified time period. When comparing number of minutes with low speed it can be seen that direction Mellangrind always have more minutes where the vehicle is driving with low speed compared to direction Norrköpings resecentrum.

Table 26 - Low speed observations for both directions during afternoon peak.

		Mellangrind		Norrköpings resecentrum	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	410	345/2918	5.75	890/8288	4.94
2018-11-06	410	552/4707	4.60	417/5495	3.48
2018-11-07	410	671/4892	5.59	556/5665	4.63
2018-11-08	410	756/5740	6.30	564/5412	4.70
2018-11-09	410	441/4162	3.68	391/5470	3.26

Average speed in direction Norrköpings resecentrum during morning peak, 2018-11-05 – 2018-11-09

In Table 27 the detailed result of the average speed investigations in direction Norrköpings resecentrum during morning peak is presented. It can be seen in the table that the average speed is always above the average speed goal and the planned speed according to the timetable.

Table 27 - Average speed in direction Norrköpings resecentrum during the morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	410	1/1	1/1	35.60
2018-11-06	410	1/1	1/1	28.83
2018-11-07	410	1/1	1/1	36.65
2018-11-08	410	1/1	1/1	41.50
2018-11-09	410	1/1	1/1	36.48

Average speed in direction Mellangrind during morning peak, 2018-11-05 – 2018-11-09

The average speed for bus line 410 in direction Mellangrind during morning peak is presented in detail in Table 28. Number of vehicles with an average speed above the average speed goal is always 100% during the examined week. However, there were some trips during the examined week that had an average speed below the planned average speed according to the timetable.

Table 28 - Average speed in direction Mellangrind during the morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	410	1/1	1/1	36.52
2018-11-06	410	1/1	1/1	38.05
2018-11-07	410	1/1	1/2	36.62
2018-11-08	410	2/2	0/1	34.14
2018-11-09	410	2/2	1/2	36.48

Average speed in direction Norrköpings resecentrum during afternoon peak, 2018-11-05 – 2018-11-09

The detailed result of the average speed investigations for direction Norrköpings resecentrum during the afternoon peak are showed in Table 29. All of the concerned trips have an average speed that is above the average speed goal that the board have drawn up. Although, many of the concerned trips have an average speed that is below the average speed according to the timetable.

Table 29 - Average speed in direction Norrköpings resecentrum during the afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	410	3/3	0/3	34.93
2018-11-06	410	2/2	0/2	34.81
2018-11-07	410	2/2	0/2	34.91
2018-11-08	410	2/2	1/2	37.31
2018-11-09	410	2/2	2/2	37.27

Average speed in direction Mellangrind during afternoon peak, 2018-11-05 – 2018-11-09

Table 30 shows the detailed result of the average speed investigations for direction Mellangrind during the afternoon peak. The concerned vehicles are always above the average speed goal set by the board. However, there number of vehicles that have an average speed above what the average speed should be according to the timetable are very few.

Table 30 - Average speed in direction Mellangrind during the afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	410	1/1	0/1	32.28
2018-11-06	410	2/2	1/2	35.32
2018-11-07	410	2/2	1/2	35.57
2018-11-08	410	2/2	0/2	32.46
2018-11-09	410	2/2	1/2	34.78

Average speed without dwell time in both directions during morning peak, 2018-11-05 – 2018-11-09

Table 31 shows the average speed without dwell time for bus line 410 in both directions during the morning peak. It can be seen that there is not a clear pattern in which direction that have the highest average speed without dwell time.

Table 31 - The average speed without dwell time in both directions.

		Norrköpings resecntrum	Mellangrind
Date	Line	Avg speed without dwell time (km/h)	Avg speed without dwell time (km/h)
2018-11-05	410	40.48	38.77
2018-11-06	410	30.54	42.30
2018-11-07	410	39.02	39.45
2018-11-08	410	44.26	35.91
2018-11-09	410	39.03	38.40

Average speed without dwell time in both directions during afternoon peak, 2018-11-05 – 2018-11-09

The detailed result of the investigations where the average speed has been calculated without including the dwell time in the total time can be seen in Table 32 for bus line 410 in both directions during the afternoon peak. It can be seen in the table that the average speed is always higher in direction Norrköpings resecentrum compared to direction Mellangrind for all of the examined days.

Table 32 - The average speed without dwell time in both directions.

		Norrköpings resecentrum	Mellangrind
Date	Line	Avg speed without dwell time (km/h)	Avg speed without dwell time (km/h)
2018-11-05	410	38.29	34.54
2018-11-06	410	38.94	37.32
2018-11-07	410	39.61	36.92
2018-11-08	410	40.91	34.07
2018-11-09	410	41.76	36.16

Travel time distribution

In Table 33, the travel time distribution for bus line 410 direction Norrköpings resecentrum during morning peak can be seen.

Table 33 - Travel time distribution for line 410 direction Norrköpings resecentrum, morning peak.

Scheduled travel time	53 minutes	58 minutes	Summary (%)
Shortest dwell time	2.0	3.2	4%
Mean dwell time	3.3	3.8	6%
Longest dwell time	5.3	4.8	10%
Shortest traffic delay	0.2	0.2	0%
Mean traffic delay	0.4	0.7	1%
Longest traffic delay	0.9	1.5	3%
Shortest signalized intersection delay	0.3	0.5	1%
Mean signalized intersection delay	0.8	0.7	1%
Longest signalized intersection delay	1.2	0.9	2%
Shortest driving time	46.3	48.3	88%
Mean driving time	50.5	49.7	91%
Longest driving time	54.3	50.5	95%
Number of trips	4	3	7

Table 33 and Table 34 together gives the result in sub section 7.3.1. In Table 34 the variation in travel time distribution can be seen. When comparing the results for direction Norrköpings resecntrum and Mellangrind morning peak, there is not much difference in the results for the both directions.

Table 34 - Travel time distribution for bus line 410 direction Mellangrind, morning peak.

Scheduled travel time	60 minutes	Summary (%)
Shortest dwell time	3.0	6%
Mean dwell time	4.0	7%
Longest dwell time	6.8	12%
Shortest traffic delay	0.2	0%
Mean traffic delay	0.9	2%
Longest traffic delay	1.5	3%
Shortest signalized intersection delay	0.1	0%
Mean signalized intersection delay	0.4	1%
Longest signalized intersection delay	0.9	2%
Shortest driving time	44.4	85%
Mean driving time	49.0	90%
Longest driving time	51.7	92%
Number of trips	5	5

Table 35 presents the result for the variation in travel time distribution during the afternoon peak in direction Norrköpings resecentrum. There is not much difference when comparing the results for the same direction in the morning peak in Table 33.

Table 35 - Travel time distribution bus line 410 direction Norrköpings resecentrum, afternoon peak.

Scheduled travel time	60 minutes	Summary (%)
Shortest dwell time	3.6	6%
Mean dwell time	5.7	10%
Longest dwell time	7.2	13%
Shortest traffic delay	0.0	0%
Mean traffic delay	0.5	1%
Longest traffic delay	1.6	3%
Shortest signalized intersection delay	0.1	0%
Mean signalized intersection delay	0.4	1%
Longest signalized intersection delay	0.9	1%
Shortest driving time	47.2	84%
Mean driving time	49.9	88%
Longest driving time	60.7	92%
Number of trips	11	11

In Table 36, the variations in travel time distribution for direction Mellangrind during the afternoon peak can be seen. Compared to the morning peak hour in the same direction, the dwell time varies less in the afternoon. On the remaining parts, there is more variation in the afternoon. Table 35 and Table 36 together gives the result in sub section 7.3.1.

Table 36 - Travel time distribution bus line 410 direction Mellangrind, afternoon peak.

Scheduled travel time	57 minutes	58 minutes	Summary (%)
Shortest dwell time	1.5	1.7	3%
Mean dwell time	2.7	2.7	5%
Longest dwell time	4.3	4.0	8%
Shortest traffic delay	0.0	0.1	0%
Mean traffic delay	0.1	1.1	1%
Longest traffic delay	0.2	2.6	4%
Shortest signalized intersection delay	0.4	1.0	1%
Mean signalized intersection delay	1.0	2.0	3%
Longest signalized intersection delay	1.3	2.6	4%
Shortest driving time	47.8	51.4	87%
Mean driving time	50.1	54.9	92%
Longest driving time	53.4	59.3	96%
Number of trips	4	5	9

Delay at regulation stops

During the morning peak in direction Norrköpings resecentrum, there was a lot of delayed trips during the route. However, none of them arrived late at the last stop, Norrköpins resecentrum as can be seen in Table 37.

Table 37 – Delay for bus line 410 direction Norrköpings resecentrum, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Mellangrind	1	5	3	2.54	1	4
Stationsvägen	5	5	5	2.77	1	5
Bävervägen	14	5	2	3.58	1	5
Vistinge	22	4	2	1.57	1	1
Skarsätter	31	4	4	4.87	1	9
Norrköpings resecentrum	49	5	0	-	-	-

In Table 38, the on-time performance for direction Mellangrind during the morning peak is presented. Along the route, several trips were delayed even though none of the trips departed late from the first stop. At the last stop, Mellangrind, three trips were at least 1 minute late. Table 37and Table 38 are the base to the results in sub section 7.3.1.

Table 38 – Delay for bus line 410 direction Mellangrind, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Norrköpings resecentrum	1	7	0	-	-	-
Skarsätter	19	6	5	2.70	1	5
Vistinge	28	6	4	3.47	1	4
Bävervägen	36	5	3	4.09	3	5
Stations-vägen	45	7	5	2.10	1	4
Mellangrind	49	7	3	2.92	1	5

In contrast to the morning peak in direction Norrköpings resecentrum, there was trips that were delayed to the last stop during the afternoon peak. Many trips were also delayed along the route, at some regulation stops all trips were at least 1 minute late as can be seen in Table 39. No trips departed late from the first stop.

Table 39 – Delay for bus line 410 direction Norrköpings resecentrum, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Mellangrind	1	11	0	-	-	-
Stationsvägen	5	11	10	1.93	1	3
Bävervägen	14	11	7	2.28	1	4
Vistinge	22	9	6	2.14	1	4
Skarsätter	31	11	11	4.00	1	7
Norrköpings resecentrum	49	11	7	2.92	1	5

Table 40 shows the on-time performance for direction Mellangrind during the afternoon peak. Similar to the morning peak in direction Mellangrind, several trips were delayed to the last stop Mellangrind. Moreover, many trips were delayed along the route as well. The information in Table 39 and Table 40 gives the result in sub section 7.3.1.

Table 40 – Delay for bus line 410 direction Mellangrind, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Norrköpings resecentrum	1	9	0	-	-	-
Skarsätter	19	9	5	7.25	2	10
Vistinge	28	9	6	8.78	1	13
Bävervägen	36	8	7	10.04	1	14
Stations-vägen	45	9	4	7.72	2	9
Mellangrind	49	9	4	5.85	1	7

Slack time at regulation stops

Table 41 shows the slack time at each regulation stop for bus line 410 during the morning peak hour in direction Norrköpings resecentrum. All trips but one arrived early at the last stop Norrköpings resecentrum.

Table 41 - Slack time bus line 410 direction Norrköpings resecentrum, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Mellangrind	1	5	3	1.81	1	1
Stationsvägen	5	5	0	-	-	-
Bävervägen	14	5	0	-	-	-
Vistinge	22	4	2	1.17	1	1
Skarsätter	31	4	0	-	-	-
Norrköpings resecentrum	49	5	4	4.88	2	9

In Table 42. the slack time at the regulation stops in direction Mellanrgrind during the morning peak is presented. Compared to direction Norrköpings resecentrum, there is not as much slack time in direction Mellangrind. Three of seven trips arrived early at the last stop Mellangrind. Table 41 and Table 42 together gives the result in sub section 7.3.

Table 42 - Slack time bus line 410 direction Mellangrind, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Norrköpings resecentrum	1	7	7	1.96	1	2
Skarsätter	19	6	0	-	-	-
Vistinge	28	6	1	1.48	1	1
Bävervägen	36	5	0	-	-	-
Stations-vägen	45	7	1	1.83	1	1
Mellangrind	49	7	3	3.08	2	3

During the afternoon peak in direction Norrköpings resecentrum, only one trip arrived early at the last stop. Generally, there are few trips with slack time as can be seen in Table 43.

Table 43 - Slack time bus line 410 direction Norrköpings resecentrum, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Mellangrind	1	11	3	1.99	1	2
Stationsvägen	5	11	0	-	-	-
Bävervägen	14	11	1	1.72	1	1
Vistinge	22	9	1	1.63	1	1
Skarsätter	31	11	0	-	-	-
Norrköpings resecentrum	49	11	1	2.42	2	2

In Table 44, which shows the slack time in direction Mellangrind during the afternoon peak, the number of trips with slack time are more than in direction Norrköpings resecentrum. The slack time is also longer for some trips in this direction, for example one trip had a slack time of eight minutes at Stationsvägen. Table 43 and Table 44 together gives the results in sub section 7.3.

Table 44 - Slack time bus line 410 direction Mellangrind, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Norrköpings resecentrum	1	9	5	1.69	1	2
Skarsätter	19	9	0	-	-	-
Vistinge	28	9	1	1.43	1	1
Bävervägen	36	8	0	-	-	-
Stations-vägen	45	9	4	5.47	1	8
Mellangrind	49	9	4	4.51	1	7

Early departure from regulation stops

As can be seen in Table 45, only on trip left early from a regulation stop during the morning peak in direction Norrköpings resecentrum.

Table 45 - Early departure from regulation stops bus line 410 direction Norrköpings resecentrum, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Mellangrind	1	5	0	-	-	-
Stationsvägen	5	5	0	-	-	-
Bävervägen	14	5	1	0.17	1	1
Vistinge	22	4	0	-	-	-
Skarsätter	31	4	0	-	-	-
Norrköpings resecentrum	49	5	0	-	-	-

For direction Mellangrind during the morning peak hour, four trips left early at the first stop and on trip left early at Stationsvägen. However, none of the trips left more than 1 minute early as can be seen in Table 46. Table 45 and Table 46 together gives the result in sub section 7.3.

Table 46 -Early departure from regulation stops bus line 410 direction Mellangrind, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Norrköpings resecentrum	1	7	4	0.23	1	1
Skarsätter	19	6	0	-	-	-
Vistinge	28	6	0	-	-	-
Bävervägen	36	5	0	-	-	-
Stations-vägen	45	7	1	0.80	1	1
Mellangrind	49	7	0	-	-	-

Table 47 shows early departures from regulation stops in direction Norrköpings resecentrum during the afternoon peak. In total, there were six early departures from regulation stops. However, the average early departure is less than a minute for all stops but one.

Table 47 - Early departure from regulation stops bus line 410 direction Norrköpings resecentrum, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Mellangrind	1	11	3	0.04	1	1
Stationsvägen	5	11	1	0.17	1	1
Bävervägen	14	11	1	1.72	2	2
Vistinge	22	9	1	0.12	1	1
Skarsätter	31	11	0	-	-	-
Norrköpings resecentrum	49	11	0	-	-	-

During the afternoon peak in direction Mellangrind, the majority of the trips left early from Stationsvägen. One of those trips left 8 minutes early. On the reaming stops, just a few trips left early and less than one minute on average. The result in sub section 7.3 is the summation of Table 47 and 48.

Table 48 - Early departure from regulation stops bus line 410 direction Mellangrind, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Norrköpings resecentrum	1	9	2	-0.13	1	1
Skarsätter	19	9	1	-0.55	1	1
Vistinge	28	9	2	-0.81	1	2
Bävervägen	36	8	1	-0.90	1	1
Stations-vägen	45	9	5	-3.74	1	8
Mellangrind	49	9	0	-	-	-

Appendix 5 – Detailed results for bus line 42

Detailed results of analysis of bus line 42 is presented below.

Low speed in direction Östra station morning peak, 2018-11-05 – 2018-11-09

The detailed result of the investigation of the KPI low speed for bus line 42 in the morning peak is shown for direction Östra station in Table 47 during the specified time period. The number of low speed minutes is rather high for all of the investigated days, except for the 9th.

Table 47 - Low speed calculations in direction Östra station during morning peak.

		Östra station	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	42	634/5235	5.28
2018-11-06	42	616/5245	5.13
2018-11-07	42	536/5055	4.47
2018-11-08	42	660/5293	5.50
2018-11-09	42	143/2263	2.43

Low speed in direction Mellangrind afternoon peak, 2018-11-05 – 2018-11-09

The detailed result of the investigation of the KPI low speed for bus line 42 in the afternoon peak is shown for direction Mellangrind in Table 48 during the specified time period. The number of low speed minutes are similar to the low speed minutes during the morning peak.

Table 48 - Low speed observations in direction Mellangrind during afternoon peak.

		Mellangrind	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	42	937/5198	7.81
2018-11-06	42	448/5079	3.73
2018-11-07	42	804/5097	6.70
2018-11-08	42	815/4852	6.79
2018-11-09	42	628/5091	5.23

Average speed in direction Östra station during morning peak, 2018-11-05 – 2018-11-09

The average speed for bus line 42 in direction Östra station during morning peak is presented in detail in Table 49. Number of vehicles with an average speed above the average speed goal is always 100% during the examined week. However, there were only a one trip that had an average speed higher than the average speed according to timetable. The average speed is consistently high throughout the week.

Table 49 - Average speed in direction Östra station during the morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	42	2/2	0/2	41.14
2018-11-06	42	2/2	0/2	41.42
2018-11-07	42	2/2	0/2	43.40
2018-11-08	42	2/2	0/2	41.06
2018-11-09	42	1/2	1/1	49.54

Average speed in direction Mellagrind during afternoon peak, 2018-11-05 – 2018-11-09

In Table 50 the detailed result of the average speed investigations in direction Mellangrind during afternoon peak is presented. Number of vehicles that have an average speed higher than the average speed goal set by the board is 100% for all of days during the examined week. The majority of the vehicles drove at an average speed above the average speed according to timetable during the examined week, which can be seen in Table 50. The average speed is consistently high.

Table 50 - Average speed in direction Mellangrind during the afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	42	2/2	0/2	38.12
2018-11-06	42	2/2	2/2	42.92
2018-11-07	42	2/2	1/2	42.30
2018-11-08	42	2/2	2/2	42.03
2018-11-09	42	2/2	1/2	41.40

Average speed without dwell time direction Östra station during morning peak, 2018-11-05 – 2018-11-09

The detailed result of the investigations where the average speed has been calculated without including the dwell time in the total time can be seen in Table 51 for bus line 42 in direction Östra station during the morning peak.

Table 51 - The average speed without dwell time in direction Östra station.

		Östra station
Date	Line	Avg speed without dwell time (km/h)
2018-11-05	42	44.35
2018-11-06	42	44.46
2018-11-07	42	47.43
2018-11-08	42	43.89
2018-11-09	42	53.19

Average speed without dwell time in direction Mellangrind during afternoon peak, 2018-11-05 – 2018-11-09

Table 52 contains the detailed result of the average speed without dwell time for bus line 42 for the afternoon peak in direction Mellangrind during the examined week. The average speed without dwell time is consequently lower in the morning peak than in the afternoon peak.

Table 52 - The average speed without dwell time in direction Mellangrind.

		Mellangrind
Date	Line	Avg speed without dwell time (km/h)
2018-11-05	42	38.12
2018-11-06	42	42.92
2018-11-07	42	42.30
2018-11-08	42	42.03
2018-11-09	42	41.40

Travel time distribution

The travel time distribution for bus line 42, direction Östra station during the morning peak can be seen in Table 53.

Table 53 - Travel time distribution for bus line 42 direction Östra station, morning peak.

Scheduled travel time	47 minutes	52 minutes	Summary (%)
Shortest dwell time	2.9	3.9	6%
Mean dwell time	3.2	4.2	7%
Longest dwell time	3.9	4.6	9%
Shortest traffic delay	0.6	0.9	1%
Mean traffic delay	1.0	1.7	3%
Longest traffic delay	1.9	2.2	4%
Shortest signalized intersection delay	0.0	0.5	0%
Mean signalized intersection delay	0.6	1.9	2%
Longest signalized intersection delay	1.8	2.7	5%
Shortest driving time	39.3	43.0	83%
Mean driving time	41.9	47.4	88%
Longest driving time	43.9	50.1	91%
Number of trips	5	4	9

During the afternoon peak, the average of all the parts of the travel time distribution are similar. However, the is more variation between the shortest and longest during the afternoon peak, as can be seen in Table 54.

Table 54 - Travel time distribution bus line 42 direction Mellangrind, afternoon peak.

Scheduled travel time	52 minutes	Summary (%)
Shortest dwell time	2.1	4%
Mean dwell time	3.8	8%
Longest dwell time	5.1	11%
Shortest traffic delay	0.0	0%
Mean traffic delay	0.7	1%
Longest traffic delay	2.0	4%
Shortest signalized intersection delay	0.5	1%
Mean signalized intersection delay	1.1	2%
Longest signalized intersection delay	2.1	4%
Shortest driving time	41.1	86%
Mean driving time	45.5	89%
Longest driving time	52.5	92%
Number of trips	10	10

Delay at regulation stops

The delays to each regulation stop for bus line 42 during the morning peak can be seen in Table 55.

Table 55 - Delay at regulation stops for bus line 42 direction Östra station, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Mellangrind	1	9	2	1.08	1	1
Stationsvägen	4	9	1	1.92	1	1
Söder tull	13	9	7	4.39	2	6
Östra station	15	9	5	3.45	1	4

During the afternoon peak, the number of delayed trips is about the same as for the morning, but the maximum delay is larger for all stops. The average delay is also larger during the afternoon except from the last stop.

Table 56- Delay at regulation stops for bus line 42 direction Mellangrind, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Östra station	1	10	1	2.77	2	2
Söder tull	3	10	3	2.32	1	3
Stations-vägen	12	10	8	4.89	1	11
Mellangrind	15	10	4	3.08	1	7

Slack time at regulation stops

At the first stop Mellangrind, all nine buses arrived early during the morning peak. In spite of all buses arriving early to the first stop, two trips were delayed from the same stop. The slack time at each regulation stop during the morning peak can be seen in Table 57.

Table 57 - Slack time for bus line 42 direction Östra station, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Mellangrind	1	9	9	2.00	2	2
Stationsvägen	4	9	0	-	-	-
Söder tull	13	9	0	-	-	-
Östra station	15	9	1	3.77	3	3

The slack time during the afternoon peak can be seen in Table 58.

Table 58 - Slack time bus line 42 direction Mellangrind, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Östra station	1	10	8	1.89	1	2
Söder tull	3	10	3	1.82	1	2
Stations-vägen	12	10	1	1.03	1	1
Mellangrind	15	10	6	2.69	1	4

Early departure from regulation stops

During the morning peak, no buses left more than one minute early. Stationsvägen had most early departures of all the regulation stops, as can be seen in Table 59.

Table 59 - Early departure from regulation stops bus line 42 direction Östra station, morning peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Mellangrind	1	9	1	0.12	1	1
Stationsvägen	4	9	3	0.22	1	1
Söder tull	13	9	1	0.98	1	1
Östra station	15	9	0	-	-	-

In Table 60, the early departures from regulation stops during the afternoon peak can be seen. Similar to the morning peak, all early departures were less than one minute.

Table 60 - Early departure from regulation stops bus line 42 direction Mellangrind, afternoon peak.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Östra station	1	10	2	0.05	1	1
Söder tull	3	10	2	0.46	1	1
Stationsvägen	12	10	1	0.72	1	1
Mellangrind	15	10	0	-	-	-

Appendix 6 – Detailed results for tram line 2

Low speed in both directions' during morning peak, 2018-11-05 – 2018-11-09

The detailed result of the investigation of the KPI low speed for tram line 2 in the morning peak is shown for both directions' in Table 61 during the specified time period. The number of low speed minutes are quite low.

Table 61 - Low speed calculations for both directions during morning peak.

		Fridvalla		Kvarnberget	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	2	491/13277	1.36	411/10528	1.37
2018-11-06	2	586/17132	1.22	595/16318	1.24
2018-11-07	2	651/17358	1.36	424/13519	1.18
2018-11-08	2	443/10692	1.48	365/12455	1.01
2018-11-09	2	520/17596	1.08	556/15612	1.32

Low speed in both directions' afternoon peak, 2018-11-05 – 2018-11-09

The detailed result of the investigation of the KPI low speed for tram line 2 in the afternoon peak is shown for both directions' in Table 62 during the specified time period. It is not possible to see a trend regarding differences between morning and afternoon peak, since the result is very similar.

Table 62 - Low speed calculations for both directions during afternoon peak.

		Fridvalla		Kvarnberget	
Date	Line	Nr obs. with low speed/high speed	Low speed minutes/vehicle	Nr obs. with low speed/high speed	Low speed minutes/vehicle
2018-11-05	2	627/18737	1.1611	508/16768	1.0583
2018-11-06	2	868/20598	1.4467	811/19622	1.5019
2018-11-07	2	703/21623	1.1717	510/22763	0.85
2018-11-08	2	542/12305	1.5056	620/16961	1.2917
2018-11-09	2	662/16948	1.3792	634/16811	1.3208

Average speed in direction Fridvalla during morning peak, 2018-11-05 – 2018-11-09

The average speed for tram line 2 in direction Fridvalla during morning peak is presented in detail in Table 63. The average speed is lower than all of the other examined transport modes. However, the average speed seems to be following the average speed according to timetable well, since almost all vehicles have an average speed above timetable. Although there are only a few vehicles that have a speed higher than the goal.

Table 63 - Average speed in direction Fridvalla during the morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	2	0/6	6/6	15.79
2018-11-06	2	0/8	6/8	15.52
2018-11-07	2	1/8	6/8	16.13
2018-11-08	2	0/5	5/5	15.83
2018-11-09	2	1/8	7/8	16.22

Average speed in direction Kvarnberget during morning peak, 2018-11-05 – 2018-11-09

The average speed for tram line 2 in direction Kvarnberget during morning peak is presented in detail in Table 64. None of the examined vehicles have a speed that is above the average speed goal set by the board. Meanwhile, almost all of the examined vehicles have an average speed above the average speed set in the timetable. When comparing to direction Fridvalla, it not evident that there are any difference in average speed.

Table 64 - Average speed in direction Kvarnberget during the morning peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	2	0/5	4/5	15.75
2018-11-06	2	0/8	6/8	15.99
2018-11-07	2	0/6	5/6	15.83
2018-11-08	2	0/6	6/6	16.05
2018-11-09	2	0/7	6/7	16.00

Average speed in direction Fridvalla during afternoon peak, 2018-11-05 – 2018-11-09

The average speed for tram line 2 in direction Fridvalla during afternoon peak is presented in detail in Table 65. When comparing to the average speed in the same direction but during morning peak, the average speed is always lower during the afternoon peak. None of the examined vehicles have an average speed higher than the average speed goal. Meanwhile almost all of the vehicles have an average speed higher than what the average speed should be according to the timetable.

Table 65 - Average speed in direction Fridvalla during the afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	2	0/9	8/9	15.66
2018-11-06	2	0/10	8/10	15.26
2018-11-07	2	0/10	6/10	14.77
2018-11-08	2	0/6	5/6	15.25
2018-11-09	2	0/6	6/8	15.19

Average speed in direction Kvarnberget during afternoon peak, 2018-11-05 – 2018-11-09

The average speed for tram line 2 in direction Kvarnberget during afternoon peak is presented in detail in Table 66. It is evident that the average speed is lower in the afternoon peak than during the morning peak in this direction as well. None of the examined vehicles have an average speed above the average speed goal. In general, the majority of the vehicles have an average speed above what it should be according to the timetable.

Table 66 - Average speed in direction Kvarnberget during the afternoon peak.

Date	Line	Nr of vehicles avg speed > goal	Nr of vehicles avg speed > timetable	Avg speed (km/h)
2018-11-05	2	0/8	4/8	15.41
2018-11-06	2	0/9	5/9	15.32
2018-11-07	2	0/10	5/10	15.07
2018-11-08	2	0/8	5/8	15.10
2018-11-09	2	0/8	5/8	15.93

Average speed without dwell time in both directions' during morning peak, 2018-11-05 – 2018-11-09

The detailed result of the investigations where the average speed has been calculated without including the dwell time in the total time can be seen in Table 67 for tram line 2 in both directions during the morning peak. When comparing the two directions it is evident that direction Fridvalla always have a higher average speed than direction Kvarnberget.

Table 67 - The average speed without dwell time in both directions'.

		Fridvalla	Kvarnberget
Date	Line	Avg speed without dwell time (km/h)	Avg speed without dwell time (km/h)
2018-11-05	2	20.27	19.61
2018-11-06	2	19.65	19.49
2018-11-07	2	20.32	19.86
2018-11-08	2	19.99	19.90
2018-11-09	2	20.94	20.28

Average speed without dwell time in both directions' during afternoon peak, 2018-11-05 – 2018-11-09

The detailed result of the investigations where the average speed has been calculated without including the dwell time in the total time can be seen in Table 67 for tram line 2 in both directions during the afternoon peak. During the afternoon peak the direction that has the highest average speed is diverging between the different days.

Table 68 - The average speed without dwell time in both directions'.

		Fridvalla	Kvarnberget
Date	Line	Avg speed without dwell time (km/h)	Avg speed without dwell time (km/h)
2018-11-05	2	19.48	19.20
2018-11-06	2	19.10	19.47
2018-11-07	2	19.41	19.57
2018-11-08	2	19.38	19.23
2018-11-09	2	19.41	19.83

Travel time distribution

Table 69 and Table 70 shows the travel time distribution for each direction during the morning peak. The results in these tables together gives the results in section 7.5.1.

Table 69 – Travel time distribution for the morning peak in direction Fridvalla.

Scheduled travel time	47 minutes	Summary (%)
Shortest dwell time	6:59	16%
Mean dwell time	9:25	21%
Longest dwell time	12:43	28%
Shortest traffic delay	0:00	0%
Mean traffic delay	0:25	1%
Longest traffic delay	2:31	5%
Shortest signalized intersection delay	0:00	0%
Mean signalized intersection delay	0:05	0%
Longest signalized intersection delay	0:51	2%
Shortest driving time	30:58	72%
Mean driving time	34:06	77%
Longest driving time	38:27	83%
Number of trips	35	35

Table 70 – Travel time distribution for the morning peak direction Kvarnberget.

Scheduled travel time	46 minutes	Summary (%)
Shortest dwell time	4:36	10%
Mean dwell time	8:28	20%
Longest dwell time	10:44	24%
Shortest traffic delay	0:00	0%
Mean traffic delay	0:43	2%
Longest traffic delay	1:58	5%
Shortest signalized intersection delay	0:00	0%
Mean signalized intersection delay	0:03	0%
Longest signalized intersection delay	0:41	2%
Shortest driving time	30:06	73%
Mean driving time	34:08	79%
Longest driving time	38:45	87%
Number of trips	32	32

Table 71 and Table 72 shows the travel time distribution for tram line 2 during the afternoon. The results are similar for the two directions. The results in section 7.5.1 is based on the results in the two tables.

Table 71 – Travel time distribution for the afternoon peak our direction Fridvalla.

Scheduled travel time	47 minutes	Summary (%)
Shortest dwell time	6:26	14%
Mean dwell time	9:40	21%
Longest dwell time	15:02	30%
Shortest traffic delay	0:00	0%
Mean traffic delay	0:27	1%
Longest traffic delay	2:15	5%
Shortest signalized intersection delay	0:00	0%
Mean signalized intersection delay	0:03	0%
Longest signalized intersection delay	0:40	2%
Shortest driving time	30:21	70%
Mean driving time	35:06	78%
Longest driving time	38:46	84%
Number of trips	43	43

Table 72 – Travel time distribution for the afternoon peak hour direction Kvarberget.

Scheduled travel time	46 minutes	Summary (%)
Shortest dwell time	4:25	10%
Mean dwell time	9:31	21%
Longest dwell time	15:24	30%
Shortest traffic delay	0:00	0%
Mean traffic delay	0:50	2%
Longest traffic delay	4:24	9%
Shortest signalized intersection delay	0:00	0%
Mean signalized intersection delay	0:08	0%
Longest signalized intersection delay	1:18	3%
Shortest driving time	29:38	67%
Mean driving time	34:38	77%
Longest driving time	39:01	86%
Number of trips	43	43

Delay at regulation stops

The on-time performance for tram line 2 can in each direction can be seen in Table 73 and Table 74. More than half of the trips are delayed to Söder tull and Norrköpings resecentrum but only a few of them are still delayed when they arrive at the last stop. The results in Table 73 and Table 74 together gives the results in section 7.5.1.

Table 73 – Delay at the regulations stops during the morning peak direction Fridvalla.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Kvarnberget	1	35	5	2.38	1	3
Söder Tull	12	35	19	2.44	1	5
Norrköpings resecentrum	19	35	20	3.12	1	6
Fridvalla	31	35	3	2.79	1	4

Table 74 – Delay at the regulations stops during the morning peak direction Kvarnberget.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Fridvalla	1	32	1	1.50	1	1
Norrköpings resecentrum	13	32	24	2.59	1	5
Söder Tull	20	32	27	3.26	1	6
Kvarnberget	31	32	4	1.83	1	2

Table 75 and Table 76 together gives the results of the on-time performance during the afternoon peak in section 7.5.1. Of the 43 trips departing to Fridvalla, 20 of them departed late from the first stop Kvarnberget. 12 of the trips arrived late at to the last stop Fridvalla, at most 11 minutes late.

Table 75 - Delay at the regulations stops during the afternoon peak direction Fridvalla.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Kvarnberget	1	43	20	2.58	1	8
Söder Tull	12	43	19	3.10	1	9
Norrköpings resecentrum	19	43	29	4.07	1	14
Fridvalla	31	43	12	4.14	1	11

As can be seen in Table 76, 14 of the 43 trips arrived late at the last stop Kvarnberget which could explain why 20 trips departed late from the same stop in the opposite direction. 34 of the 43 trips departed late at Söder tull.

Table 76 - Delay at the regulations stops during the afternoon peak direction Kvarnberget.

Stop name	Stop sequence	Number of trips	Number of trips delayed	Average delay	Minimum delay	Maximum delay
Fridvalla	1	43	5	2.96	1	3
Norrköpings resecentrum	13	42	26	2.76	1	6
Söder Tull	20	43	34	3.88	1	9
Kvarnberget	31	43	14	2.81	1	5

Slack time at regulation stops

Table 77 and Table 78 shows the slack time at regulation stops in each direction and gives the results in section 7.5.1. In both directions, more than half of the trips had slack time at the last stop during the morning peak. Probably an error has caused the maximum slack time of 9 minutes at Norrköping resecentrum in direction Fridvalla and 17 minutes at Söder tull in direction

Kvarnberget since the scheduled travel time between these stops is 11 minutes and 12 minutes and no trips have departed more than 1 minutes early.

Table 77 – Slack time at the regulation stops during the morning peak in direction Fridvalla.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Kvarnberget	1	35	6	1.93	1	2
Söder Tull	12	35	6	1.36	1	1
Norrköpings resecentrum	19	35	2	5.38	1	9
Fridvalla	31	35	21	4.13	1	6

Table 78 – Slack time at the regulation stops during the morning peak in direction Kvarnberget.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Fridvalla	1	32	7	1.74	1	2
Norrköpings resecentrum	13	32	0	-	-	-
Söder Tull	20	32	4	4.87	1	17
Kvarnberget	31	32	23	3.32	1	6

Table 79 and Table 80 shows the slack time during the afternoon peak and gives the results in section 7.5.1.

Table 79 - Slack time at the regulation stops during the afternoon peak in direction Fridvalla.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Kvarnberget	1	43	5	1.68	1	2
Söder Tull	12	43	16	2.67	1	4
Norrköpings resecentrum	19	43	0	-	-	-
Fridvalla	31	43	21	2.96	1	5

Table 80 - Slack time at the regulation stops during the afternoon peak in direction Kvarnberget.

Stop name	Stop sequence	Number of trips	Number of trips with slack	Average slack time	Minimum slack time	Maximum slack time
Fridvalla	1	43	12	1.69	1	2
Norrköpings resecentrum	13	42	4	1.42	1	1
Söder Tull	20	43	9	1.64	1	2
Kvarnberget	31	43	18	3.24	1	6

Early departure from regulation stops

The results for early departures from regulation stops for the morning peak in section 7.5.1 derive from Table 81 and Table 82. Only a few trips departed early and not more than one minute.

Table 81 – Early departures at regulation stops during the morning peak direction Fridvalla.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Kvarnberget	1	35	0	-	-	-
Söder Tull	12	35	3	0.23	1	1
Norrköpings resecentrum	19	35	1	0.02	1	1
Fridvalla	31	35	0	-	-	-

Table 82 - Early departures at regulation stops during the morning peak direction Kvarnberget.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Fridvalla	1	32	0	-	-	-
Norrköpings resecentrum	13	32	1	0.20	1	1
Söder Tull	20	32	0	-	-	-
Kvarnberget	31	32	0	-	-	-

Table 83 and Table 84 gives the results of early departures at regulation stops during the afternoon peak. Compared to the morning peak, more trips departed early from regulation stops during the afternoon peak.

Table 83 - Early departures at regulation stops during the afternoon peak direction Fridvalla.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Kvarnberget	1	43	2	0.10	1	1
Söder Tull	12	43	5	0.51	1	2
Norrköpings resecentrum	19	43	3	0.10	1	1
Fridvalla	31	43	0	-	-	-

Table 84 - Early departures at regulation stops during the afternoon peak direction Kvarnberget.

Stop name	Stop sequence	Number of trips	Number of trips with early departure	Average early departure	Minimum early departure	Maximum early departure
Fridvalla	1	43	3	0.09	1	1
Norrköpings resecentrum	13	42	8	0.26	1	1
Söder Tull	20	43	3	0.17	1	1
Kvarnberget	31	43	0	-	-	-