



Aalto University
School of Engineering

Tsegaye Firew

**Analysis of Service Reliability of Public Transportation in
the Helsinki Capital Region: The Case of Bus Line 550**

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Supervisor: Professor Milos Mladenovic

Advisor: Christoffer Weckström

Author Tsegaye Firew

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Abstract

The rate of automobile ownership in Helsinki Capital Region has been on the rising trajectory, even bypassing population growth rate of the region. The population of the region expected to double in 2050, planning for a sustainable mobility becomes crucial. Effort is being exerted to minimize private car dependence and innovative transport solutions are being tested in the region. Increasing the share of public transport (PT) in the region is the main goal of Helsinki Regional Transport Authority (HSL). To increase the share of PT, improving its efficiency and reliability becomes a crucial strategy by attracting private car users and keeping existing passengers. Therefore, PT agencies need to continuously evaluate the reliability of their service and take improvement actions accordingly.

A reliable PT service is one that adheres to schedule and whose vehicles run on-time. It is generally recognized that deviation from schedule (unreliability) in PT is an important operational problem that affects both operators and passengers. Measuring the level of deviation from schedule helps operators and PT authorities identify and improve gaps in service delivery. Recorded large operational data from Automatic Vehicle Location (AVL) and Automatic Passenger Counter (APC) provide an opportunity to analyze operational performance quality of a PT with a minimum cost.

The objective of the thesis was to analyze service reliability of a circumferential high-frequency bus line 550 in Helsinki Capital Region (HCR) using data from AVL and APC systems. Five different service reliability measures were used in this study. These were on-time performance, headway adherence, vehicle trip-time variability, passenger wait time and passenger travel time. The first three are agency oriented reliability measures and the last two are passenger oriented.

This study has provided a quantitative overview over several service performance measures. The results of the agency-based analysis revealed that for trips along direction 1, 60% of all departures at five stops were on-time using 0.5-minutes-early and 1-minute -late time window. The corresponding average headway deviation was 84 seconds, with average vehicle run time of 1.4 minutes. The passenger-based analysis showed that for all trips along direction 1, the average additional waiting time per passenger was 42 seconds with average additional passenger travel time of 1.7 minutes.

The APC data analysis along direction 1 revealed that average passenger load was 26.5 passengers per bus per direction. The average highest and lowest passenger loads were 38.3 passengers per bus and 2.7 passengers per bus respectively. Overall, Passenger activity over the first half of the route is characterized by high load which is about twice that of the second half of the route.

The overall analysis revealed that performance deteriorated further along the line in both directions. The occurrence of bunching increased towards the end of the route. There is a room for improvement in both agency and passenger oriented measures. Keeping a regular headway on the route is very important, especially for short headway service periods. Passengers perceive reliability mainly in terms of additional waiting and travel time. Improving these aspects of service leads to higher passenger satisfaction which could translate into increased patronage for the PT agency.

Keywords Bus service reliability analysis, measures of reliability, public transport, AVL data, APC data

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Abbreviations and symbols

APC	Automatic Passenger Count
AVL	Automatic Vehicle Location
EBL	Exclusive Bus Lane
HCR	Helsinki Capital Region
HSL	Helsinki Regional Transport Authority
PT	Public Transport
TSP	Traffic Signal Priority

1 Introduction

The rate of automobile ownership in Helsinki Capital Region is on the rising trajectory, even bypassing population growth rate of the region. (HSL moves Us All, 2015). The population of the region expected to double in 2050, planning for a sustainable mobility becomes crucial. Effort is being exerted to minimize private car dependence and innovative transport solutions are being tested in the region. Increasing the share of public transport (PT) in the region is the main goal of Helsinki Regional Transport Authority (HSL). To increase the share of PT, improving its efficiency and reliability becomes a crucial strategy by attracting private car users and keeping existing passengers. Therefore, PT agencies need to continuously evaluate the reliability of their service and take improvement actions accordingly.

A reliable public transport (PT) service is one that adheres to schedule and whose vehicles run on-time. Operating a PT, without deviating from schedule in urban areas is a difficult task. It is generally recognized that deviation from schedule (unreliability) in public transport is an important operational problem that affects both operators and passengers. Measuring the level of deviation from schedule helps operators and public transport authorities identify and improve gaps in service. Recorded large operational data from Automatic Vehicle Location (AVL) and Automatic Passenger Counter (APC) provide an opportunity to analyze operational performance quality. Measures of reliability from the perspective of operators include schedule adherence, headway regularity and run-time. (Cham 2006). Measures from the passenger's perspective include passenger waiting time and travel time. (Van Oort 2011).

1.1 Overview and motivation

A high volume of mobility characterizes today's cities of which personal mobility has been a major part of it. Automobile ownership characterized by alluring qualities such as speed, freedom and convenience has become a major force in shaping urban transportation, reaching a critical point where the problems of dependence on personal automobile are outweighing its profits. (Lowe 1990). While increase in personal mobility becomes the trend in many places, the share of public transport has not shown much increase over the years. Pressed with the

attractive qualities of automobiles, provision of public transportation should be good enough to become a viable transport option. (Ceder 2016). Many quality aspects of public transport service should be improved, in order to raise its share. A high-quality PT will result in modal shift from private car use into PT. The need to run PT service with a limited budget and with increased service quality is putting a lot of pressure on PT providers. (Van Oort 2011). Therefore, making PT cost-effective and high quality is in the interest of all stakeholders in public transportation.

Helsinki Capital Region (HCR) is a growing metropolitan area, serving its inhabitants with various modes of transportation. Helsinki at its heart, HCR consists of Helsinki, Espoo, Vantaa and Kauniainen. The four cities with land area of 964 square Km, are home to one million inhabitants (which represents close to 20% of the Finnish population). Considering the effects of growing region that should meet mobility needs of its residents, quality of PT in the region becomes an important factor in building a sustainable mobility in the region.

1.2 Objective and scope of the thesis

The objective of the thesis is to analyze service reliability of bus route in Helsinki Region using data from Automated Vehicle Location (AVL) systems and Automatic Passenger Counter (APC). To this end, a bus line 550 will be examined as an example. An overview of service reliability of PT and different measures of reliability will be provided through literature review. Reliability indicators to be used in the analysis will be proposed. The underlying causes of unreliability will be investigated. The thesis proposes measures to improve reliability and ends with conclusion and recommendation.

The thesis uses reliability indicators that measure reliability from both the operators' and passengers' perspective. The outcomes of this thesis will complement the Helsinki Region Public Transport Authority (HSL) and contractors' own reliability results of the bus line 550, and hence benefit them to better improve reliability of their service from the passengers' perspective as well.

Operational data from AVL system and APC is used to carry out an empirical assessment of service reliability of bus line. Operational data for the month of March 2015 is the duration of the data for the AVL system. For APC system data period is 3 months (January-March 2015). The reliability analysis has made use of five reliability indicators where three of them are based on operational reliability (focuses on perspectives of service operators on reliability) and two of them are based on passengers 'perspective of reliability.

1.3 Thesis Structure

This thesis is composed of 6 major chapters. Chapter 1, *Introduction*, gives background, motivation, objective and scope of the study. It also includes structure of the thesis. Chapter 2, *Literature Review*, presents literature related to over view of reliability, definitions of reliability, different aspects of reliability, reliability indicators, causes of unreliability and improvement strategies of reliability. Furthermore, an overview of the role of automated data collection is presented at the end of the chapter. Chapter 3, *Case study background*, gives an overview of the region's public transport situation in general and main characteristics of bus line 550, in particular. Available modes in the region, public transport networks, share of different public transport modes and organizational structure of the public transport agency of the region are briefly presented in the first section of this chapter. The second section of the chapter on *Case study description* includes information on the bus route 550 such as route, vehicle types, stops and priority measures. Chapter 4, *Methodology*, describes different steps taken and assumptions made in carrying out the study including data preparation and type of indicators used to analyze data. Chapter 5, *Results and discussion*, presents the outcomes of the analysis with the use of illustrations including graphs and tables and discussion on the results. And the final chapter, chapter 6, *Conclusions and recommendations*, draws conclusions from the previous chapters and gives recommendations for further study.

2 Literature review

In chapter one, it is stated that there is an increasing need to improve quality of PT and that reliability being the most important indicator of service quality. In this chapter, literature on public transport reliability is reviewed. The chapter presents literature related to overview of reliability, definitions of reliability, different aspects of reliability, measures of reliability, reliability indicators, causes of unreliability and improvement strategies of reliability.

2.1 Reliability in public transport

Why Reliability in urban public transport?

Cities across the world are facing an increased level of mobility. Congestion, noise, greenhouse gas emissions, sprawl and traffic accidents are some of urban transportation challenges facing many cities. Congestion in cities and around cities alone costs European Union around 100 billion Euros a year. (European Commission).

(Commission of the European Communities, 2009) report reveals that one of the most important strategies to meet urban transportation challenges and its unintended outcomes is to facilitate a shift from personal car use in to public transportation use. Unreliability of public transport is a significant set back towards achieving this goal. To overcome this setback, one of the targets of the European Commission is to make public transport schedules 50% more reliable (European Commission).

Service reliability is in the interest of both public transport operators and passengers. Unreliability directly affects both operators and passengers. Unreliability affects operators through increased operation costs, decreased ridership, and consequently dwindling revenue. For passengers, unreliability in service may mean longer waiting times, longer travel times, difficulty in making transfers, overcrowding and dissatisfaction with the service. In order to counter the negative effects of unreliable service, the issue of reliability in public transportation has been a focus of performance measure for more than a century. (Levinson 2005). Reliability

is even more relevant in today's world since passengers have more options of different modes to choose from.

There are a number of quality aspects of public transportation including safety, comfort, reliability, convenience. (Van Hagen & Bron 2014) described the level of these quality aspects of public transport using a pyramid also called as "pyramid of Maslow for public transport".

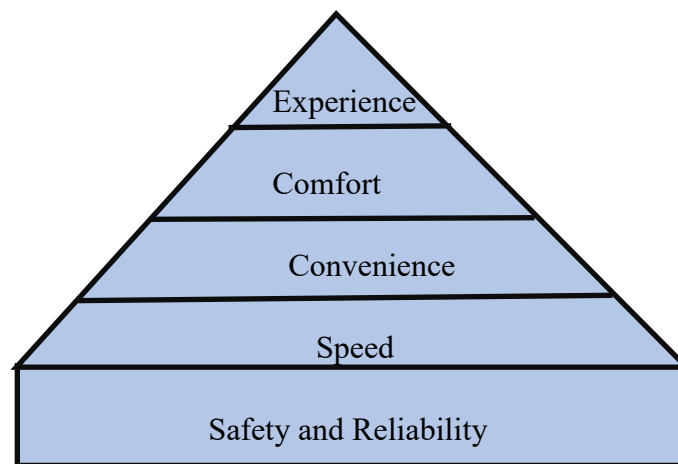


Figure 1. Public transport quality dimensions in terms of importance. Source: (Van Hagen & Bron 2014)).

As can be seen from figure 1, at the base of the pyramid are safety and reliability forming the foundation of passengers' quality needs. Unsafe environment in vehicles, at stops or stations will deter passengers away from using the service. In the same way, if passengers cannot get service as promised by operators, they will be dissatisfied. Next to safety and reliability, speed has also a high importance in the hierarchy of quality dimensions. The faster the service, the better for passengers. Passengers choose shorter trip times whenever possible. Passengers value easy, trustworthy, and convenient travel experience with ample travel information. Going up the pyramid, comfort in the vehicles, at stops or at stations is at the interest of passengers. Sheltered stops and seats at stops for instance increases the comfort of passengers. Passengers want a pleasant experience of their travel, which can be influenced by several factors such as cleanliness, wireless internet, color, music, refreshment shops and friendly driver. This hierarchical requirement of needs in service quality of public transport represents passengers

core values. The focus of this thesis study is reliability, which is at the base of the pyramid of ‘‘Maslow for public transport’’.

Overview of definitions of reliability

Reliability in public transport is a generally understood concept. However, when it comes to definitions or interpretations of reliability, different groups have varying concepts as to what reliability means and how to measure it. In order to grasp the objective nature of service reliability, one should understand the different definitions of service reliability in public transportation and the relative significance of these definitions for each interest groups. (Ap. Sorratini et al. 2008)

According to (Ap. Sorratini et al., 2008), reliability is defined as a measure of the probability of a trip to take place in accordance with the expected trip elements, such as travel time, comfort and cost. In other words, reliable public transport service can broadly mean one that consistently operates based on its schedule or time table. As of (Cham 2006), reliability is defined as the availability and stability of travel attributes at a given point influencing the decision making of passengers and transit operators. This definition holds the distinctive perspectives that exists between operators and passengers. In a broader way, (Ceder 2016) defines reliability as level of dependability on waiting time, riding time, passenger load, vehicle quality, safety, amenities, and information. The way reliability is defined by (Ap. Sorratini et al. 2008) is purely on the operational side. In this thesis, the definitions provided by (Cham 2006) and (Ceder 2016) which captures aspects related to both operators and passengers will be adopted.

Overview of public transport reliability

Literature on service reliability of public transport dates many decades back and is still an ongoing research area. This is an indication not only that reliability has become a key indicator of quality of public transport service but also showing its complexity about which performance indicators to use. Even though service reliability is critical to both operators and passengers, its interpretation by each group varies. Supply (operator) based service quality indicators are

different from demand(passenger) based quality indicators. (Liu & Sinha 2007), (Van oort 2011). To improve service reliability, it is essential to monitor and predict the level of service reliability of a public transport system. For this we need proper indicators. The commonly used indicators which are supposed to express reliability do not completely focus on service reliability concerning passenger impacts. In fact, they focus more on service variability of the system than on the actual impacts on passengers.

Reliability measures that incorporate both passengers and operators' perspective is a solution where everyone benefits. Operators will minimize operation cost, maximize revenues there by retaining existing passengers and attracting new passengers. (Diab et al, 2015).

Even though, passengers of public transport consider service reliability as a major indicator of service quality, there exists variations in the actual service reliability. The existence of unreliability leads to passengers that are less satisfied with transport service. Unreliability in public transportation deters existing and prospective passengers from using public transport service. (Ap. Serratini et al. 2008).

2.2 Overview of different perspectives on public transport reliability

While operators monitor service punctuality, regularity and vehicle run times to improve reliability of their service, passengers perceive reliability in the form of length of waiting times, travel times of their journey and other quality aspects such as safety and comfort. (Van Oort 2011). In this section, these two major perspectives of service reliability measures are summarized.

2.2.1 Overview of agency perspective on reliability

From the perspective of operators/transit agencies, service reliability is mostly expressed in terms of on-time performance, also expressed as schedule adherence. (Cham 2006). On-time performance and running time are the two main operation measures carried out by operators. (Furth, 2000). For public transport operators, schedule adherence, headway adherence and run-time adherence are the most commonly used measures to assess reliability of their service. (Arhin et al. 2014). In the following section, these measures of reliability will be briefly discussed.

2.2.2 Overview of passenger experience of reliability

Earlier surveys indicated that reliability is one of the most important aspect of service quality aspects by travelers. (Chakrabarti 2015) states that unreliability is consistently ranked among the highest inconvenience cost in passengers' travel experience of public transportation. Travelers' decisions are significantly influenced by reliability of travel time, as personally experienced by travelers. (Carrel et al. 2015). These decisions that are based on passengers' perception of variability in travel time, may include which mode to choose and what time to arrive at a stop.

(Ceder 2016) states that unreliability in public transport is a major deterrent to existing and potential passengers. He reports a study carried out in UK to assess passengers' perception of local bus services. The results of the assessment are formulated in terms of ranking of importance. That is, reliability (34), frequency (17), vehicles (14), driver behavior (12), routes (11), fares (7), and information (5). The given weights add up to 100. As can be observed from this assessment, from the passengers' perspective, reliability is about 5 times as important as fares and it is twice as important as frequency.

Improving reliability benefits passengers in saving their time and increasing their trust of the transit service. According to (Cham 2006), the major benefits of an improved reliability service includes a reduction in total travel time, satisfaction with the transit service and attraction of

new passengers. A lower value in travel time variability may allow passengers to choose later departure times and be at their destination on-time.

2.3 Measures of reliability

Measuring reliability has gone through a different phase regarding reliability indicators and data use. Earlier attempts to capture reliability were based on operators' perspective and data used were manually collected.

Different types of reliability measures are used in literature. Some studies focused on headway reliability which measures and analyzes the consistency between actual and scheduled headways. (Liu & Sinha 2007), (Abkowitz et al. 1990). (Van Oort 2011) focuses his public transport reliability research on passengers' travel time reliability, others in this category include (Carrel et al. 2015), (Carrion & Levinson 2012), (Huo et al. 2014), (Kouwenhoven et al. 2014), (Polytechnic 1982), (Abkowitz,1982) and (Liu & Sinha 2007). The research paper of (Arhin et al. 2014) and (Strathman & Hopper 1993) focused on on-time performance reliability. Infrastructure (network connectivity) reliability was the focus by (Tahmasseby, 2008) and (Hongwei & Xizhao 2015).

In (Abkowitz et al. 1990), headway reliability is analyzed before and after implementing a headway-based holding technique to assess the effects of headway-based holding strategy on the level of reliability.

Liu et al (2007) discussed three types of bus service reliability aspects which are travel time reliability, headway reliability and passenger waiting time reliability. These aspects of reliability are all defined in the context of the match between actual and schedule components of each aspect.

(Van Oort 2011) discussed reliability from both operators and passengers' perspective, claiming that both perspectives are equally important to capture the whole effect of reliability. He asserts that indicators of reliability measures from the passengers' perspective had been missing in earlier researches. Passengers are affected from unreliability in the form of variations

related to travel time. To capture the effect of unreliability on passengers, he formulated two new additional indicators. These indicators are additional travel time and reliability buffer time(RBT). The additional travel time, as defined by (Van Oort 2011) is the additional time a passenger spends compared to the average travel time a passenger experiences to complete a journey.

According to (Cham 2006), reliability measures in the past were characterized by inherent weaknesses and some of these weaknesses are tendency to concentrate on actual schedules (leading to a skewed results of reliability which ignores inefficient schedule), exclusion of passengers' perspective and lack of consistent comparisons of measures. Easy and measurable reliability indicators are useful tools to help regulators to identify aspects of unreliable service and set new standards. (Ap. Sorratini et al. 2008)

Contemporary reliability measures incorporate indicators that capture the perspective of both transit agencies and passengers. Data that is collected through intelligent means such as AVL system facilitates such improved ways of measuring reliability. Table 1 gives a summary of major measures of reliability.

Table 1. Major reliability measures. Source: (Cham 2006).

Distributions of travel time (total travel, in-vehicle, wait times).	<ol style="list-style-type: none"> 1. Mean. 2. Coefficient of variation (for skewed distributions, standard deviation should exclude extreme values). 3. Percent of observations 'N' minutes greater than the mean values
Schedule adherence, measured at any point along the route.	<ol style="list-style-type: none"> 1. Average deviation from schedule at any point along the route. 2. Coefficient of variation (from average deviation, not schedules) 3. Percent of arrivals N minutes later than average deviation from schedule
Distribution of headways	<p>Distribution of headways</p> <ol style="list-style-type: none"> 1. Mean. 2. Coefficient of variation. 3. Percent of headways: <ol style="list-style-type: none"> a) Greater than X percent of average or scheduled headways, where $X > \text{or} = 1$ b) Lower than Y percent of average or scheduled headways, where $Y < \text{or} = 1$
Seat availability	Passenger loads (demand and capacity)

Contemporary research on service reliability of public transport is dedicated to both operators and passengers' perspective. Schedule punctuality and service regularity represent the operators' perspective and are commonly used indicators to measure reliability. Schedule punctuality and regularity are indicators of service variability of the system than tools for expressing the actual impacts on passengers. Passengers' travel time related aspects such as average waiting time, additional waiting time, average travel time and average additional travel time describe passengers' perspective of reliability. In this thesis, indicators that capture both perspectives of the operator (schedule adherence and regularity indicators) and that of the passenger (additional waiting and travel time) are considered.

2.3.1 On-time performance/Schedule punctuality

On-time performance reflects the degree of matching between schedule and actual trips. In other words, on-time performance measures how well actual departures and arrivals conform to scheduled departures and arrivals. On-time performance is important for those passengers who consult the time table. This is often the case for passengers using low frequency routes. If a vehicle departs early, then it is not “on-time” from the perspective of passengers because that will mean that passengers have to wait a full headway until the next vehicle arrives. (Cham 2006).

On-time performance reliability promotes the attractiveness of public transport to existing and prospective passengers. (Arhin et al., 2014). Transit agencies apply reliability strategies that maintain on-time performance and provide sufficient number of vehicles and drivers. (Cham 2006) lists the benefits of improving service reliability to the transit agencies as lower capital and operational costs, reduced fleet size, increase ridership of existing and new travelers and maximized revenues for the agencies.

On-time performance is often measured as a percentage of bus arrivals or departures at a given point within a predetermined range of time. The threshold range of acceptable delay or earliness to measure on-time performance depends on public transport agencies goals and aspirations. As can be seen from figure 2, there are different windows of time to measure on-time performance. For instance, New Jersey’s public transportation uses 1-minute-early and 5-minute -late time range to measure on-time performance based on bus departure, while Southeastern Pennsylvania Transportation Authority (SEPTA) uses 1 minute early and 4 minutes late range of time to measure on-time performance. (Diab et al 2015). Washington Metropolitan Area Transport Authority (WMAT uses the definition of on-time performance for its buses to be two minutes early to seven minutes late. (APTA 2010).

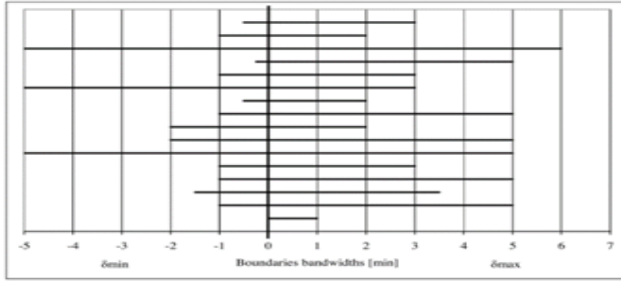


Figure 2. Boundaries of time bandwidth used in many cities to measure on-time performance based on departures. Source: (Van Oort 2011)

On-time performance indicator

Average departure deviation (average punctuality) for a complete line is given by equation 1. (Van Oort et al, 2012). Passengers are assumed to arrive randomly between scheduled time minus the lower bound bandwidth schedule deviation and scheduled time plus upper bound bandwidth schedule deviation.

$$P_l = \frac{\sum_{j=1}^{n_{l,j}} \sum_{i=1}^{n_{l,i}} P_{l,i,j} (\delta^{\min} < \tilde{D}_{l,i,j}^{act} - D_{l,i,j}^{sched} < \delta^{\max})}{n_{l,i} * n_{l,j}}$$

..... Equation 1

where:

- P_l = relative frequency of vehicles on line l having a schedule deviation between δ^{\min} and δ^{\max}
- $P_{l,i,j}$ = relative frequency of vehicle i on line l having a schedule deviation between δ^{\min} and δ^{\max} at stop j
- $\tilde{D}_{l,i,j}^{act}$ = actual departure time of vehicle i on stop j on line l
- $D_{l,i,j}^{sched}$ = scheduled departure time of vehicle i on stop j on line l
- δ^{\min} = lower bound bandwidth schedule deviation
- δ^{\max} = upper bound bandwidth schedule deviation
- $n_{l,i}$ = number of trips of line l
- $n_{l,j}$ = number of stops of line l

Deviation from the time table for all stops of a given line (for instance line l) is given by equation 2. (Van Oort, 2011).

$$p_l = \frac{\sum_j \sum_i | \tilde{D}_{l,i,j}^{act} - D_{l,i,j}^{sched} |}{n_{l,j} * n_{l,i}} \dots\dots\dots \text{Equation 2.}$$

where:

- p_l = average punctuality on line l

2.3.2 Headway regularity

Headway is the time between two vehicles passing the same point traveling in the same direction on a given route. Headway adherence is a good measure of reliability for high frequency routes since passengers arrive randomly without consulting schedule. Irregular headways lead to variability in expected waiting times and variability in load characteristics. (Cham 2006).

When the level of headway regularity decreases, it causes a well-known impact that passengers experience as bunching. The ‘bunching’ phenomenon is a consequence of variation in headways. Bunching of buses occurs when a bus becomes so late that the next scheduled bus catches up to it. Bunching is undesirable for passengers due to the increased average waiting time, thereby reducing the predictability of the service. Headway-based holding strategy is often a solution to minimize the occurrence of bunching.

Headway irregularity indicator

Headway regularity is an important reliability indicator, especially for high frequency routes. The variation in headways is often represented by coefficient of variation.

Coefficient of variations in headways is given by equation 3. (Cham, 2006).

$$CoV(\tilde{H}_{l,j}^{act}) = \frac{StD(\tilde{H}_{l,j}^{act})}{E(\tilde{H}_{l,j}^{act})} \dots\dots\dots \text{Equation 3.}$$

where:

- $CoV(\tilde{H}_{l,j}^{act})$ = coefficient of variation of actual headways of line l at stop j
- $\tilde{H}_{l,j}^{act}$ = actual headway of line l at stop j
- $StD(\tilde{H}_{l,j}^{act})$ = standard deviation of actual headways of line l at stop j
- $E(\tilde{H}_{l,j}^{act})$ = expected headway of line l at stop j

One way to describe the regularity of a public transport service is using percentage regularity deviation mean (PRDM). The average deviation from the scheduled headway as a percentage

of the scheduled headway is given by equation 4. (Van Oort 2011). The lower the PRDM, the better the regularity of a bus service.

$$PRDM_{l,j} = \frac{\sum_i \left| \frac{H_{l,i}^{sched} - \tilde{H}_{l,i,j}^{act}}{H_{l,i}^{sched}} \right|}{n_{l,j}} \dots\dots\dots \text{equation 4.}$$

where:

- $PRDM_{l,j}$ = relative regularity for line l at stop j
- $H_{l,i}^{sched}$ = scheduled headway for vehicle i on line l
- $\tilde{H}_{l,i,j}^{act}$ = actual headway for vehicle i on line l at stop j
- $n_{l,j}$ = number of vehicles of line l departing at stop j

2.3.3 Vehicle trip time/Run time variability

Vehicle run time is the time it takes a vehicle to make one trip along the whole length of the route. Vehicle trip time variability distribution can be plotted on a graph, by filtering and rearranging AVL data to retrieve run times of vehicle trips from first stop to last stop of the route. Operators use run-time to monitor service reliability of a route. Variability in run times affect a number of reliability aspects such as on-time performance and headway. (Cham 2006). To compensate for a possible variability in trip times, planners often include recovery time embedded in the schedule to ensure that the next trip departs on-time.

AVL-APC data provides the opportunity to get large run time data to analyze actual trip time distributions. The average run time (trip time), the degree of deviation from average run time value and extreme values are all important values that reflect run time characteristics along a given line. To increase run time schedule quality, 85th -percentile value of actual (observed) run time is often used to set schedule run time. (Furth 2006). Setting the schedule run time this way gives an 85% probability that the actual run time matches the scheduled run time. Depending on the results of the run time analysis, a recovery time to the schedule at the end of the line, also called slack time could be added. Furthermore, for high frequency routes,

headway-based vehicle holding at selected time points could be implemented to minimize early departures.

2.3.4 Passenger wait times

Wait time is part of service reliability and one of the tools to measure the effects of unreliable service to passengers. According to (Furth & Muller 2006) wait time is a major push factor for passengers from using public transport and plays a pivotal role in shaping demand of users and service reliability. Therefore, it is also in the interest of an agency operating a public transport to minimize passenger waiting time to attract more broad based passenger volumes. Reliability from the perspective of passengers is to consistently lower their overall waiting and travel time. (Diab et al. 2015). For passengers, unreliability regarding waiting time would mean that they should budget more time in terms of departure time from home and arrival time at their destination.

Waiting time at stops is an important indicator of the level of service as felt by passengers. As noted by (Van Oort & Nes 2004), passengers give a higher value to waiting time than the value they give to in-vehicle time. Since wait times are part of travel time, longer wait times are undesirable by passengers. Transport for London, a transit agency in London where it sets headways while outsource operation to contractors, uses additional waiting times as a key reliability indicator for high frequency services. (Liu & Sinha 2007). London transport incentivizes its contractors during service outsourcing based on average additional waiting time. (Furth & Muller 2006).

An investigation about passenger wait time perceptions by (Psarros et al. 2011) concludes that passengers perceive their wait time to be much longer than the actual waiting period. This might be caused by anxiety over whether arriving at destination on time, weather condition or attitude to assume waiting time as wasted time.

Passenger waiting time is affected by punctuality, regularity and arriving patterns of passengers at departure stop (schedule-based or random arrival). Additional waiting time demonstrates the

extra time passengers spend compared to waiting time corresponding to schedule. Waiting time distribution can be estimated based on a set of observed headways.

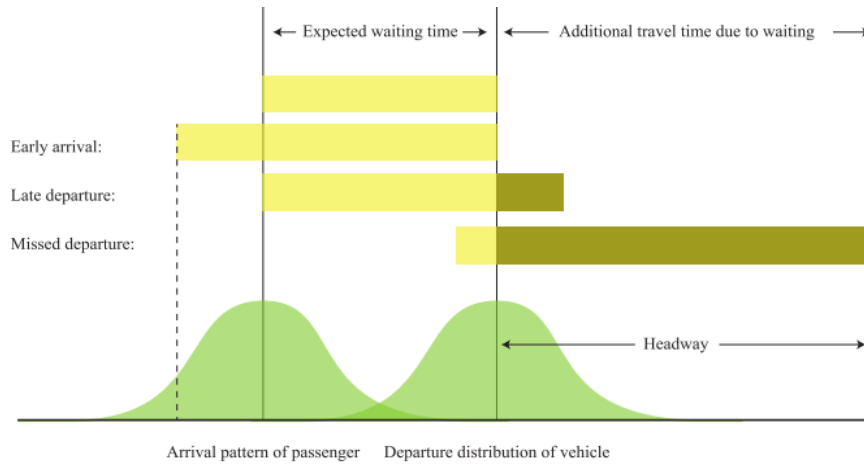


Figure 3. Additional waiting time at departure stop showing the link between passenger arrival pattern and vehicle departure pattern distributions. Source: (Lee 2013).

According to (Furth & Muller 2006), distribution of passengers waiting time at departure stops can be derived from headway distributions, which lies in the interval $[0, H]$, H being headway.

Passenger-wait-time-variations indicator

Average additional waiting time in seconds per passenger is the indicator used to measure wait time reliability. To draw values for average additional passenger-wait time, average schedule passenger wait time and average actual passenger wait times are calculated using equation 5. In the following section, indicators of passenger waiting time under both assumptions of random passenger arrival pattern and scheduled arrival pattern at original stop are presented.

Additional wait time for short headways

For short headways (less than or equal to 10 minutes), it is assumed that passengers arrive randomly. In this case, schedule is not relevant anymore. If arrival pattern of passengers is random, expected waiting time per passenger can be calculated by using the coefficient of

variance of headways. Hence, expected waiting time per passenger is given by equation 5. (Van Oort 2011).

$$E(\tilde{T}_{l,j}^{waiting}) = \frac{E(\tilde{H}_{l,j}^{act})}{2} * (1 + CoV^2(\tilde{H}_{l,j}^{act})) \dots\dots\dots \text{Equation 5}$$

where:

$$\tilde{T}_{l,j}^{waiting} = \text{passenger waiting time at stop } j \text{ on line } l$$

The average additional waiting time per passenger is given by equation 6.

$$E(\tilde{T}_{l,j}^{Add,waiting}) = \frac{E(\tilde{H}_{l,j}^{act})}{2} * (CoV^2(\tilde{H}_{l,j}^{act})) \dots\dots\dots \text{Equation 6.}$$

where:

$$E(\tilde{T}_{l,j}^{Add,waiting}) = \text{average additional waiting time per passenger due to unreliability of line } l \text{ at stop } j$$

The average additional waiting time per passenger on a complete line is given by equation 7. (Van Oort 2011).

$$E(\tilde{T}_l^{Add,waiting}) = \sum_j (\alpha_{l,j} * E(\tilde{T}_{l,j}^{Add,waiting})) \quad \text{with} \quad \sum_j \alpha_{l,j} = 1 \quad \dots\dots\dots \text{Equation 7}$$

where:

$$\alpha_{l,j} = \text{proportion of passengers of line } l \text{ boarding at stop } j$$

Additional wait time for long headways

Distribution of passengers' arrival time around scheduled departure determines passengers' waiting time. Depending on where they lie on the distribution of arrival times, passengers can

reach their planned vehicle or miss it and wait for the next vehicle. This arrival time distribution is related to high and low extremes of schedule deviation distribution.

In (Van Oort 2011), it is assumed that all passengers will arrive in a certain time band, namely between τ_{early} and τ_{late} . If a vehicle departs before τ_{early} , all passengers will miss the vehicle and they must wait for the next departing vehicle. Passengers waiting time will be zero if vehicle departure time lies between τ_{early} and τ_{late} . Vehicles departing after τ_{late} will cause all passengers to have an additional waiting time equivalent to difference between the schedule and actual headway.

Additional waiting time per stop can be calculated by using equation 8 and 9, and additional waiting time for all passengers along the line can be calculated by equation 10. (Van Oort 2011).

$$\begin{cases} \tilde{T}_{l,j}^{Add,waiting} = H_l^{sched} & \text{if } \tilde{d}_{l,j}^{departure} \leq -\tau_{early} \\ \tilde{T}_{l,j}^{Add,waiting} = 0 & \text{if } -\tau_{early} < \tilde{d}_{l,j}^{departure} < \tau_{late} \\ \tilde{T}_{l,j}^{Add,waiting} = \tilde{d}_{l,j}^{departure} & \text{if } \tilde{d}_{l,j}^{departure} \geq \tau_{late} \end{cases}$$

$$E(\tilde{T}_{l,j}^{Add,waiting}) = \frac{\sum_i E(\tilde{T}_{l,j}^{Add,waiting})}{n_{l,j}} \dots\dots\dots \text{Equation 8.}$$

$$E(\tilde{T}_l^{Add,waiting}) = \sum_j (\alpha_{l,j} * E(\tilde{T}_{l,j}^{Add,waiting})) \quad \text{with } \sum_j \alpha_{l,j} = 1 \dots\dots \text{Equation 9}$$

where:

- $E(\tilde{T}_{l,j}^{Add,waiting})$ = average additional waiting time per passenger due to unreliability of vehicle *i* of line *l* at stop *j*
- H_l^{sched} = scheduled headway at line *l*
- $\tilde{d}_{l,j}^{departure}$ = departure deviation of vehicle *i* at stop *j* on line *l*
- τ_{early} = lower bound of arrival bandwidth of passengers at departure stop
- τ_{late} = upper bound of arrival bandwidth of passengers at departure stop
- $n_{l,j}$ = number of trips on line *l*

2.3.5 Passenger travel time variability

Travel time represents passengers' time expenditure through waiting and in-vehicle time. Additional travel time captures the extra time spent on waiting and in-vehicle time caused by variability in waiting and in-vehicle time as compared to schedule.

Additional in-vehicle time represents the extra in-vehicle time passengers spend on the vehicle compared to the scheduled in-vehicle time. In-vehicle time constitutes dwell time (stop times for boarding and alighting) and stop time (at traffic lights or due to congestion).

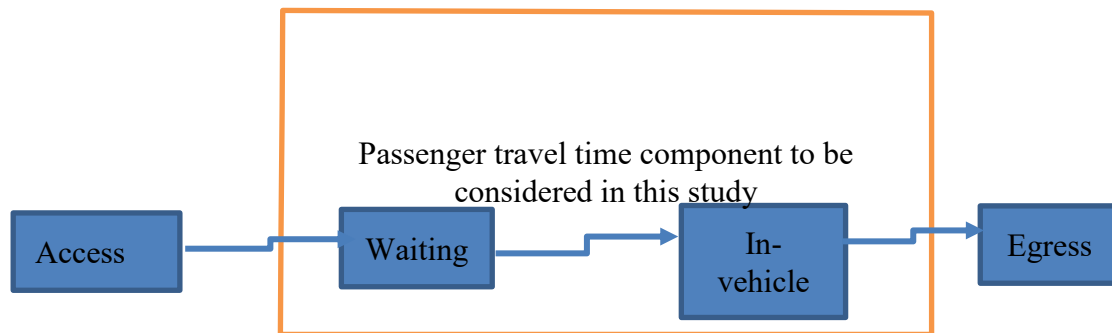


Figure 4. Passenger travel time component considered in this study.

Time taken to complete the whole public transport journey includes many parts. According to (Van Oort 2011), passenger travel time for the complete journey is divided into waiting time at the origin, access time, waiting at departure stop, in-vehicle time and egress time (time taken from final stop to destination). Travel time of passenger includes the time between arrival at departure stop and alighting at the final stop. In this thesis, passengers travel time consists of waiting time at first stop and in-vehicle time.

Passenger travel time = passenger waiting time + in-vehicle time

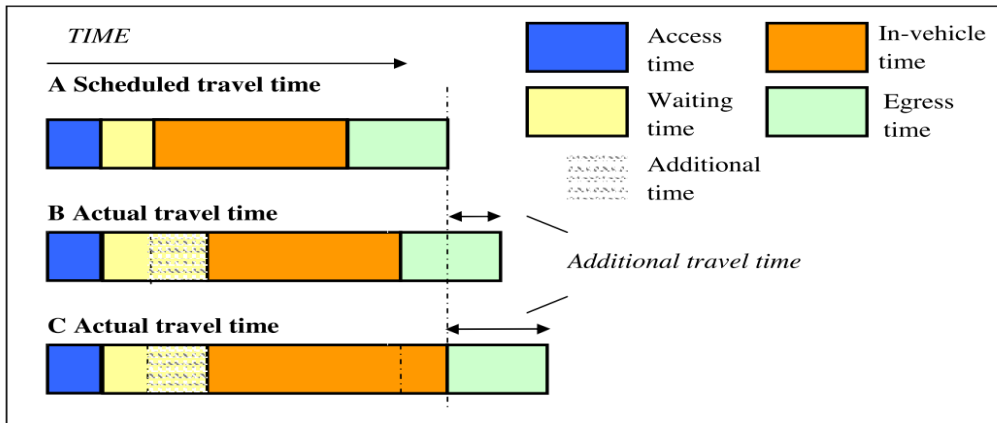


Figure 5. Additional wait time and additional travel time as compared to scheduled travel time and waiting time. Source. (Van Oort 2011).

Passenger travel time variability indicator

Average additional passenger travel time measured in minutes per passenger is the indicator used to measure passenger travel time reliability. To draw values for average additional passenger-travel time, average schedule passenger travel time and average actual passenger travel time are calculated.

Passenger activity and load

Boarding and alighting characters of a route affects service reliability. Variability in crowding affects reliability in terms of on-time performance and headway. In this regard, deviation from scheduled headway is an indicator of the level of crowdedness. It is often the case that overcrowding occurs alongside under crowding, a situation where vehicles are much less occupied compared to usual level of crowding. One way to measure the effects of passenger load on service reliability is to monitor its load along the route. (Cham 2006).

2.4 Causes of variability and unreliability

(Van Oort et al. 2015) classify the major causes of variability in public transport in to three components. These are driving time, dwell time and stopping time. The authors make a further distinction between internal and external factors that may cause variability of these components.

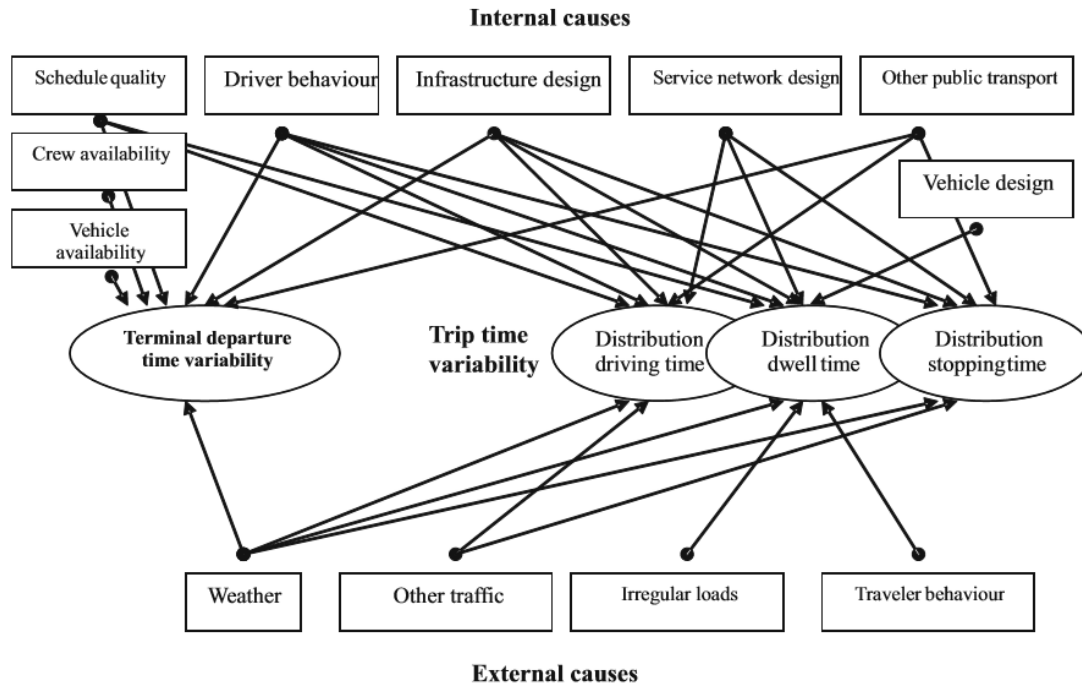


Figure 6. Major causes of service variability in public transportation. Source: (Van Oort et al. 2015)

Public transport operation at the basic level deals with a single bus, or vehicle whose departure and arrival time is scheduled in time and space. Operators use their resources to monitor and control whether actual performance matches scheduled service. As trips suffer from variations from departure and arrival times, the consequences are felt both to the operators and passengers. While operators must deal with enforcing schedule adherence, vehicle maintenance or driver behavior, increased waiting and travel time affect passengers.

According to (Van Oort 2011), variations in the supply (operations) side emanates from two sources, namely:

- a) Terminal departure time variability: distribution of schedule deviation (early or late)
- b) Vehicle trip time variability: distribution of trip times along the route.

In the following section both of these two sources of variability will be discussed briefly.

a). Variability of schedule departure time at terminal

The beginning of every trip may start at a terminal. Late departure from terminal will have significant effect on reliability because unreliability tends to propagate down the route. Greater number of passengers will be affected due to trips deviating from schedule times or headways.

Schedule deviations at a terminal is relatively easier for the operators to deal with since controllers can easily enforce schedule at the terminal. Controlling other points along the route may not be as easy as at the terminal. At a terminal, supervisors may control driver behavior and enforce on time departure from the terminal.

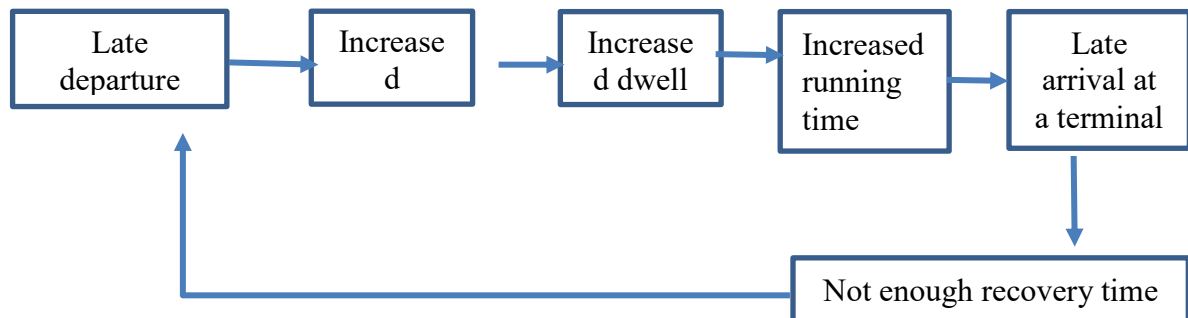


Figure 7. Effects of late departure from terminal. Source: (Cham 2006)

b). Variability of trip time

Driving time variability

Driving time includes actual vehicle driving time and unplanned stops between stops. Variability in actual driving time due to various factors such as driver behavior, climate or traffic conditions leads to variability in total driving time. Unplanned stops such as due to traffic lights will add to the variability in driving time. Targeting to minimize driving time and unplanned stopping time variabilities will increase reliability. Here, line length of the route

plays a big role in trip time variability. According to (Van Oort 2011), driving times is proportional to the line length of the route. That is, the longer the route length is the likelihood of having a large driving time variability is higher.

Dwell time variability

Dwell time is the time the vehicle stops for boarding and alighting purposes. The variability of dwell time could be caused by several factors including driver behavior, variability of headway (if variable, more boarding may happen) and loading and alighting conditions. It is evident that the number of stops on a given route determines the level of variability in driving time. More stops tend to increase variability in driving time. When dwell time increases, it leads to poor service regularity.

The need to keep headways consistent is an important service provision element of a public transport agent. To reduce the need for assigning an additional vehicle to a route, operators must control headways by keeping an evenly spaced vehicles along routes (Abkowitz et al. 1990). When headway adherence in practice is different from scheduled headway, operators may carry out holding strategy by controlling problematic headways.

Both terminal departure variability and vehicle run time variability described above lead to passenger travel time variability, which is directly experienced by passengers.

Passengers' travel time variability

Passengers travel time variability is a result of supply side variability other than passengers' arrival patterns at departure stops. Supply (operation) side variability includes deviations of headways, variation in vehicle departure time, variations in trip times and arrival times. The components of passengers' travel time affected by variations in supply side include, waiting time, in-vehicle time, and arrival time.

Variations in the demand side can also be observed due to a different arrival pattern of passengers at stops. Passengers arrival pattern has two parts, random arrival pattern and

schedule based arrival pattern Passengers tend to arrive randomly for short headway (≤ 10 minute) routes while for longer headway routes (> 10 minutes), passengers tend to arrive according to schedule. (Van Oort 2011).

2.5 Strategies to improving reliability

Operation of public transportation is a complex activity due to its inherent stochastic nature such as congestion, weather, and interference from other traffic. Implementation of various control strategies by public transport agencies to minimize the influence of variability in service has a paramount importance.

Even though, passengers of public transport consider service reliability as a major indicator of service quality, there exists variations in the actual service reliability. The existence of unreliability leads to passengers that are less satisfied with transport service. Unreliability in public transportation deters existing and prospective passengers from using public transport service. (Ap. Sorratini et al., 2008). Therefore, using different strategies to improve reliability will be beneficial to both operators and passengers.

If appropriate strategies to improve reliability are implemented, they will help operators make efficient use of their fleet and human resources and at the same time help operators offer high-quality service which increases patronage and revenue.

In his study, (Turnquist 1982) considers four major service reliability improvement strategies: he lists them as vehicle-holding, signal prioritization, reducing number of bus stops and giving exclusive right of way to buses. Applying any or a combination of these strategies may depend on a specific situation. Frequency seems to be the most important aspect regarding which strategy to implement. Generally, for long routes reducing the number of bus stops could be considered. According to (Turnquist 1982), for long headway services, schedule-based vehicle holding should be considered while for shorter headways a combination of provision of exclusive right of way and signal prioritization should be considered.

2.5.1 Network design based instruments

- *Terminal design*

Terminal configuration may affect on-time departure of vehicles from terminals. Therefore, during design of terminal, an optimal configuration should be considered. Optimally designed terminal shortness vehicle trip time variability which also reduces passenger travel time. (Van Oort 2011).

- *Exclusive bus lanes (EBLs)*

Traffic congestion affects the performance of buses. One of the solutions that has been widely recognized to relieve traffic congestion for PT vehicles is PT vehicle priority measures. (Yao et al 20120). Bus priority in the form of exclusive bus lanes (EBLs) as a way of traffic control measures is an effective way to improve PT reliability. (Yao et al 20120).

- *Traffic signal priority (TSP)*

The effort to operate a public transport by adhering to schedule is challenged by other traffic conditions, if public transport vehicles must share the right-of-way with mixed traffic. Public transport vehicles running on exclusive right of way route (for the entire route or on most congested parts of the route), will have a higher chance of adhering to schedule by minimizing travel time and waiting time. Priority of traffic signal to public transport vehicles at controlled intersections will have a similar effect on the overall performance of the vehicles by reducing delay. TSP is as an instrument that results in a more reliable public transport. (Smith et al 2005).

- *Stop design*

Optimal bus stop spacing is a crucial component of service reliability, as it minimizes trip time through increased bus speed. (Furth & Muller 2006) recommends a stop spacing of

320 to 400m (which is the standard European value of stop spacing) for busy urban corridors, the corresponding US stop spacing value is lower.

A combination of exclusive right of way and signal prioritization for a public transport line has big potential to improve service reliability. According to a result of a simulation experiment by (Turnquist,1982), average and standard deviation of travel time were reduced through implementation of a combination of strategies, namely, provision of EBLs and TSP.

Table 2. A result of a simulation experiment that involved implementation of combination of EBLs and TSP. Source. (Turnquist,1982).

Measure	Travel Time (min)		
	Base Case (no reserved lane)	Reserved Lane Only	Reserved Lane and Preemption
Average bus travel time	25.2	23.8	20.8
SD of bus travel time	5.1	4.4	4.2
Average wait time	0.9	0.8	0.7
SD of wait time	1.3	1.2	1.1

2.5.2 Operation based instruments

Vehicle holding can be used as a valuable tool to provide opportunity for returning to schedule for vehicles, especially those vehicles running on long route. Vehicle holding strategy can be implemented based on two attributes, the first one being holding vehicles in order that vehicles run according to schedule. The second one is holding vehicles to maintain a constant headway between successive vehicles.

– *Schedule-based holding*

In this strategy, checkpoints (also referred to as time points in many current literature) are selected on the route. Insisting that every vehicle passing these checkpoints should depart

according to schedule, is referred to as schedule-based holding strategy. According to (Turnquist 1982), for a schedule-based strategy to be effective, the scheduled arrival time at time point should be realistic (should be set to mean of arrival time at that time point) and enforcement of no early departures from the time points. This strategy becomes important on large headway routes.

– *Headway-based holding*

Holding strategies involving headway control can be explained using this example. If a driver of a bus arrives late at a stop less than ‘x’ minutes from its operational headway, the bus is held for ‘x’ minutes before departing the stop. However, if he arrives ‘x’ minutes longer than the operational scheduled headway, the bus is not held. In this scenario, the driver is encouraged to depart immediately.

Reliability satisfies both adherence to schedule (time table) and regularity of headways between successive transit vehicles in order to make transit service more attractive to existing and potential users. (Ap. Sorratini et al., 2008, Van Oort 2005).

– *Stop-skipping*

When a bus is behind schedule during its run time, it may skip one or more stops to reduce its trip time and catch up with schedule time. This is termed as a stop-skipping scheme. This scheme could be useful when number of passengers passing over the ‘skip-stop’ is large and number of boarding passengers at the ‘skip-stop’ are minimum. (Van Oort 2011).

– *Deadheading*

The deadheading is a special case of the stop-skipping scheme, where the bus skips the last part of the route in order to depart on schedule time from the terminal (in the opposite direction of the route). In this scheme, a priority over the passengers at the end of the route and passengers in the opposite direction of the route must be made. (Van Oort 2011).

2.6 Importance of Automated Data

Automated operational data of public transport service can be used to analyze service performance more efficiently. Manual data collection techniques to evaluate level of operation was a huge set back to operators.

Automatic data sources on public transport operations can be collected through a variety of technologies including Automatic Passenger Counter (APCs) such as passenger smart cards, Automatic Vehicle Location Systems (AVL), and mobile phones.

The primary design and use of AVL systems are to acquire real-time location and information of schedule adherence at a control center. (Larrousse et al. n.d.). As far as data on public transport is concerned, time table information could be considered to be one of the first public transport data to be made accessible to all stakeholders. (Van Oort et al. 2013). Information on schedule time table could be a useful tool for passengers and schedule planners, even though it cannot alone explain whether actual operation matches the scheduled service. In recent times, AVL data is becoming publicly available in many cities around the developed world, as part of a growing trend for public open data access in many societal sectors. (Van Oort et al. 2013)

Automated data collection and use (through technologies such as AVL and APC) has several advantages compared to traditional ways of collecting data. These benefits include reduced cost of expensive manual data collection, reduced labor (in the form human data collectors and data processors), reduced human error and increased data accuracy. (Cham 2006)

In this thesis, archived data from Automatic Vehicle Location (AVL) system and Automatic Passenger Counter (APC) is used to analyze service reliability of public transport.

3 Case study background

This chapter gives a description of the case study. The first section of this chapter summarizes the state of public transportation system in the Helsinki Capital Region. The second section describes the case study bus line that is chosen for the analysis of service reliability. The first section includes information on public transport authority of the region, types of modes, passenger flow figures and map of public transport networks. Some of the covered topics in the second section include characteristics of the route, especial bus treatments along the route, vehicle types, and a summary of recent service improvements along the line.

3.1 Public transport in Helsinki Capital Region (HCR)

Public transportation in Helsinki Region is a combination of route networks of five different modes of transport: bus, tram, metro(Subway), local commuter train and Suomenlinna ferry. Metro, VR's commuter train services complemented by buses make the backbone of the regions public transport. Trams serve the inner city of Helsinki. Increasing modal share of public transport is a major planning objective of the region's transport authority. (HSL 2016).

The modal share of public transport in HCR is 43%, making it a major share of the region's transport mode. 80 % of residents have their own travel card or other form of public transport pass. (HSL 2013).

Helsinki region transport authority (HSL) is the official joint local entity that plans and operates public transport in its member municipalities. Among its other responsibilities are procurement of services for different modes, preparation of the Helsinki Region Transport System Plan, approval of ticket prices, marketing of public transport and information dissemination. Member municipalities of HSL are Helsinki, Espoo, Vantaa, Kauniainen, Kerava, Kirkkonummi and Sipoo. HSL is founded in 2010. (HSL 2016).

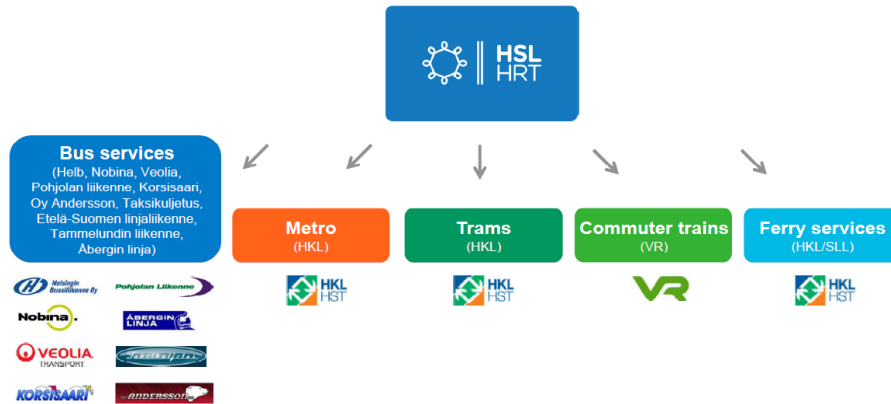


Figure 8. Purchaser-provider cooperation among HSL and different operators. Source: HSL moves us all. (HSL moves Us All, 2015).

In 2014, HSL operating income amounted to 601.6 million of which 48,2% is obtained from municipal contributions, 48,7% from ticket revenue and the remaining 2.1% from other sources. (HSL moves Us All, 2015).

Of all the six modes constituting public transportation in Helsinki region, buses have the largest share of moving passengers around, making buses the most popular mode of public transport. Over half of all journeys of public transport in Helsinki region is made on buses, in year 2015. There are 272 bus routes in the Helsinki region and a total of 1,366 buses are allocated to serve over the entire route.

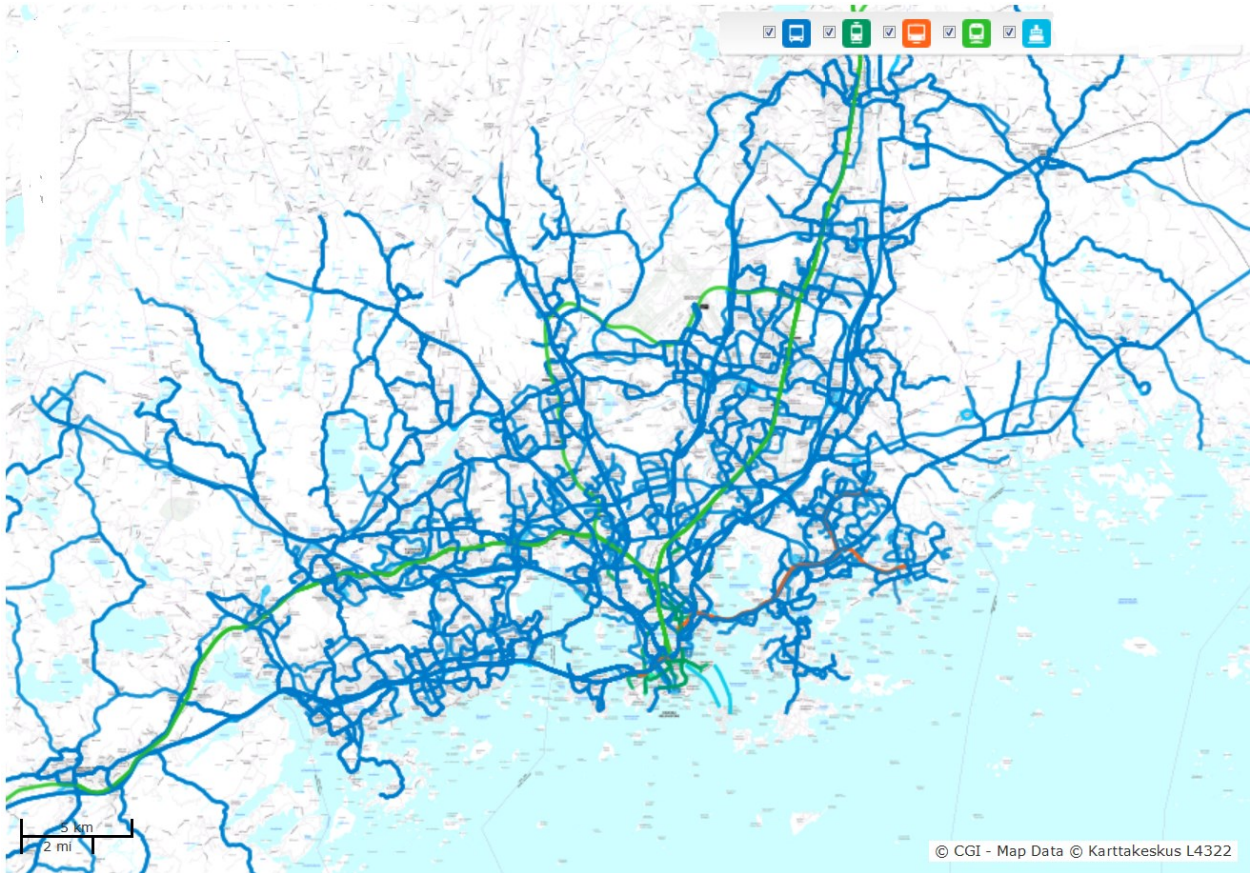
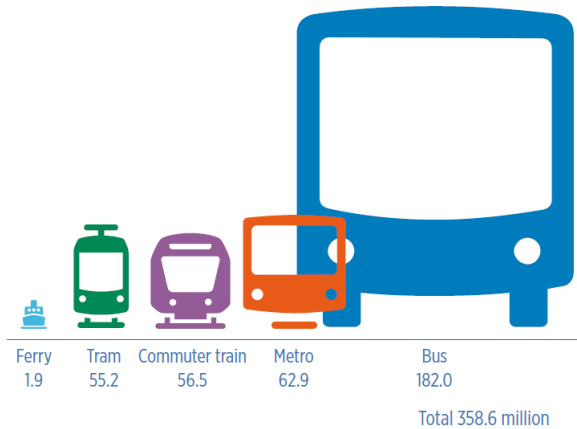


Figure 9. Public transportation network of Helsinki region, the blue lines representing bus mode dominate the network volume. The green line represents rail lines and the orange line represents metro line. Source: (HSL-Linjakartha, 2016).

It can be observed from figure 9, the Helsinki Capital Region (HCR), has radial rail networks (green lines) with origin point at Helsinki Central Rail Way Station. The bus network however follows a transversal distribution. The region has three major ring roads.

Per Helsinki region transport authority (HSL) assessment of service reliability, in the year 2015, 99% of its services were operated according to schedule. As mentioned earlier, such reliability measure is operator focused than passengers experience. Adherence to schedule being an important part of reliability, it does not alone capture passengers experience, for example as compared to personal automobile mode. Non-optimal scheduled time table does not serve the interest of passengers. Passenger numbers by mode of transport for the period is given by figure 10.

Passenger numbers by mode of transport



Passenger numbers by mode of transport 2013-2015 (million)

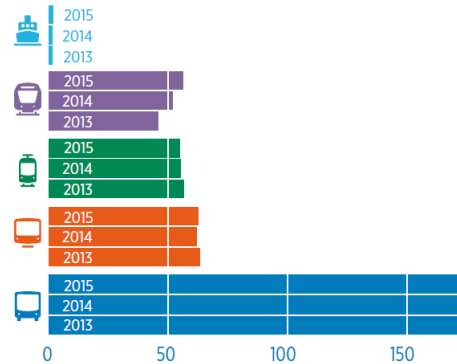


Figure 10. Passenger numbers by mode of transport in Helsinki region. Source. (HSL moves Us All, 2015).

As can be seen from figure 11, the rate of automobile ownership in Helsinki region is clearly on the rising trajectory, even bypassing population growth rate of the region. Efficient and reliable public transport hence becomes a valuable strategy to bring a paradigm shift from automobile use in to public transport use.

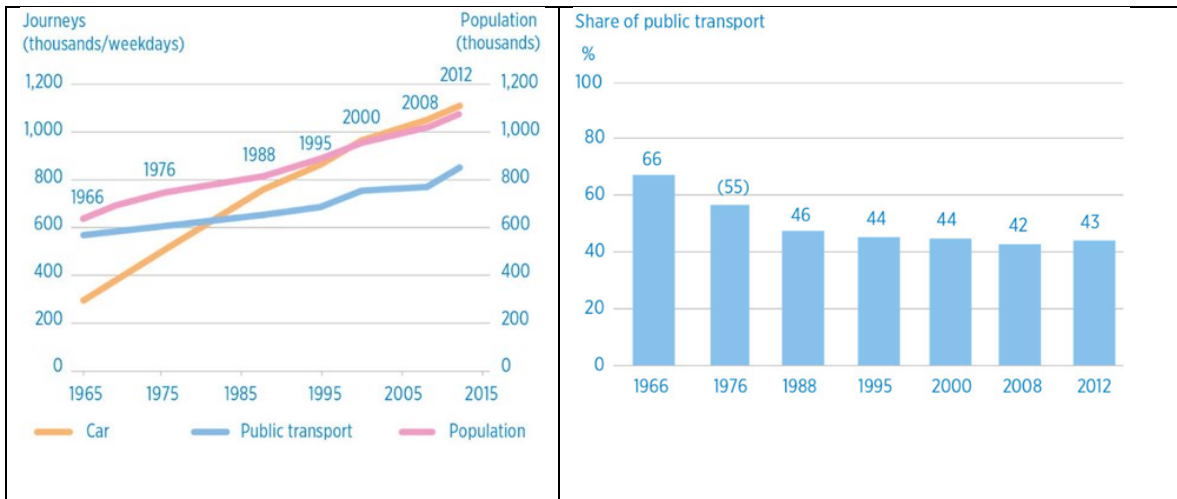


Figure 11. Journeys by different modes and share of public transport in Helsinki region. Source: (HSL moves Us All, 2015).

HSL has several goals to improve service reliability of its public transport, one of them being addition of time points along every route of operations. (HSL 2012).

Assigning time points along a given route will improve vehicle run times by enforcing no early departures of vehicles at these checkpoints (time points), thereby improving service punctuality. Increasing average speed of public transport is in the interest of HSL. According to (HCTPU 2009), passenger satisfaction is on decreasing trend due to deteriorating overall service reliability, especially large variations of travel time in downtown Helsinki. Decreased reliability in down town Helsinki could be linked with congestion.

Traffic signal priority at intersections speeds up average vehicle speed which affects vehicle run times. Therefore, providing signal priority at intersections directly affects service reliability. For instance, out of 400 intersection traffic signals in Helsinki city, about 40% give priority to buses, whereas the percent in city of Espoo and Vantaa are about 10% and 15% respectively of all traffic signals at intersections. (HSL 2012).

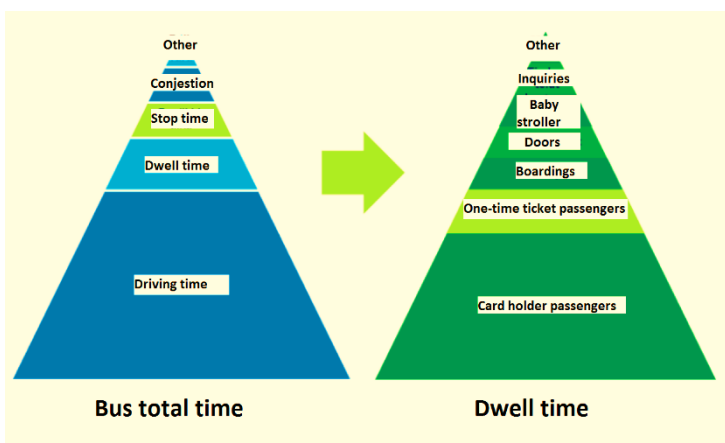


Figure 11. Bus trip time and dwell time components in Helsinki region. Source: (HSL 2012).

3.2 Bus line 550

The bus line taken for a case study in Helsinki region is Bus route 550. This line is chosen due to its popularity in Helsinki region as the busiest bus line, serving a cross region public transport, which makes it an interesting route for conducting service reliability analysis. The route is orbital, connecting many radial public transport lines. The line's ridership has seen fast increase over the years, and authorities are now using the increase in ridership as a justification for replacing the bus with a light rail system. (Lento 2015). Using buses on this line is not

sustainable in the long run due to limited capacity of a bus line and the growing ridership in the future. During peak hours, the headway on the line is 3 minutes, making capacity of the line already near its maximum.

3.2.1 Bus route 550

The bus line got its current form as a trunk bus line in 2006, even though the line was opened in 2003. Bus line 550, also called ‘‘Runkolinja 550’’ in Finnish, the bus line is Helsinki region’s first public transport trunk line. Ridership of the bus line has risen over the years. For instance, in 2015, about 40,000 passengers rode the bus on weekdays, as compared to 30,000 passengers in 2013. (Lento 2015).

Due to the trend in increase of ridership over the years, the city of Espoo and Helsinki reached an agreement to finance light rail line (from Itäkeskuks in Helsinki to Keilaniemi in Espoo) that will replace bus route 550 in the coming years. (HSL Uutiset 2016).

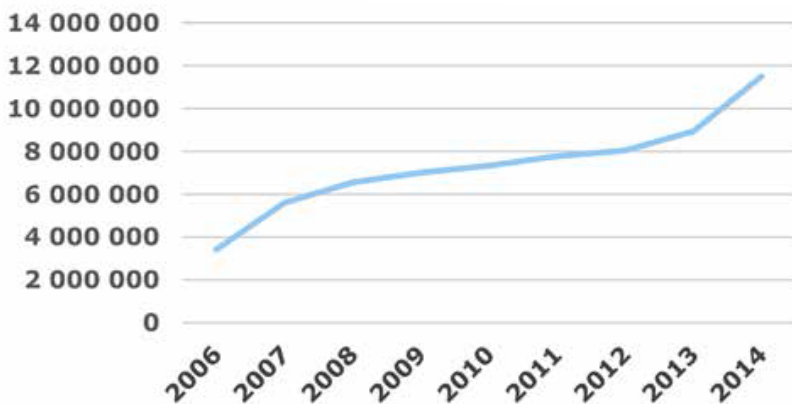


Figure 12. Passenger volume trend of bus line 550 over the years. Source: (Espoon ja Helsingin kaupungit, 2015).

3.2.2 Line branding and improvements

Introduction of new bus fleets raised the expectation for improved operational reliability of the line. Raised expectation was from both service providers and passengers side. The bus fleets of line 550 got their orange color in the summer of 2013, with revised time tables. The color also gives a kind of ‘branding’ of the service which may give image of metro-level service. Changes to the bus line also include the use of the middle door for boarding passengers alongside the alighting passengers. Passengers with valid trip ticket or smart card do not need to show their smart card to the driver or card reader, to facilitate quick boarding thereby shortening dwell time. Therefore, boarding on bus line 550 involves getting into the bus directly for a seat or a standing position. Ticket controllers can randomly ask passengers for a valid ticket or smart card at random times to discourage passengers without valid cards or tickets. Smart ticket readers are also installed in the middle door area which helps passengers check their cards balance. If capacity of the bus is full and cannot take more passengers, it will read “full” on its front display screen so that waiting passengers in the upcoming stops are communicated of the situation.

3.2.3 Route

The route of bus line 550 stretches from Itäkeskus in Helsinki to Westendinasema in Espoo, providing an orbital public transport service in the metropolitan area. It has a length of 25 km with average trip time of an hour.



Figure 13. Route map of bus line 550 shown by thick blue line, point A indicating Itäkeskus and point B Westendinasema. Source. (HSL Linjakartta 2016).

3.2.4 Stops

The route of bus line 550 has 39 passenger stops, of which 13 have real-time arrival times displayed on a screen. On the screen is displayed arrival times of oncoming buses and notifications on possible changes. There are three time-points (control points) where buses cannot leave before schedule. These stops are Oulunkylänasema, Hämeenlinnanväylä/Viihdentie and Leppävaara.

Current number of stops on the line is 38 per direction. The orders and names of stops valid during the study period are shown in table 8. The stops names and orders were valid for January, February and March 2015 which is the data period for this study. Current stop orders and names can be seen from table 13 in Appendix.

3.2.5 Vehicles

Vehicles that run on line 550 are Scania made, and are front low floor urban buses. All vehicles on this route have orange color. Inside the bus there is a screen panel that displays the name of the next stop and destination. During peak hours 33 buses are used with headways 3–5 minutes. Off peak hours are served with only 13 buses and headways is 10 minutes.

Table 3. Specifications of vehicles running on route 550.

Vehicle type	Scania K280UB tri-axle chassis
Manufacturer name	Lahti
Built year	2013
Floor type	Low front floor
Body	Lahti Scala
Capacity	52 seats and 58 standing
Length	14,5 m

3.2.6 Priority measures

Along the route there are 35 traffic light-controlled intersections and 8 pedestrian crossing lights. Bus gets traffic signal priority at one of the traffic light-controlled intersections and at one pedestrian crossing lights. Along part of the route that lies in Helsinki, buses get traffic light priority at one traffic light-controlled roundabout. Parts of the route has also bus only lane (right of way A). In Haaga and between Viikki and Oulunkyla bus 550 runs on bus-only lane.

4 Methodology

The main steps taken in carrying out this study involved literature search, literature review, data collection and data analysis. In this section data collection methods and data analysis techniques will be described. Data retrieved from AVL data system and APC is used in analyzing service reliability of bus line 550. Indicators that measure the level of reliability are given in this section.

4.1 Data

Empirical data is used to measure and analyze service variability and reliability. Detailed operational data from Automatic Vehicle Location (AVL) system and Automatic Passenger Counter (APC). These data sets were obtained from Helsinki Regional Transport Agency (HSL).

4.1.1 Automatic Vehicle Location (AVL) data

In analysis of service reliability of bus line 550, operational data collected through Automatic Vehicle Location system (AVL) and Automatic Passenger Counter (APC) is used. The scope of operational data in the analysis from AVL system consists of data for a duration of one month. That is, for the whole month of March 2015. All data contents are measured at stop level. The operational data consisted of a total of 324,075 stop level observations for 72 bus stops in both directions of the route. These records were filtered and analyzed based on type of analysis needed, for instance weekday peak time records for certain stops. The study month, March lies in a winter season.

Data at the stop level included stop identification number, date, terminal departure times, schedule departure and arrival times, actual arrival, and departure times, run code, number of

stops made and time taken for a stop and other variables. AVL sample data for some of the fields is shown in table 4.

Table 4. Sample AVL data

Stop ID	Run code	Schedule run start time	Date	Schedule time	Actual arrival time	Actual departure time	Stop Time (sec)
1453287	255010705	1425186300	1.3.2015	1425186300	1425186310	1425186310	0
1456118	255010705	1425186300	1.3.2015	1425186420	1425186467	1425186473	6
1454120	255010705	1425186300	1.3.2015	1425186540	1425186584	1425186584	0
1362112	255010705	1425186300	1.3.2015	1425186720	1425186718	1425186726	8
1362140	255010705	1425186300	1.3.2015	1425186780	1425186793	1425186808	15
1383101	255010705	1425186300	1.3.2015	1425186900	1425186903	1425186920	17
1285101	255010705	1425186300	1.3.2015	1425187020	1425187011	1425187011	0
1285103	255010705	1425186300	1.3.2015	1425187080	1425187056	1425187087	31
1284101	255010705	1425186300	1.3.2015	1425187140	1425187158	1425187168	10
1284113	255010705	1425186300	1.3.2015	1425187200	1425187223	1425187232	9
1284126	255010705	1425186300	1.3.2015	1425187260	1425187285	1425187297	12
1284103	255010705	1425186300	1.3.2015	1425187380	1425187352	1425187366	14
1282103	255010705	1425186300	1.3.2015	1425187440	1425187419	1425187427	8
1281105	255010705	1425186300	1.3.2015	1425187500	1425187484	1425187492	8
1281112	255010705	1425186300	1.3.2015	1425187560	1425187552	1425187552	0
1281160	255010705	1425186300	1.3.2015	1425187620	1425187611	1425187627	16
1293140	255010705	1425186300	1.3.2015	1425187740	1425187711	1425187723	12
1291128	255010705	1425186300	1.3.2015	1425187800	1425187782	1425187804	22
1291117	255010705	1425186300	1.3.2015	1425187860	1425187850	1425187850	0
1465101	255010705	1425186300	1.3.2015	1425187980	1425187909	1425187909	0
1465103	255010705	1425186300	1.3.2015	1425187980	1425187938	1425187938	0

4.1.2 Automatic Passenger Counter (APC) data

The data from APC is used to analyze passenger activity at stops of the route. Number of boarding and alighting passengers at every stop is used to determine bus load along the route.

Data collected from APC has a total record of 2969 vehicle trips in both directions, consisting of number of boarding and alighting passengers at each stop. The data covers three months in winter season of 2015, January, February, and March 2015. These records contain weekday measures only. Variables of the APC data included calendar date, direction of the trip, scheduled trip start time, boarding at stops, and alighting at stops. A sample of the APC data is shown in table 5.

Table 5. Sample APC data

					Itäkeskus(M)		Roihupelto	
Line	Calendar date	Day of week	Direction	Trip start time	Boarding	Alighting	Boarding	Alighting
2550	02.01.2015	Friday	1	08:04:00	15.00		1.00	0.00
2550	02.01.2015	Friday	1	08:29:00	11.00		1.00	0.00
2550	02.01.2015	Friday	1	11:59:00	20.00		5.00	6.00
2550	02.01.2015	Friday	1	13:09:00	34.00		5.00	6.00
2550	02.01.2015	Friday	1	14:21:00	42.00		6.00	2.00

4.2 Reliability measures and their indicators used in this study

As shown in the literature section (section 2.4), the most common measures of reliability by public transport agencies are on-time performance, headway regularity and vehicle run times. A growing body of literature is now focusing also on passenger inclined reliability measures such as passenger wait time and passenger travel time. Since they capture reliability perspectives of both operators and passengers, these two categories of measures of reliability

are the basis of reliability measures used in this thesis. Other than their common use in literature, the selected measures were based on available data. A review of reliability measures and indicators in this thesis is shown in table 7.

4.2.1 On-time performance /Schedule adherence

The indicator used to measure on-time performance is percentage of average departures that are on-time, late or early based on a range of time bandwidth. On-time performance is calculated by comparing actual departure/arrival times with schedule departure/arrival time. Equation 1 in section 2.4.1 gives on-time performance at route/line level.

Equation 1 is applied to calculate the percentage of on-time performance, where the lower and upper boundaries of bandwidth for departure reliability was set to 30 seconds and 60 seconds respectively. That is, time range within 0.5-minutes early and 1-minute late. This equation is used to determine on-time performance at selected stop levels.

Table 6. Boundaries bandwidth of time used to measure on-time performance in this research

On-time departure	Late departure	Early departure
Departure between 30 sec early and 60 sec late from schedule departure time.	Departure later than 60 seconds from schedule departure time.	Departure earlier than 30 seconds from schedule departure time.

On time, late and early departures are based on set boundaries of time bandwidth. A bus that departs no earlier than 30 and no later than 60 seconds compared to schedule departure time is set to be departing on-time. Departure after 60sec is labeled as late and departure before 30 seconds of schedule is labeled to be early departure. In other words, on-time performance is based on 0.5-minute early and one-minute-late departure range. Compared to on-time performance range found in literature (Arhin et al. 2014), the range applied in this study is quite conservative. This choice of the time range for on-time performance is because the route under study is a high frequency route of up to 3 minutes' headway.

4.2.2 Headway irregularity

Average headway deviation in seconds is the indicator used to measure the headway irregularity of service provided by bus line 550. Other additional indicator used is coefficient of variance of headways. Headways are based on vehicle departure times.

Headway irregularity is calculated at stop level. Schedule and actual headways for both departures and arrivals are derived by sorting the data in selected stops in chronological order and then taking the differences of consecutive headways for both actual and schedule trips involving arrivals and departures. Once actual and schedule headways for arrivals and departures are determined from the AVL data, the irregularity in headways is determined by comparing the actual headways with schedule headways. Equation 3 in section 2.4.2 are used to calculate coefficient of variance of headways.

4.2.3 Vehicle trip time variability

The specific indicator used to measure the variability in trip/run time on the route is average trip time deviation in minutes.

Vehicle trip time analysis involves the route level. To derive trip time variability distributions, total trip times for individual trips must be filtered out from the AVL dataset. This can be done for both actual and schedule trip times. Actual and schedule trip time distributions can be plotted on a graph. Deviation of actual trip time from schedule trip time can be plotted on a graph. Dwell time at selected stops was also calculated by taking the difference of arrival and departure times of a given vehicle at a given stop.

4.2.4 Passenger wait time

The indicator used to measure passenger wait time is average difference in schedule and actual wait times, referred to as average additional wait time in seconds.

Passenger wait time calculation is carried out at stop level in both directions. Equation 5 and 6 in section 2.4.4 are used to determine different components of wait time for passengers. Since bus line 550 is a high frequency route, passenger wait times are calculated only for trips that have a headway value of 10 minutes or less. Three components of waiting time are considered in this study, namely ideal wait time, schedule wait time and additional wait time. Each of these components will be explained briefly as follows.

- Schedule/Ideal wait time is wait time based on schedule performance. It captures the time passengers wait for their bus if service runs according to schedule.
- Actual wait time is wait time based on actual performance and refers to times that the passengers waited for their bus.
- Additional wait time is the difference between actual and ideal wait times. The added waiting time, in short is the extra time imposed by operators due to delays as compared to the ideal waiting time.

4.2.5 Passenger travel time variability

Indicator used to measure passenger travel time variability is average difference in schedule and actual passenger travel time, also called as average additional passenger travel time in minutes.

Passenger travel time variability distribution is plotted after adding components of passenger travel time. These components are in-vehicle time (assumed to be equivalent to vehicle trip time) and passenger wait times. Passenger travel time is determined at the line level, from initial stop until final stop per direction. Average passenger wait time along the bus line in both directions is approximated into average wait times at 10 selected bus stops in both directions.

In this way, average passenger travel time along the line becomes the sum of average in-vehicle time on the route and average wait time along the route.

Table 7. A summary of measures of reliability and the corresponding indicators.

Reliability measures	Indicators
On-time performance	Percentage of average departures that are on-time, late or early based on a range of time bandwidth, [0.5-min, 1-min].
Headway regularity	Average headway deviation in seconds
Distribution of vehicle run times	Average vehicle run-time deviation in minutes.
Passenger wait times	Average difference in schedule and actual wait times measured in seconds, also referred to as average additional wait time in seconds.
Distribution of passenger travel time	Average difference in schedule and actual passenger travel time measured in minutes, also called as average additional passenger travel time in minutes.

4.3 Level of Reliability Analysis

In this study, two types of level of analysis are performed. Analysis at stop level and at the line level. Stops to be used for analysis are chosen from the bus line. All together there are five stops. The criteria to choose the stops is mainly based on having higher passenger activity which makes reliability analysis interesting. The chosen stops are evenly distributed over the bus line. Two of the stops are located near the start and end stops of the line and the other three are scattered over the rest of the line which also serve as transfer points. The same five stop points are used in the analysis for both directions along the route. On-time performance, headway adherence and passenger wait time are all analyzed at the stop level. On the other hand, vehicle-trip time and passenger travel time analysis are performed at the line level. When considered

necessary, the analysis was done for different days of the week such as week days only, or for different hours of the day such as morning peak (7:00-9:00) and afternoon peak (14:00-17:00). Most of the analysis is done for the whole-time. The relevant time of analysis is always indicated.

4.4 Selected stops for reliability analysis and trip direction setting

There are 39 bus stops per direction along bus line 550. Reliability analysis is carried at selected stops for performance measures including on-time performance, headway regularity and passenger wait time. Vehicle trip times and passenger travel time measures are carried out at the line-level. The yellow colored stops are where reliability analysis is carried out. Five stops are selected in such a way that they are spaced out evenly on the route and that they are characterized by high passenger activity which makes reliability analysis interesting. Other than the selected first and the last stops along the route per direction, all the middle three selected stops are part of a terminal where transfers occur. The same five selected stops are used in both directions in using performance indicators.

Table 8. Stop name and order of bus line 550 in both directions. The yellow colored stops are stops selected for stop-level reliability analysis.

Direction 1				Direction 2			
Stop No	Stop Name	Stop No	Stop Name	Stop No	Stop Name	Stop No	Stop Name
1	Itäkeskus(M)	21	Takomotie	1	Westendin asema	21	Vihdintie
2	Roihupelto	22	Takkatie	2	Tapiolansilta	22	Huopalahden asema
3	Myllärintie	23	Pitäjänmäen asema	3	Revontulentie	23	Ilkantie
4	Latokartano	24	Vermo	4	Kontiontie	24	Hämeenlinnan väylä
5	Viikin tiedepuisto	25	Mäkkylä	5	Otsolahdentie	25	Pirkkola
6	Viikinmäki	26	Puustellinmäki	6	Kemisti	26	Pirjontie

7	Veräjämäki	27	Leppävaaranase ma	7	Konemies	27	Maunula
8	Oulunkylän asema	28	Säterinmetsä	8	Innopoli	28	Tuusulanväylä
9	Mäkitorpantie	29	Laajalahdenristi	9	Maarinsilta	29	Mestarintie
10	Käskynhaltija ntie	30	Turvesuontie	10	Turvesuontie	30	Käskynhaltijan tie
11	Mestarintie	31	Maarinsilta	11	Laajalahden risti	31	Mäkitorpantie
12	Tuusulanväyl ä	32	Innopoli	12	Säterinmetsä	32	Oulunkylän asema
13	Maunula	33	Konemies	13	Leppävaaranase ma	33	Veräjämäki
14	Pirjontie	34	Kemisti	14	Puustellinmäki	34	Viikinmäki
15	Pirkkola	35	Otsolahdentie	15	Mäkkylä	35	Viikin tiedepuisto
16	Hämeenlinna n väylä	36	Kontiontie	16	Vermo	36	Latokartano
17	Ilkantie	37	Revontulentie	17	Pitäjänmäen asema	37	Myllärintie
18	Huopalahden asema	38	Tapiolansilta	18	Takkatie	38	Roihupelto
19	Vihdintie	39	Westendinasem a	19	Takomotie	39	Itäkeskus(M)
20	Valimotie			20	Valimotie		

Trip direction setting

It is important to separate the directions along the route. The two end stops of the bus line are Westendinasema and Itäkeskus. For simplicity, bus trip that starts at Itäkeskus and bound towards Westendinasema is termed as ‘direction 1’ and bus trip in the opposite direction is termed as ‘direction 2’, that is a trip from Westendinasema towards Itäkeskus. In the remaining of this study the two trip directions are referred to as ‘direction 1’ and direction 2’. (see illustration in figure 14).

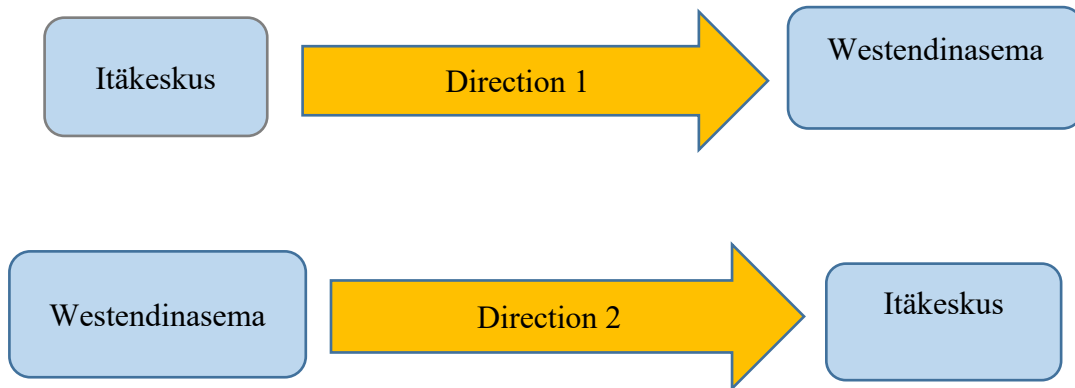


Figure 14. Framing of directions for the two-way trips along bus route 550.

5 Results and Discussions

In this chapter, outcomes of the analysis are described followed by discussions. Service reliability analysis is based on different reliability indicators using operational off-line data from AVL and APC. Graphs and tables are used to better illustrate the results. The chapter is divided into 6 sub- sections, each section providing results of analysis based on the corresponding reliability indicator. Each result of the analysis of reliability indicator is followed by discussion. Five reliability indicators were used in the results and discussions section. These indicators are schedule adherence/on-time performance, headway regularity, vehicle trip time/run time, passenger waiting time and passenger travel time. Furthermore, results and discussion of dwell time at five stops and passenger activity along the line will be presented at the end of this chapter.

5.1 On-time performance/Punctuality

Distribution of on-time performance or schedule adherence at selected five stops is shown in graphs 15,16 and 17. These figures show the percentage of departures within a given time range in seconds. The average percentage of the five stops is also calculated for figures 16 and 17. which is shown below.

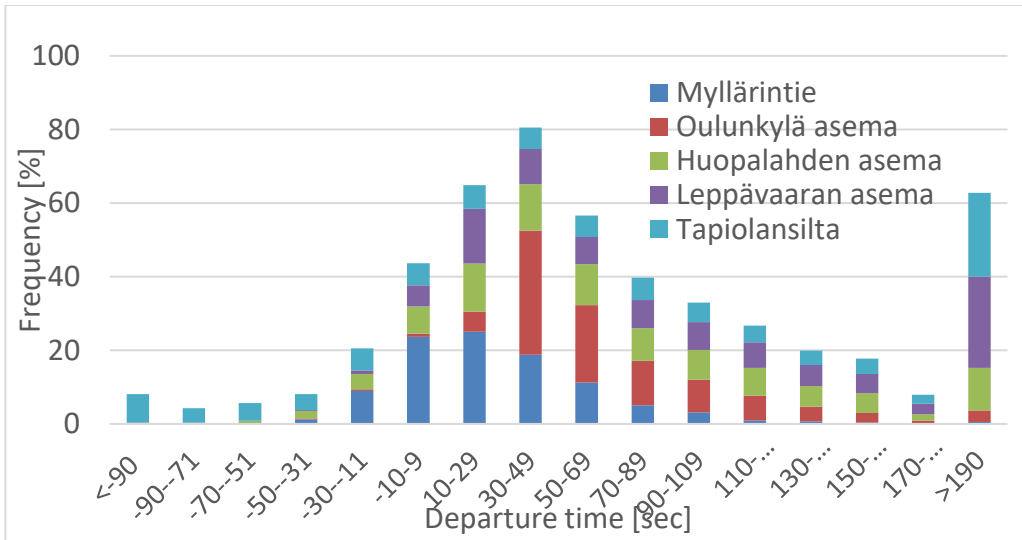


Figure 15. Distribution of departure times at 5 stops along direction 1, for the whole period during March 2015.

It can be seen from figure 15 that the values along the horizontal axis are range of time period in second, while the vertical values represent percentage of departures falling in the corresponding time period indicated on the horizontal axis.

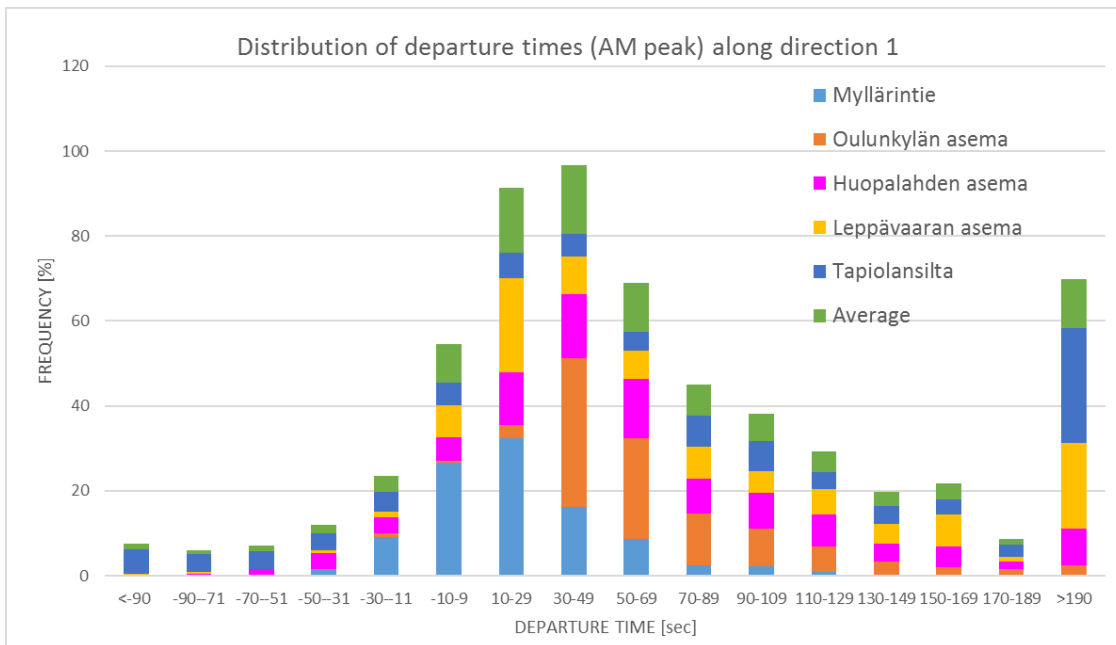


Figure 16. Distribution of departure times (AM peak) along direction 1, for the whole-time during march 2015. The average value (portions of the bar in green) is calculated for the five stops.

Figure 16 shows the departure time distributions during morning rush hour along direction 1, Morning rush hour is 7:00 AM to 9:00 PM. Unlike figure 15, in figure 16 the average distribution time for the five stops is also shown (portion of the bars which is green). The duration of distribution of departures times is for the whole month of March, with weekdays during morning peak hours.

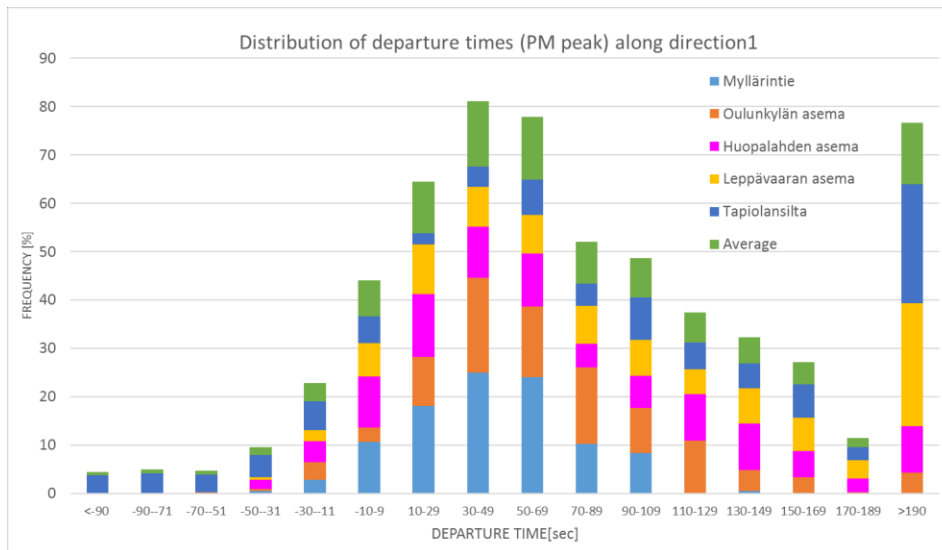


Figure 17. Distribution of departure times (PM peak) along direction 1, for the whole period during march 2015. The average value (portions of the bar in green) is calculated for the five stops.

In a similar way, figure 17 also shows horizontal values being time ranges in seconds and the vertical values being percentage of distribution falling with in a given time range. Different colors on sections of the bar stand for differnt stops as indicated in the key of the graph.

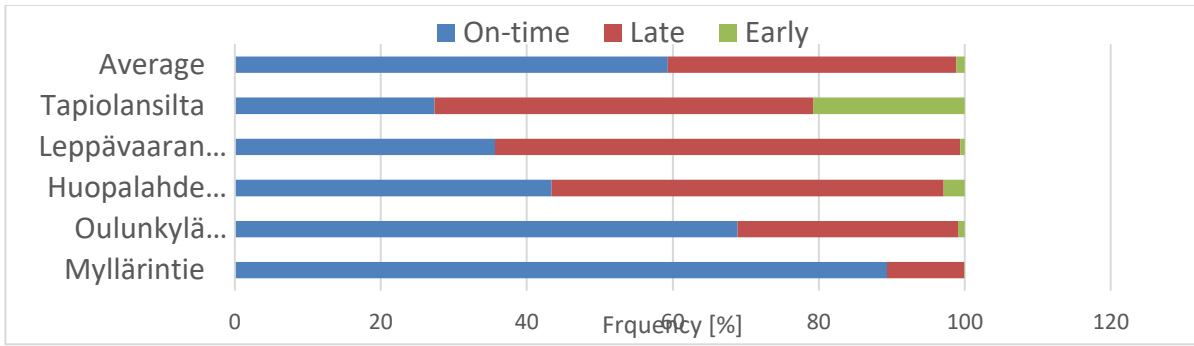


Figure 18, On-time performance at 5 stops based on departure times along direction 1, during March 2015. The average value is calculated for the five stops.

Values along the horizontal line in figure 18 stand for percentage of category of on-time performance measures which are on-time, late, and early. The selected five stops are indicated along the vertical axis. The average value represents the five stops.

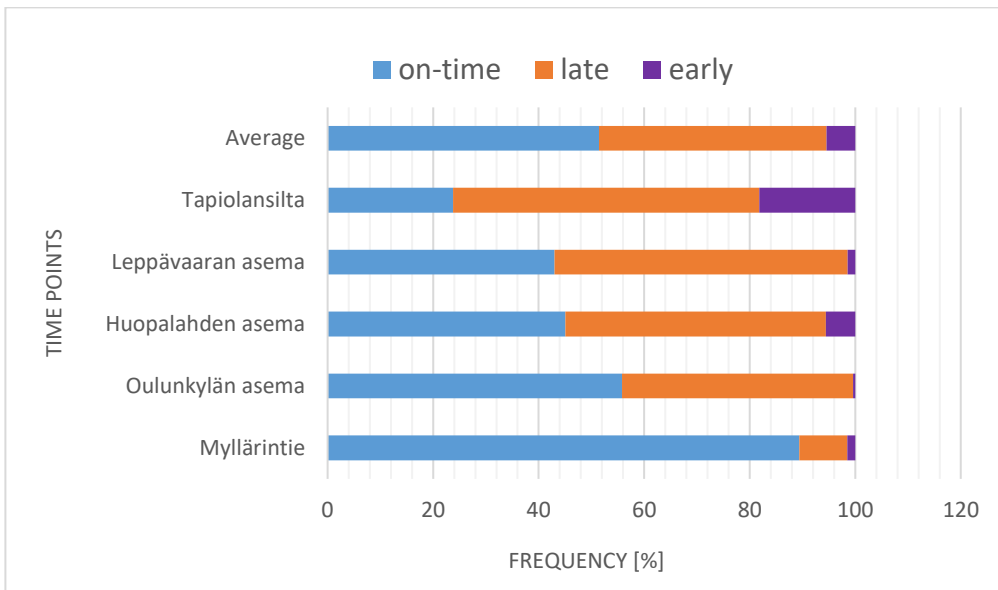


Figure 19. On-time performance based on departure times during AM peak along direction 1, during March 2015. The average value is calculated for the five stops.

Values along the horizontal line in figure 19 stand for percentage of category of on-time performance measures which are on-time, late, and early. The selected five stops are indicated along the vertical axis. The average value represents the five stops. Morning rush hour is the period for analysis.

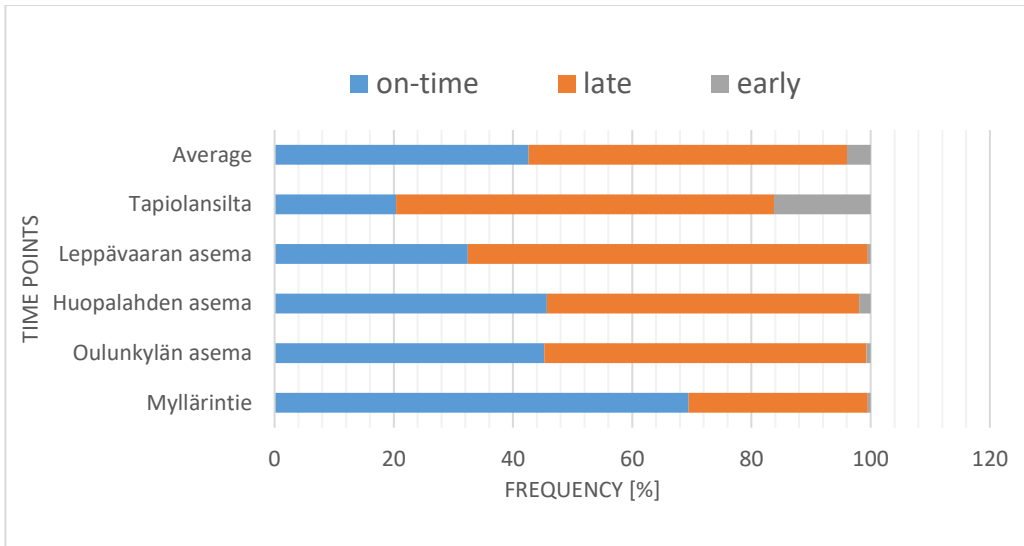


Figure 20. On-time performance based on departure times during PM peak along direction 1, during March 2015. The average value is calculated for the five stops.

Values along the horizontal line in figure 20 stand for percentage of category of on-time performance measures which are on-time, late, and early. The selected five stops are indicated along the vertical axis. The average value represents the five stops.

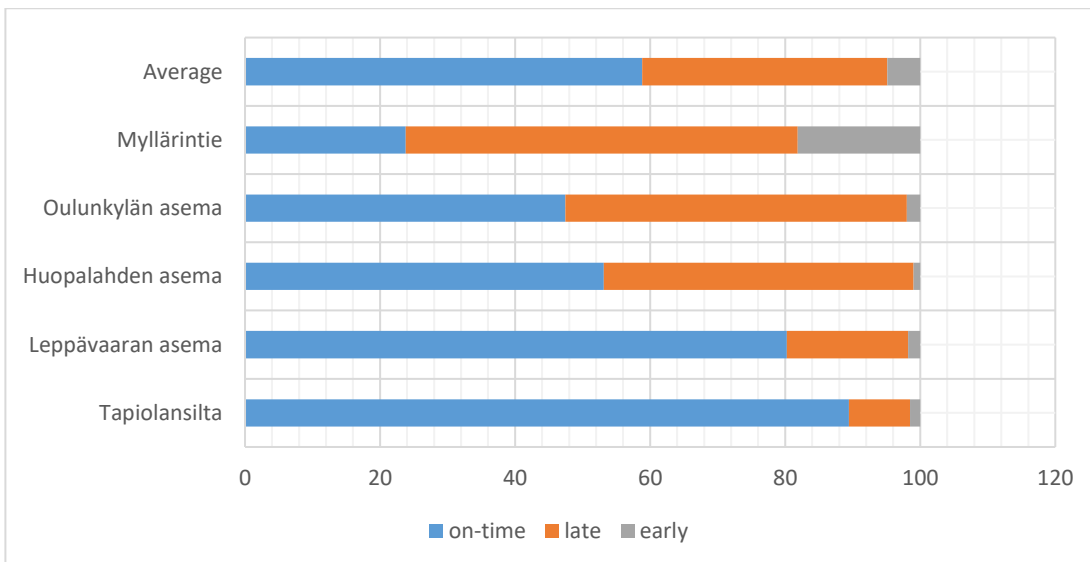


Figure 21. On-time performance based on departure times during AM peak along direction 2, during March 2015. The average value is calculated for the five stops.

Values along the horizontal line in figure 21 stand for percentage of category of on-time performance measures which are on-time, late, and early. The selected five stops are indicated along the vertical axis. The average value represents the five stops.

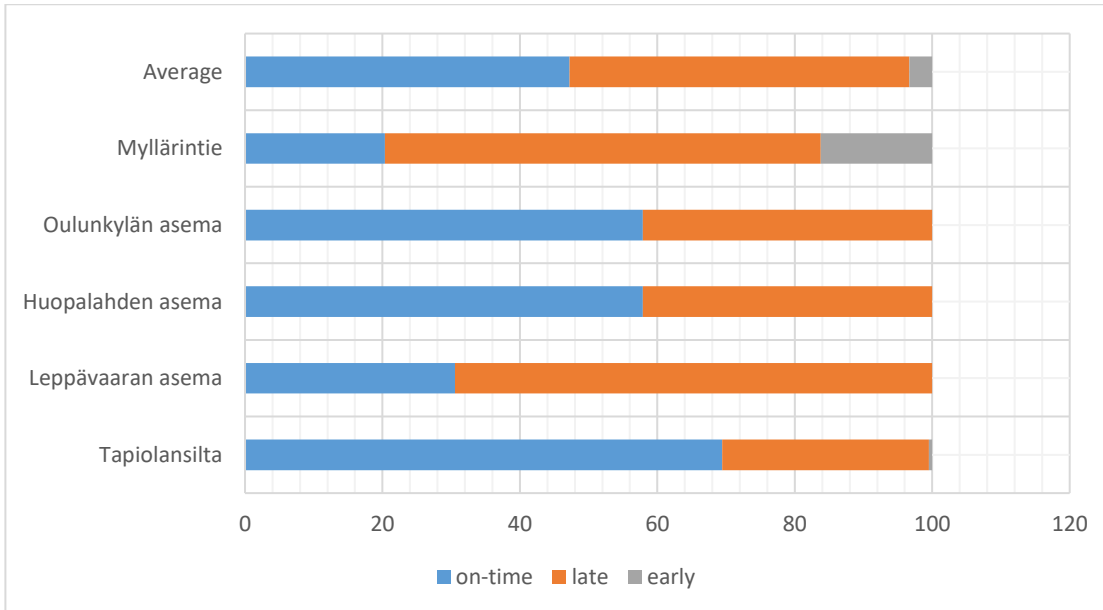


Figure 22. On-time performance at 5 stops based on departure times during PM peak along direction 2, during March 2015. The average value is calculated for the five stops

Values along the horizontal line in figure 22 stand for percentage of category of on-time performance measures which are on-time, late, and early. The selected five stops are indicated along the vertical axis. The average value represents the five stops.

Discussion

On-time performance is often measured as a percentage of buses that arrive or depart a certain location within a given range of time. The on-time performance/ schedule adherence of bus line 550 is carried out at the stop level. On-time performance at five stops for different time periods were analyzed. In this study, the criteria for evaluating the on-time performance is based on half-a-minute early and a-minute late. That is, arrival or departure of a vehicle with in the interval [0.5 minutes early, 1 minute late] is considered to be on-time. This range is strict

compared to international ranges for evaluating on-time performance of a public transport. For instance, several public transport agencies in the United States make use of the range [1 min early, 5 min late] to evaluate on-time performance of their service. (Arhin et al. 2014). Scheduled bus time table does not distinguish between schedule arrival and schedule departure times, because dwell time at stops is stochastic (varies randomly) in nature making it difficult to incorporate it into time tables. In this study, on-time performance based on vehicle departure times is analyzed.

On-time performance at stops along direction 1

Average on-time performance at five bus stops along direction 1 (see figures 18, 19 and 20) is evaluated based on the criteria of half-a-minute early and a-minute late. The evaluation showed that 59 % of all departures are on-time, 40 % late and 1% early. As figure 18 shows on-time performance for the whole-time deteriorates further away along the line from 90 % at Myllärintie (the 3rd stop) to under 30 % at Tapiolansilta (the 38th stop). During peak hours, both morning peak (7:00-9:00 AM) and afternoon peak (2:00-5:00 PM), the average on-time performance showed a decline compared to over the whole period of the day. This is expected since a higher passenger activity during peak hours is likely to cause delays. The results for morning peak period is 51% on-time, 36% late and 3% early departures. (refer to figure 19). For afternoon peak, 43% on-time, 53% late and 4% early departures are encountered. (Refer to figure 20). Afternoon peak hours have a higher percentage of late and early departures compared to morning peak hours.

On-time performance at stops along direction 2

Along direction 2, average morning peak on-time performance at five stops was found to be 58% on-time, 37% late and 5% early. (see figure 21). Performance decreased consistently further away along the line. For instance, the on-time score at Tapiolansilta (2nd stop) is 90%, Huopalahdenasema (the 18th stop) is 52% and only 47% for that of Myllärintie (37th stop). Average early departure for morning peak is about 5%. For the afternoon peak, average on-time

performance at all five stops was 47% on-time, 50% late and 3% early departures. (see figure 22). At Leppävaaranasema (the 13th stop) 70% buses departed late during afternoon peak. A higher percentage of late departure at Leppävaaranasema along direction 2 reflects the expected higher passenger activity at this stop. This stop is within a hub-like transfer station where several bus lines and commuter trains converge.

On-time performance at stops along both directions

When we look at the general on-time performance for both directions, the performance score along direction 2 is better than along direction 1. This result is in accordance with expected passenger activity along direction 1 compared to direction 2. A higher passenger activity translates in to higher dwell time, which directly affects vehicle departure times. For instance, morning peak average late departure for the five stops along direction 1 is 43%, the equivalent score along direction 2 is 36%. Percentage of late departure during afternoon peak along direction 1 is 52%, while along direction 2 is 49%. A common trend to average on-time performance level at these five stops along both directions is that, performance decreases along both directions during afternoon peaks compared to morning peak.

There is a clear pattern that can be seen from figure 19,20, 21 and figure 22, that the overall on-time performance drops consistently at all five stops along each direction for both morning and afternoon peaks, except at Leppävaaranasema during afternoon peak. (See figure 22).

Afternoon peak periods exhibited lower average on-time performance compared to morning peak periods along both directions. This phenomenon could be linked to difficult snow conditions in the afternoon compared to morning conditions, since street snow is usually cleared before morning peak starts. It is also possible that there is a higher passenger activity and worse traffic conditions during afternoon peaks than morning peaks which affects on-time performance.

The situation regarding early departure along both directions can be seen from figures 18,19,20,21 and 22. From passenger perspective, early departure has the worst effect on their travel experience by increasing waiting time by the full length of headway. (Van oort 2011).

Morning peak periods along direction 1 and 2 had a higher percentage of average early departures compared to afternoon peaks with a score of 6% and 5% respectively. It is interesting to see that percentage of early departure at stops near the end of the bus line is higher for both directions. For instance, along direction 1, morning and afternoon peak period early departure at Tapiolansilta (38th of the 39 stops) was 18% and 20% respectively. For direction 2, an equivalent score was 18% and 15%. The trend for a higher early departure at stops near end of the bus line along both directions could be attributed to driver behavior. Drivers may be inclined to get to the terminal quicker to have their breaks.

It can be assumed that the overall on-time performance of bus line 550 is very high if larger ranges of time boundaries were considered. For instance, on average about 60% of departures at all five stops along direction 1 are on-time for the whole AVL data for the month of March 2015. When interpreting this result, one must keep in mind that the on-time performance time range taken in this research is quite strict. That is half-a-minute early and one-minute late. [0.5 min early, 1 min late]. However, the on-time performance of the line at the selected five stops could be improved. For instance, there were on average 38.8% late departures and 1.2% early departures on the five stops along direction 1. To improve this situation, implementing schedule-based holding could increase the percentage of on-time performance by minimizing percentage of early vehicle departures.

5.2 Headway regularity

Headway deviation is calculated by taking the difference between scheduled headway (scheduled time between successive buses) and actual headways (actual time between successive buses). Actual headways are based on departure times. There are three time points (check points) along the route in both directions. These time points are Oulunkylänasema, Hämeenlinnanväylä and Leppävaara.

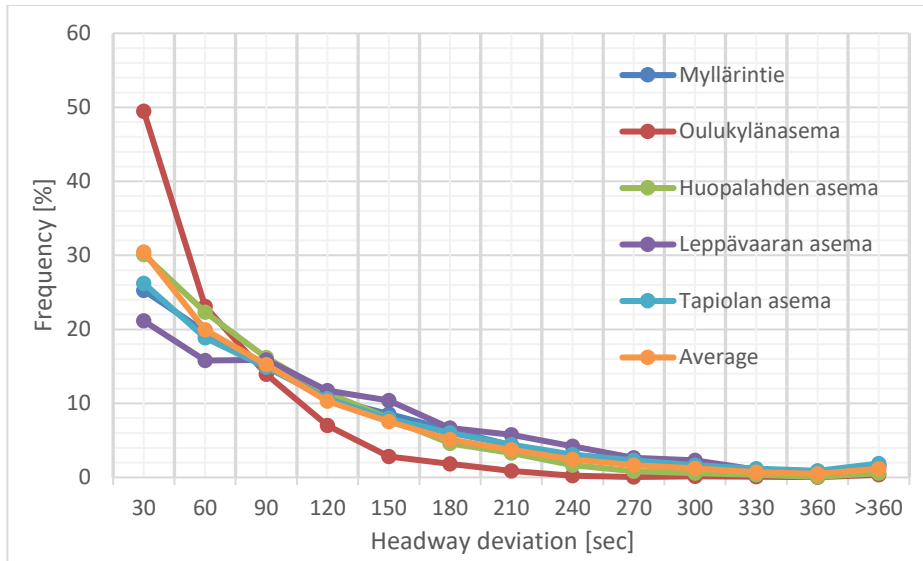


Figure 23. Distribution of headways at five stops along direction 1, during March 2015. The average value (orange line) is calculated for the five stops.

The horizontal values in figure 23 represent headway deviation in seconds and the corresponding vertical values stand for percentage of departures. The time period of headways departures is during the whole month of March along direction 1. The average value (shown in yellow line in the graph) represents average values for the five selected stops.

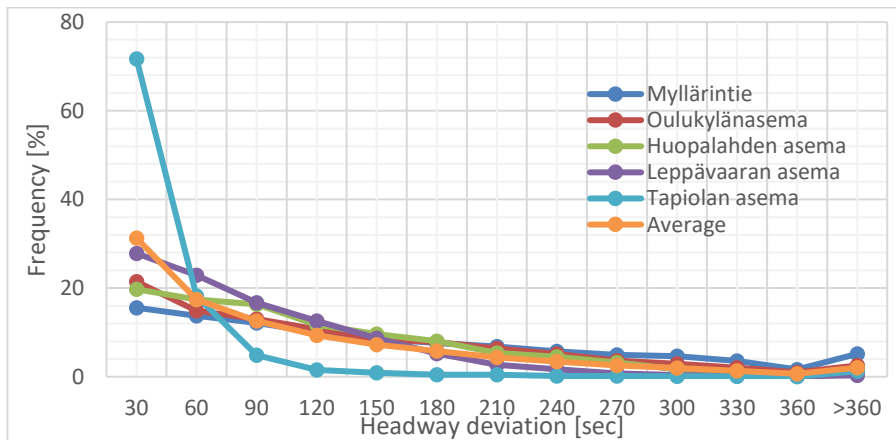


Figure 24. Distribution of headways at five stops along direction 2, during March 2015. The average value (orange line) is calculated for the five stops.

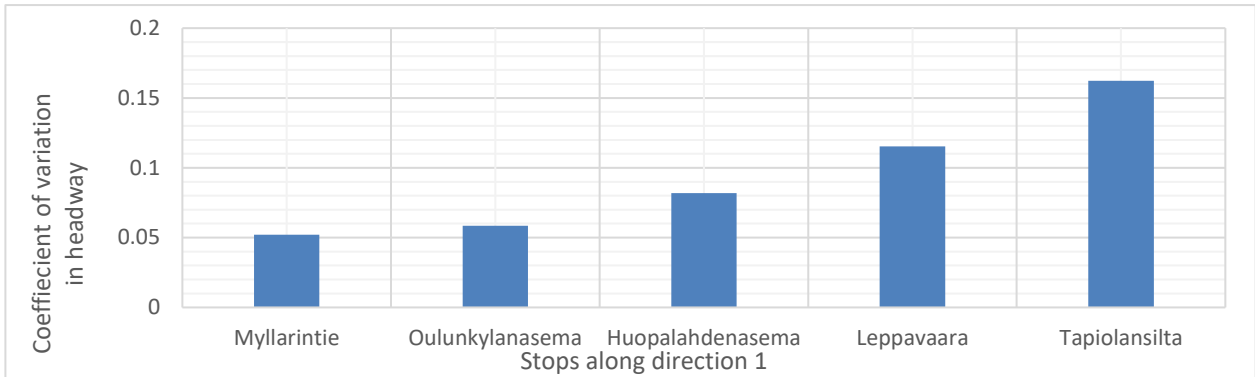
To get a better picture of headway reliability, coefficient of variation of headway is calculated for all 5 stops in both directions. Weekends and weekday times such as evenings and nights are excluded so that shorter headways are represented. Hence, all headways on weekdays of March 2015, in the period 7:00 AM - 6:00 PM is considered. Both morning and afternoon peak hours are inside this time window. Standard deviation of headways and coefficient of variation of headways for five stops for both directions are given in table 9. Coefficient of variation of headways is also shown in figure 25 and figure 26 for direction 1 and direction 2 respectively.

Table 9. Standard deviation and coefficient of variation of headways for five stops, during 7:00 AM - 6:00 PM in March 2015.

	Direction 1				
	Myllärintie	Oulunkylan asema	Huopalahden asema	Leppävaaran asema	Tapiolansilta
Average headway deviation (sec)	37.0	46.0	78.0	104	154.0
Standard deviation (sec)	39.39	45.24	60.62	84.26	117.35
Coefficient of variation	0.052	0.058	0.082	0.012	0.162
	Direction 2				
	Tapiolansilta	Leppävaaran asema	Huopalahden asema	Oulukylän asema	Myllärintie
Average headway (sec)	27.2	75.4	106.6	118.1	144.6
Standard deviation (sec)	52.02692	63.75971	82.73512	98.79119	114.0487
Coefficient of variation	0.068919	0.085412	0.111368	0.135312	0.156574

In the figures that follow, i.e., figures 25 and 26 coefficients of variation of headways for the five stops in both directions is shown. The horizontal words in these figures stands for the

selected analysis stops and the vertical axis stands for values of coefficient of variation of headways.



in the Figure 25. Coefficient of headways at 5 stops, along direction 1, on weekdays of March 2015, period 7:00 AM -6:00 PM.

The higher the coefficient of variation of headway is the higher the average headway deviation, while smaller values indicate smaller average headway deviation. Coefficient of variation of headway is a without units, since it is expressed as the ration of the standard deviation to the mean.

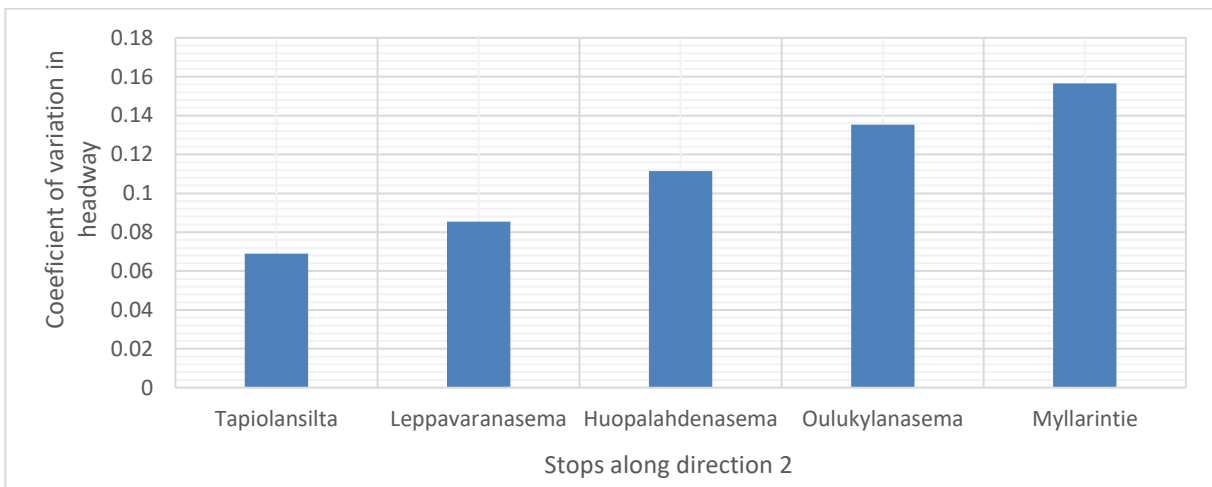


Figure 26. Coefficient of headways at 5 stops, along direction 2, on weekdays of March 2015, in the period 7:00 AM -6:00 PM.

Vehicle trajectories/diagrams of time-distance for consecutive buses

Trajectories of consecutive bus vehicles with time-space relationship were plotted to illustrate if there is any occurrence of bunching across the dimension of time-space. (see figure 27). The trajectory in the illustration represents all vehicle departures during morning peak period 7:00-8:00 AM on the 19th of March 2015 along direction 1. There were ten vehicles departing the original terminal (westendinasema) between 7:00-8:00 AM that morning.

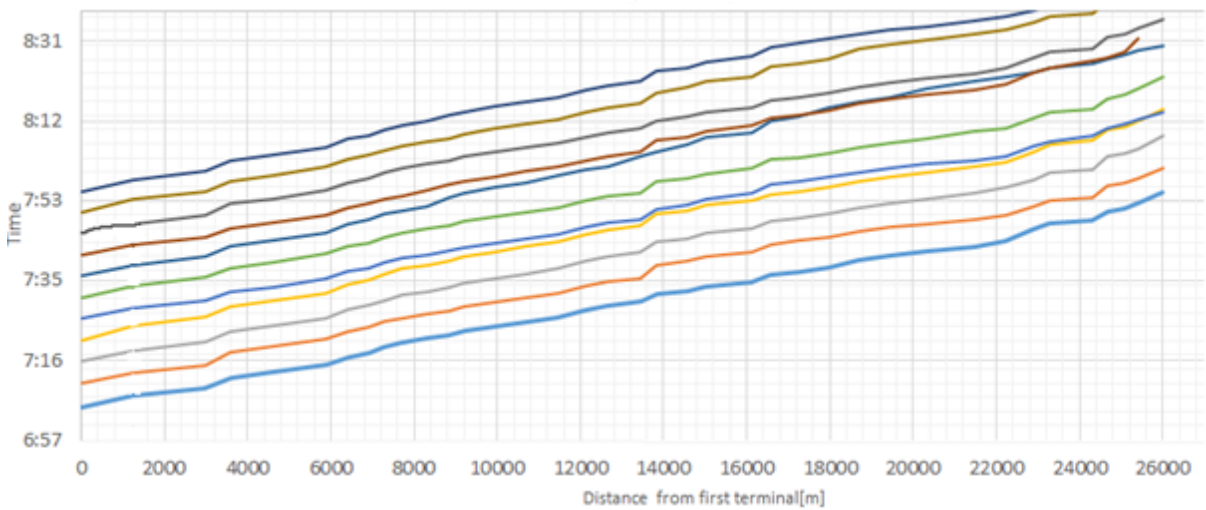


Figure 27. Bus trajectory for buses departing in the period 7:00-8:00 AM on March 19th 2015, along direction 1.

The graph of trajectories of buses is represented with two axes, namely the time and distance axes. The value along the horizontal axis represents the distance in meters from the original terminal (westendinasema). The vertical values represent the time. Each line represents a bus. Each departing bus at the origin terminal has a zero value of distance along the horizontal axis and departure time represented at the vertical axis. The slope of each line represents the speed of the corresponding bus. The steeper the line is the slower the speed of the bus. The vertical distance between two lines at any given point on a horizontal axis is equivalent to the headway value of the corresponding buses.

Discussion

Keeping an even headway between consecutive vehicles is important for high frequency public transport line such as bus line 550. Higher values of headway deviation reflect higher vehicle bunching activity. For high frequency routes, passengers arrive at stops without consulting time tables and uneven headways increase passengers waiting time.

Headway regularity at stops along direction 1

Distribution of headways at five bus stops along direction 1 is shown in figure 23. It can be seen from graph 23, 30% of all departures at the five stops had headway deviation of 0.5 minutes. At oulunkylanasema (8th stop) headway deviation is the smallest of all other four stops, that is, 50% of all departures had a headways deviation of 0.5 minutes. The reason for better headway adherence at oulunkylanasema compared to other stops could be holding activity taking place at the stop.

Average headway deviation, standard deviation of headway and coefficient of variation of headway at each five stops are given in table 9. It can clearly be seen from table 9, that the standard deviation increases on the stops further along the route, which is a sign that the occurrence of bunching also increases further along the route. In the same way, the coefficient of variation of headways consistently increases on all the five stops further along the route. The calculations headway deviation leading to a phenomenon of increase of occurrence of bunching further along the line is consistent with literature. A headway analysis study carried out by (Bellei & Gkoumas 2010) shows that bunching tends to increase further along a public transport route.

Headway regularity at stops along direction 2

Distribution of average headways at five stops along direction 2 is shown in graph 24. It can be seen from the graph 24 that, 32% of all departures at the five stops had headway deviation of 0.5 minutes. At tapionsilta (2nd stop) headway deviation is the smallest compared to all other

four stops, that is 70% of all departures have 0.5 minutes headway deviation. The next smallest score is 28% at Leppävaranasema with headway deviation of 0.5 minutes. Tapiolansilta stop is near the beginning of the route which explains for the highest performance of headway regularity.

Average headway deviation, standard deviation of headway and coefficient of variation of headway at each five stops along direction 2 are given in table 9. It can clearly be seen from table 9 that the standard deviation increases on the stops further along the route, indicating the increase in occurrence of bunching further along the route. In a similar fashion, it is evident that coefficient of variation increases consistently at all the stops further along the route. (refer to graph 26).

Headway regularity at stops along both directions

Overall, the average headway deviation at all five stops along direction 1 was 1.4 minutes while the corresponding score along direction 2 was 1.6 minutes. Similarly, the standard deviation of headway at all the five stops along direction 1 and direction 2 was 1.2 minutes and 1.4 minutes respectively. This shows that the headway regularity along direction 1 is higher than that along direction 2.

Another noticeable trend is the general increase in average headway deviations at the five stops further along direction 1 and 2. This could be the result of occurrences of deviations in headway near the start of the line propagating further along the line.

Looking at figure 27, illustration of bus trajectories reveals that occurrence of bunching tends to increase at stops near the end of the line. In this case, buses departing in the morning of 19th March 2015, during morning peak of 7:00-9:00 AM along direction 1, it can be clearly seen in figure 27 that bunching occurs for some of the buses right after mid distance of the line, at about 13.600 m from origin terminal. There is even bunching where there is one case of overtaking at the final terminal. It is important to notice that the bus trajectory represents a fraction of the

AVL data and is only for a single day bus departures at original terminal during the period 7:00-8:00 AM.

From the analysis, it is now evident that some degree of bunching occurs along the bus line 550, especially at stops near the end of the line. The occurrence of bunching along bus line 550 (a result of irregular headway in service provision) could occur because of one or more factors such as traffic congestion, higher dwell time due to high passenger activity at stops (boarding and alighting), driver behavior and a possible variability in vehicle driving speed due to weather conditions. (March is a snowy winter month in Helsinki Capital Region area).

Headway is affected by variability in dwell time, driver behavior, traffic, and weather conditions. Keeping a regular headway along a given high frequency bus line such as bus line 550 is crucial to provide a reliable service. As mentioned in literature review (chapter 2) in section 2.6, the mechanisms for improving headway irregularity and hence minimizing the effects of bunching on passengers, adoption of headway-based holding at time points could be implemented. With the adoption of AVL systems mounted on buses, real-time monitoring for occurrence of bunching and direct communication with drivers could minimize the bunching. In addition, to improve driver behavior regarding early departures especially at stops near the end of the route, a stricter regulation on driver behavior could be applied.

5.3 Vehicle trip time variability

Figures 28, 29 and figure 30 show trip time components during different time of the day (rush hour and outside rush hour). The sample data for the analysis is taken to be just one vehicle-run, hence the result may not represent concrete scenario but only a glimpse of the components of the trip time during these two periods.

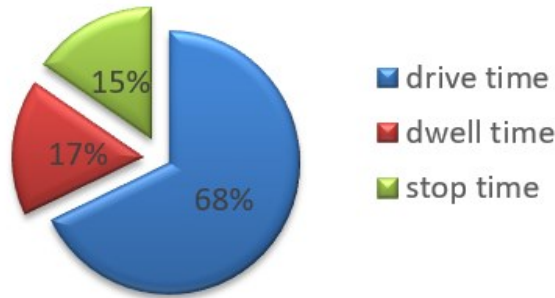


Figure 28. Trip time components for one run-trip on Thursday 5.3.2015 whose trip started at 7:00 AM from Westendinasema and ended at Itäkeskus.

The trip time with its components shown in figure 29 represents off-peak hour. Since the data sample is just for a single vehicle run, the result may not represent actual percentage of the trip time components. It only gives a preliminary composition.

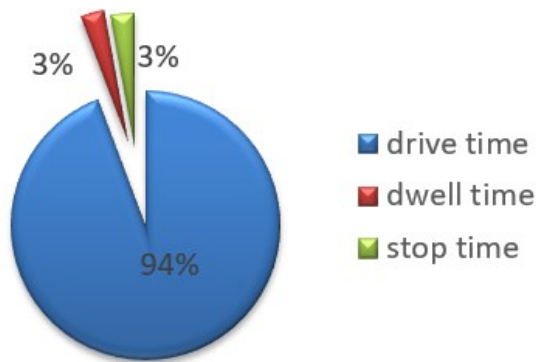


Figure 29. Trip time components for one run on Thursday 5th of March 2015 whose trip started at 18:02 from Westendinasema and ended at Itäkeskus.

Figure 30 shows a side by side comparison of the trip time components (drive time, dwell time and stop time) of one vehicle trip time during peak time and off peak period along direction 2. The vertical values in the graph represent percentage.

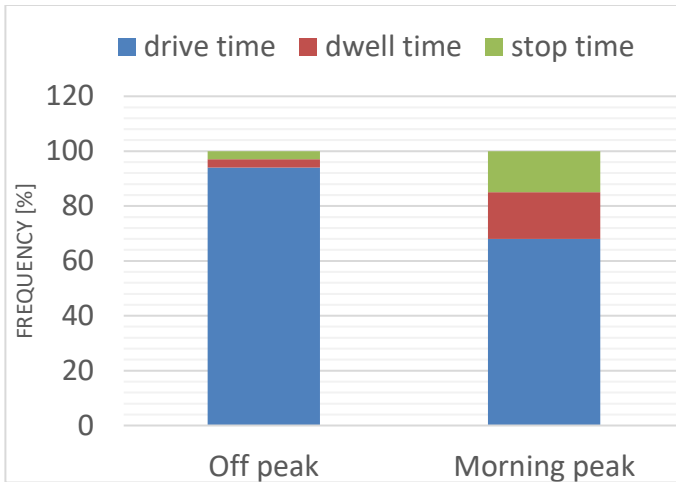


Figure 30. Comparisons of trip time components for two trips along direction 2 which departed their route's first stop (westendinasema) at 7:00 AM (morning peak) and 6:02 PM (off peak) on Thursday, March 2015.

Vehicle trip time

Vehicle trip time constitutes drive, dwell and stop time. Variability in any of these elements leads to poor service reliability. In the following figures the variability in vehicle trip time is shown. Figures starting from figure 31 up to figure 36 illustrate vehicle run time variability for both directions, namely direction 1 and direction 2.

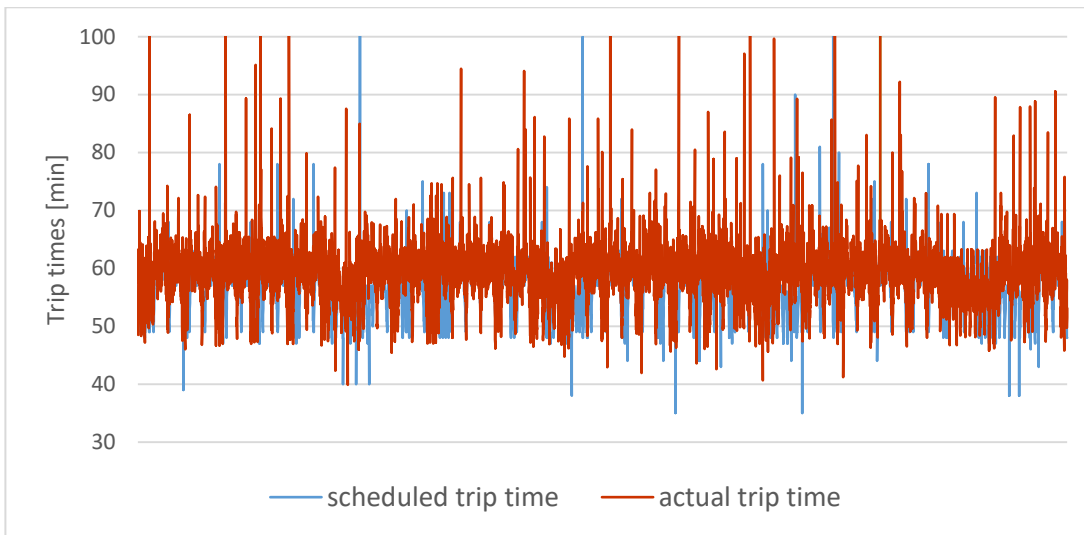


Figure 31. Distribution of average actual and schedule trip times (for a total of 7195 trips made during March 2015) both directions.

The blue lines in figure 31 represent schedule trip time distribution while the red line represent actual vehicle trip time distribution. The values along the vertical axis of the graph stands for trip times in minutes. The distribution in this graph represents all vehicle trips along both directions. In total, about 7,195 vehicle trips were made during the month of March.

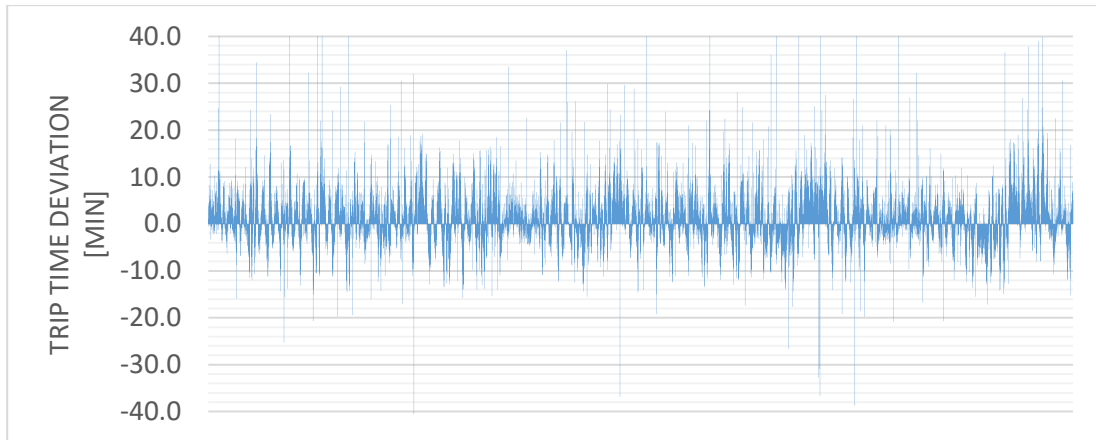


Figure 32. Distribution of additional trip time (for a total of 7195 trips) during March 2015 along both directions.

The vertical values in of the graph in figure 32 stands for additional trip time deviation in minutes. The figure represents additional trip time distribution. The values along the vertical axis of the graph stands for trip times in minutes. In total, about 7,195 vehicle trips were made during the month of March. The distribution of additional trip time in the graph includes all vehicle trips made in both directions.

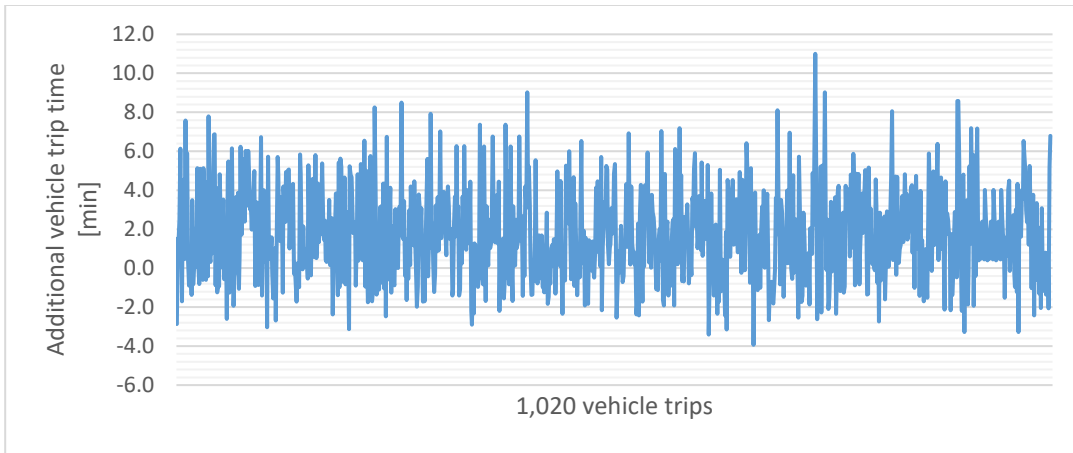


Figure 33. Distribution of additional trip time (for a total of 1020 trips) during March 2015 along direction 1.

The vertical values in of the graph in figure 33 stands for additional trip time in minutes. The figure represents additional trip time distribution. The values along the vertical axis of the graph stands for trip times in minutes. The distribution in this graph represents all vehicle trips along direction 1. In total, about 1,020 vehicle trips were made during the month of March.

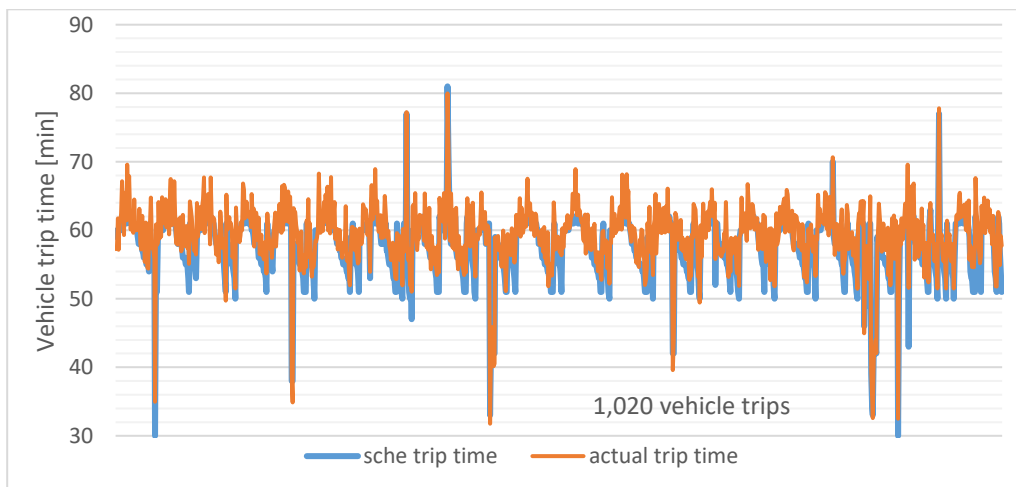


Figure 34. Distribution of average actual and schedule trip times (for a total of 1020 trips) made during March 2015 along direction 1.

The blue lines in figure 34 represent schedule trip time distribution while the orange line represents actual vehicle trip time distribution. The values along the vertical axis of the graph stands for vehicle trip times in minutes. The distribution in this graph represents all vehicle trips along direction 1. In total, 1,020 vehicle trips were made during the month of March.

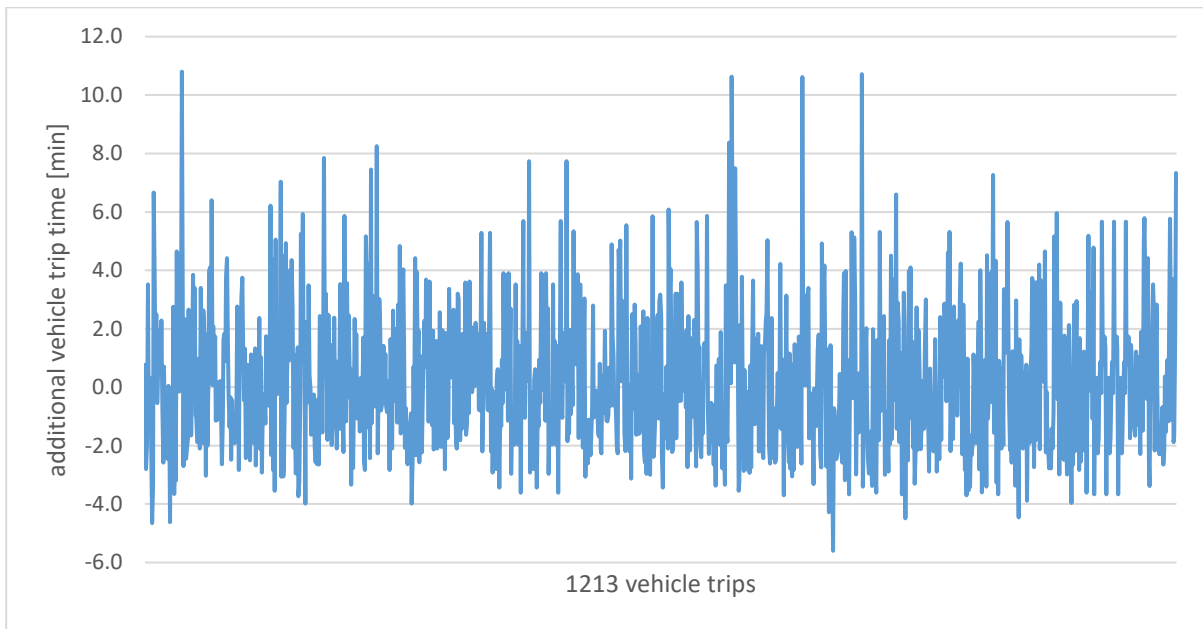


Figure 35. Distribution of additional trip time (for a total of 1213 trips) during March 2015 along direction 2.

The vertical values in of the graph in figure 35 stands for additional vehicle trip time in minutes. The figure represents additional trip time distribution. The values along the vertical axis of the graph stands for trip times in minutes. The distribution in this graph represents all vehicle trips along direction 2. In total, about 1,213 vehicle trips were made during the month of March.

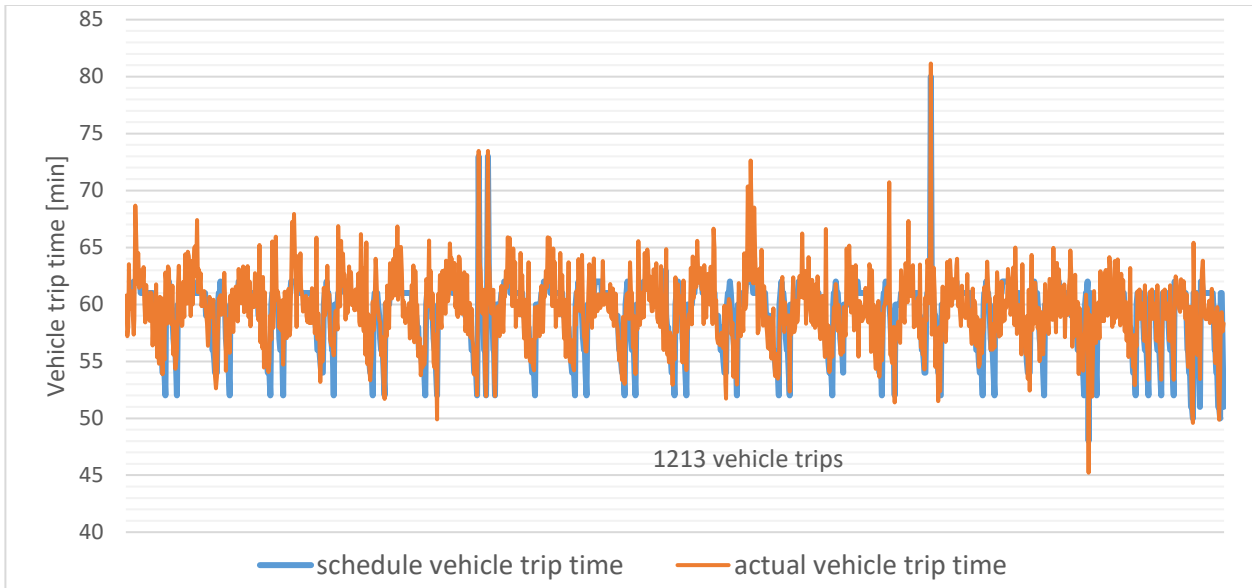


Figure 36. Distribution of average actual and schedule trip times (for a total of 1213 trips) made during March 2015 along direction 2.

The blue lines in figure 36 represent schedule trip time distribution while the orange line represents actual vehicle trip time distribution. The values along the vertical axis of the graph stands for vehicle trip times in minutes. The distribution in this graph represents all vehicle trips along direction 2. In total, 1,213 vehicle trips were made during the month of March.

A summary of average and standard deviation of vehicle trip time and average deviation of vehicle-trip time from schedule along both directions is shown in table 10. All trips occurred during weekdays in the period of 7:00 – 14:30.

Table 10. Average and standard deviation of vehicle trip time and average deviation of vehicle-trip time from schedule along both directions. (all trips occurred during weekday 7:00 – 14:30).

	Number of trips made (March 2015)	Average trip time		Standard deviation of trip time		Average additional vehicle trip time
		Schedule	Actual	Schedule	Actual	
Direction 1	1019	57.6 min	59.0 min	4.4 min	4.6 min	1.4 min

Direction 2	1212	59.4 min	59.6 min	2.9 min	3.2 min	0.2 min
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Discussion

For bus line 550, sample trip-time analysis during peak and off-peak period showed that dwell time and stop time, each constitute 3% of the total vehicle time during off peak period, the remaining 94% of the trip time is made up of driving time. (See figure 29). For the peak period, a different scenario holds true. That is, the vehicle trip time constitutes 15% stop time, 17% dwell time and the rest 68% drive time. (see figure 28). The sample analysis of run times shows that there is a significance difference in the percentage of components over the peak and off-peak periods. The higher value of dwell and stop time during peak period compared to the off-peak period can be explained by greater passenger activity and possible road congestion.

Vehicle trip time distribution can shed some light on the level of reliability of a public transport. With AVL data, such analysis can be carried out to gauge the level of variation of vehicle trip times. For the case of bus line 550, actual and schedule vehicle trip time distributions for both directions were plotted. Average trip time, and the standard deviation of trip time was also calculated. Deviations of actual trip times from scheduled trip times are also plotted. Figures 31, 32, 33, 34, 35 and 36 illustrate distribution of actual and schedule vehicle trip times for both directions.

Vehicle trip time variations along direction 1

The average actual vehicle trip time (of 1020 trips made) was 59.0 minutes and the corresponding score for the schedule trip time is 57.6 minutes. The standard deviation of vehicle trip times is 4.6 minutes and 4.4 minutes for actual and schedule trip times respectively. This result reveals that the actual trip time varies from the schedule trip time. The deviation of actual trip times from schedule trip times gives rise to the term used in this study as the additional vehicle time. Additional vehicle trip time captures the additional time it takes a vehicle to complete a trip under to a variable service. Along bus line 550, the average additional vehicle

trip time is calculated to be 1.4 minutes, with a standard deviation of 2.4 minutes. (See table 10).

Vehicle trip time variations along direction 2

The average actual vehicle trip time (of 1212 trips made) was 59.5 minutes and the corresponding score for the schedule trip time is 59.4 minutes. The standard deviation of vehicle trip times is 3.2 minutes and 2.9 minutes for actual and schedule trip times respectively. Similar to line 1, the actual vehicle trip time on line 2 as well varies from schedule vehicle trip time. The average additional vehicle trip time was 0.2 minutes with a standard deviation of 2.4 minutes. (See table 10).

Comparison of vehicle trip time consistency along both directions shows that direction 2 has a better performance compared to direction 1. That is, the variability of trip times is less along direction 2 compared to direction 1. Standard deviation of actual trip times is 4.6 minutes along direction 1 and 3.2 minutes along direction 2. Similarly, the average additional vehicle trip time (difference of actual and schedule trip time) is 1.4 minutes along direction 1 and 0.2 minutes along direction 2. This performance difference along the two directions is a result of higher passenger activity along direction 1 compared to direction 2. Refer to figures 48 and 49, to see higher average dwell times at the five stops along direction 1 as compared to direction 2.

5.4 Passenger waiting times

As discussed in section 2.3.4, average additional waiting time in seconds per passenger is the indicator used to measure wait time reliability. To draw values for average additional passenger-wait time, average schedule passenger wait time and average actual passenger wait times are calculated using equation 5. Since bus line 550 is a high frequency line, only indicator of passenger waiting time under the assumptions of random passenger arrival pattern at original stop was considered. Passenger waiting time for long headways is not included in this study.

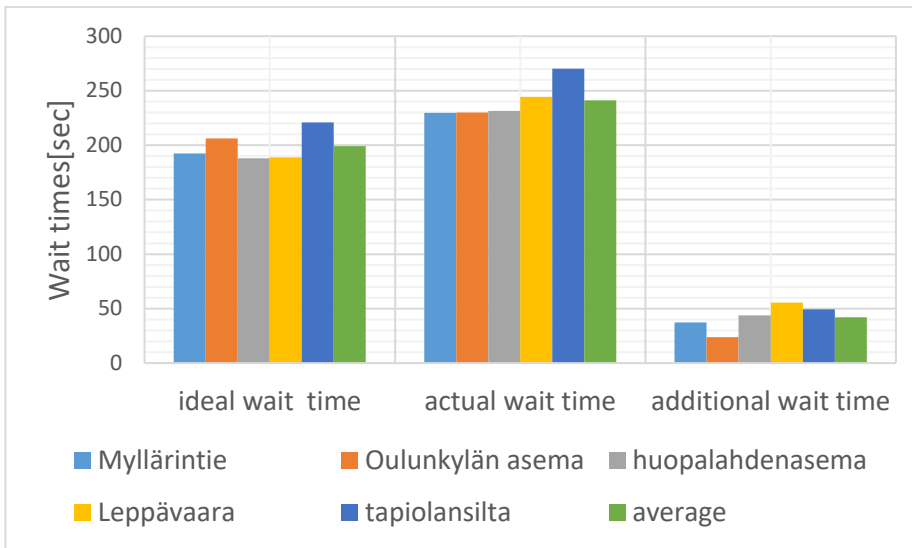


Figure 37. Ideal, actual, and additional wait times at selected stops along direction 1 for headways less than 10 minutes during 7:00 - 14:30.

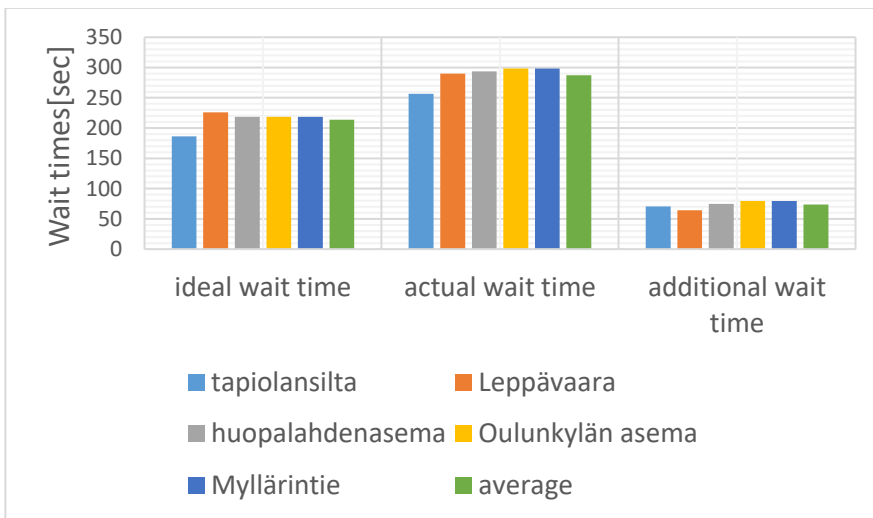


Figure 38. Ideal, actual, and additional wait times at selected stops along direction 2 for headways less than 10 minutes during 7:00 - 14:30.

Discussion

Reliability indicators in this study in sections 7.1, 7.2, and section 7.3 focused on results of reliability measurements from a public transport agency's perspective. The results of reliability analysis in the above sections measure the performance of the vehicle and misses to capture the effects of irregular service on passengers. However, this section and section 7.5 deal with the effects of irregular service to passengers, namely passenger waiting time and passenger travel time. Passenger waiting time in this study has three components, namely, ideal/schedule, actual and additional waiting times. Graphs 37 and 38 illustrate these components of passenger wait time for the five stops along both directions.

Passenger wait time at stops along direction 1

Passenger wait time at five stops along direction 1 is calculated and the average wait times for all the three components were 3.3 minutes, 4.0 minutes, and 0.7 minutes for ideal, actual, and additional wait times respectively.

Passenger wait time at stops along direction 2

Passenger wait time at five stops along direction 1 is calculated and the average wait times at all five stops for all the three components were 3.6 minutes, 4.8 minutes, and 1.2 minutes for ideal, actual, and additional wait times respectively.

In general, passengers at five stops along direction 2 waited an additional 1.2 minutes on average due to delay caused by the operator whereas the corresponding score along direction 1 is 0.7 minutes. Passengers along direction 2 has longer average additional waiting times at the five stops. Due to higher passenger activity and a greater variability in vehicle trip times along direction 1 compared to direction 2, the expectation was that additional waiting time for passengers along direction 1 is longer than for those passengers along direction 2. However, the result conflicts with the expected value. Calculating average additional wait times at all 39

stops for each direction may give a better performance comparison of passenger wait times along each direction and expected and calculated values may match.

5.5 Passenger travel time

Passenger travel time is the sum of in-vehicle time and waiting time. As discussed in section 2.3.5, travel time represents passengers' time expenditure through waiting and in-vehicle time. Additional travel time captures the extra time spent on waiting and in-vehicle time caused by variability in waiting and in-vehicle time as compared to schedule. In this section the results of the analysis of passenger travel time is shown.

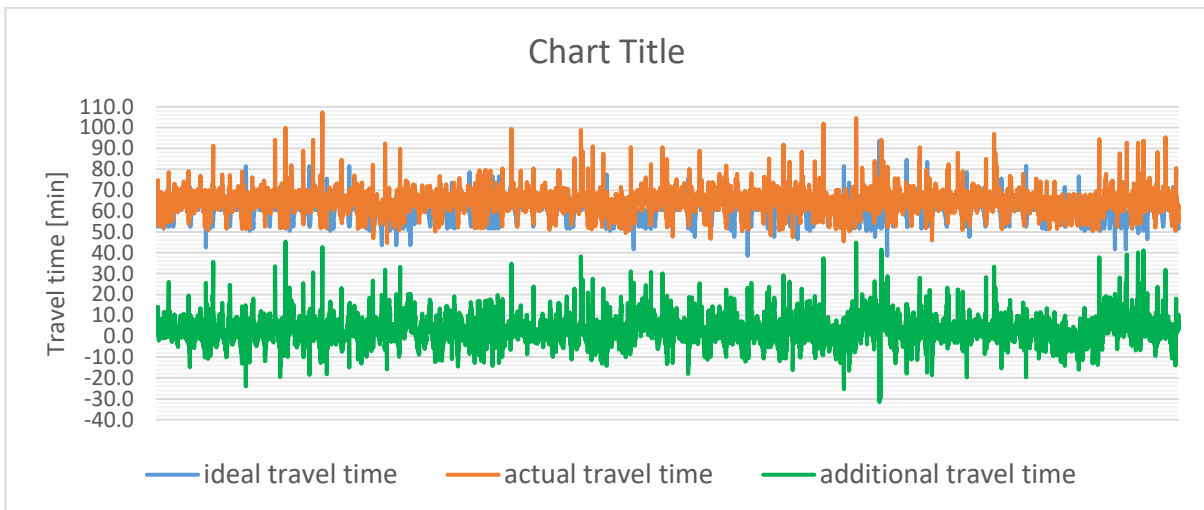


Figure 39. Average Ideal/schedule, actual and additional passenger travel time for a total of 7195 trips made during March 2015 for both directions.

In figure 39, all the three components of passenger travel time, namely, schedule, actual and additional passenger travel time is shown. The vertical value in figure 39 represents distribution of travel time in minutes. The blue line represents distribution of ideal passenger travel time, the orange representing actual passenger travel time and the green line represents distribution of passenger additional travel time. A total of 7,195 passenger trips (under the assumption that they all travelled the whole route) were made during the month of March 2015 along both directions.

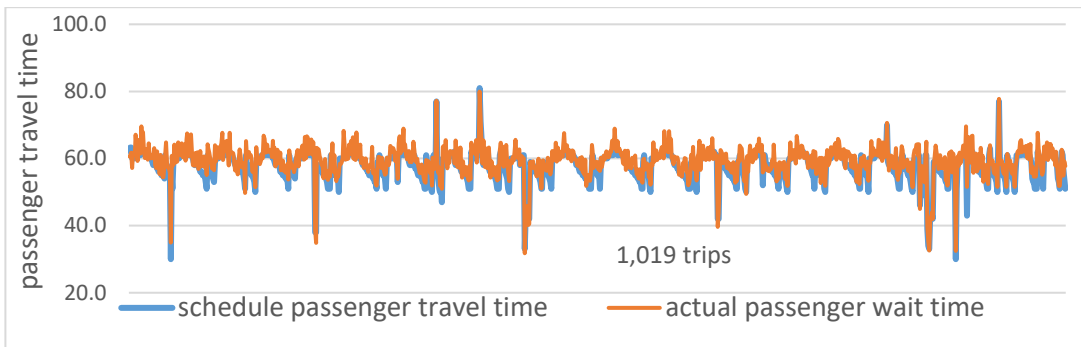


Figure 40. Average schedule/ideal and actual passenger travel time for a total of 1019 trips made during March 2015 along direction 1.

In figure 40, the two components of passenger travel time, namely, schedule and actual passenger travel time is shown. The vertical value in figure 40 represents distribution of travel time in minutes. The blue line represents distribution of ideal passenger travel time and the orange representing actual passenger travel time. A total of 1,019 passenger trips (under the assumption that they all travelled the whole route) were made during the month of March 2015 along direction 1.

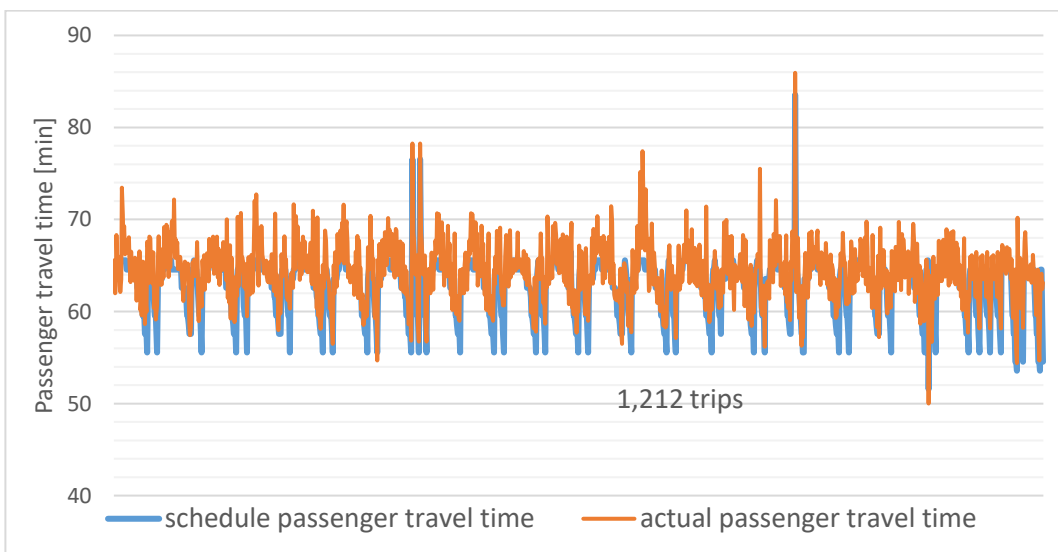


Figure 41. Average schedule/ideal and actual passenger wait time for a total of 1212 trips made during March 2015 along direction 2.

In figure 41, the two components of passenger travel time, namely, schedule and actual passenger travel time is shown. The vertical value in figure 41 represents distribution of travel time in minutes. The blue line represents distribution of ideal/schedule passenger travel time and the orange representing actual passenger travel time. A total of 1,212 passenger trips (under the assumption that they all travelled the whole route) were made during the month of March 2015 along direction 1.

Additional passenger travel time is the one important indicator to the level of additional time passengers spent in waiting at the original stop and the time spent in-vehicle during trip. The following two graphs represent average additional passenger travel time due to delay caused by operator.

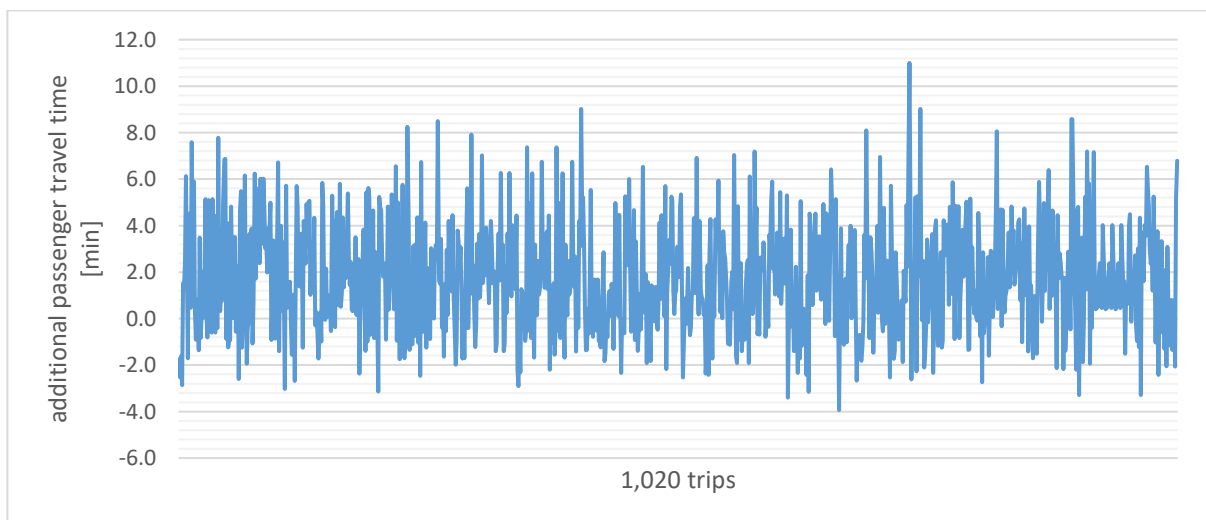


Figure 42. Average additional passenger travel time for a total of 1020 trips made during March 2015 along direction 1.

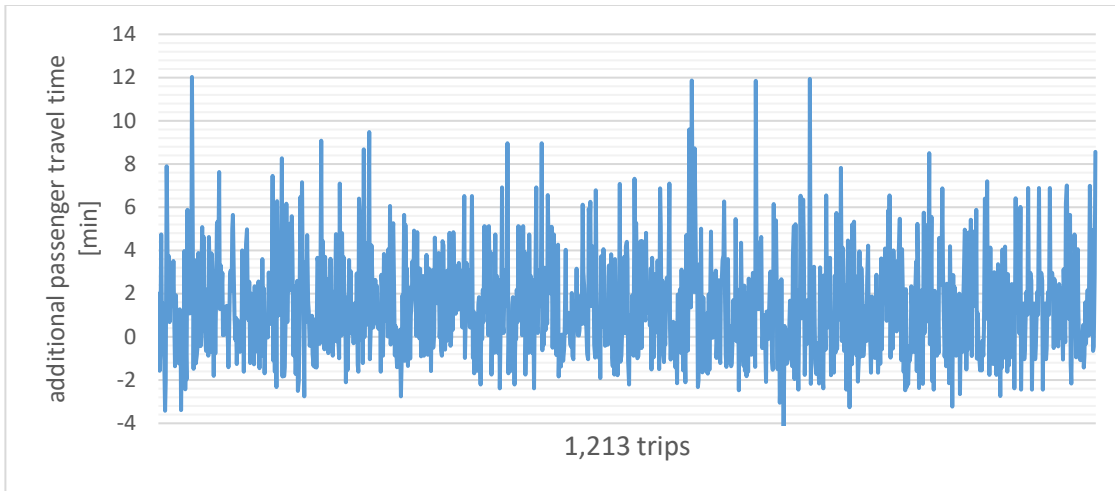


Figure 43. Average additional passenger travel time for a total of 1213 trips made during March 2015 along direction 2.

Discussion

Passengers are interested in minimizing their travel times there by increasing their time usage. Passenger travel time in this study has two components: waiting time and in-vehicle time. Passenger travel time for the while route is calculated by assuming that the average waiting time along the route per direction is equivalent to the average waiting time at the five stops per direction. Refer to figures 39,40,41,42 and figure 43 to see illustrations of distributions of actual and schedule passenger travel time and additional passenger travel time along both directions.

Passenger travel time along direction 1

The result of the passenger travel time calculation (for a total of 1019 trips) shows that the scheduled and actual passenger travel time were given by 57.6 minutes and 59.3 minutes respectively. The standard deviation of scheduled and actual passenger travel time were 4.4 minutes and 4.6 minutes respectively. The average additional passenger travel time along the route was found to be 1.7 minutes. See figure 40 and figure 42 for actual and schedule passenger travel time and additional travel time distributions along direction 1.

Passenger travel time along direction 2

Average passenger travel time calculation (for a total of 1212 trips) showed that schedule passenger travel time was 63.0 minutes whereas the actual passenger travel time was 64.3 minutes. The standard deviation of scheduled and actual passenger travel time were 2.9 minutes and 3.2 minutes respectively. The average additional passenger travel time along the route was found to be 1.3 minutes. See figure 41 and figure 43 for distribution of schedule, actual and additional passenger travel time.

Table 11. Average passenger travel time and additional passenger travel time for both directions

Direction	Number of vehicle trips made by passengers (March 2015)	Average passenger travel time		Standard deviation of passenger travel time		Average additional passenger travel time
		Schedule/Ideal	Actual	Schedule/Ideal	Actual	
Direction 1	1019	57.6 min	59.3 min	4.4 min	4.6 min	1.7 min
Direction 2	1212	63.0 min	64.3 min	2.9 min	3.2 min	1.3 min

As can be seen from the calculated numbers (See table11), passenger travel time variability is higher for direction 1 compared to direction 2, as expected. This again must do with higher dwell time along direction 1.

5.6 Boarding, alighting, passenger load and dwell time

In this section, results of the passenger characteristic analysis are presented. Boarding and alighting pattern along the route and passenger load patterns are illustrated using graphs for trips occurred in both directions.

Boarding, alighting and passenger load

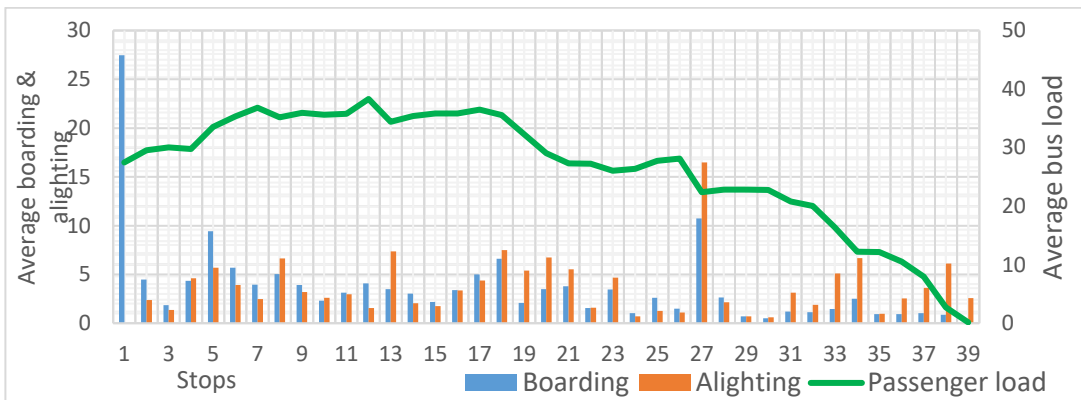


Figure 44. Boarding, alighting and passenger load on weekdays for January, February, and March 2015 along direction 1.

The numbers along the horizontal line in figure 44 represent bus stop numbers along direction 1. The vertical values represent number of average boarding and alighting passengers. The blue bars represent boarding, the orange bars represent alighting and the green line represent passenger load. The period of distribution of boarding, alighting and passenger load was during January, February, and March 2015.

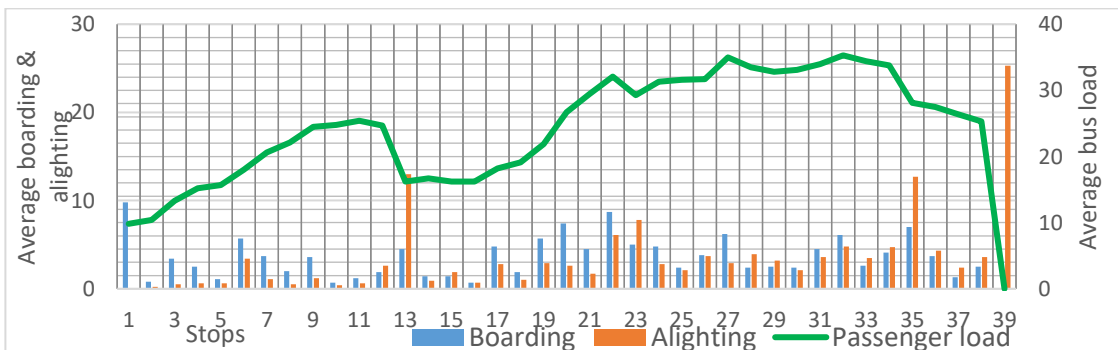


Figure 45. Boarding, alighting and passenger load on weekdays for January, February, and March 2015 along direction 2.

The numbers along the horizontal line in figure 45 represent bus stop numbers along direction 2. The vertical values represent number of average boarding and alighting passengers. The blue bars represent boarding, the orange bars represent alighting and the green line represent passenger load. The period of distribution of boarding, alighting and passenger load was for the period January, February, and March 2015.

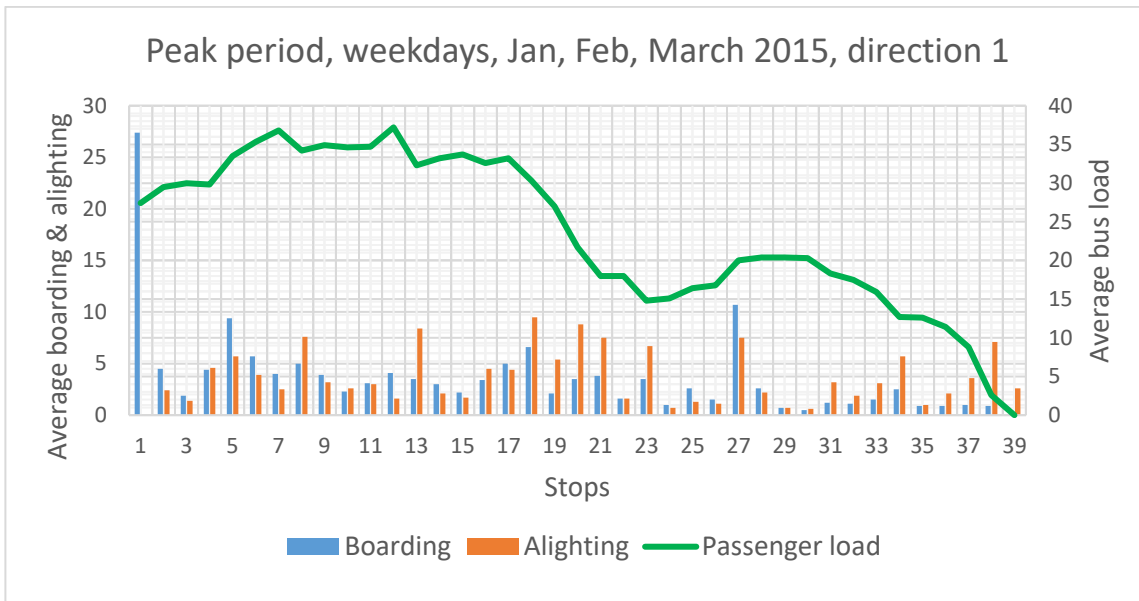


Figure 46. Peak period boarding, alighting and passenger load for January, February, and March 2015 along direction 1.

The numbers along the horizontal line in figure 46 represent bus stop numbers along direction 1. The vertical values represent peak period (morning and afternoon peak) number of average boarding and alighting passengers. The blue bars represent boarding, the orange bars represent alighting and the green line represent passenger load. The period of distribution of boarding, alighting and passenger load was during January, February, and March 2015.

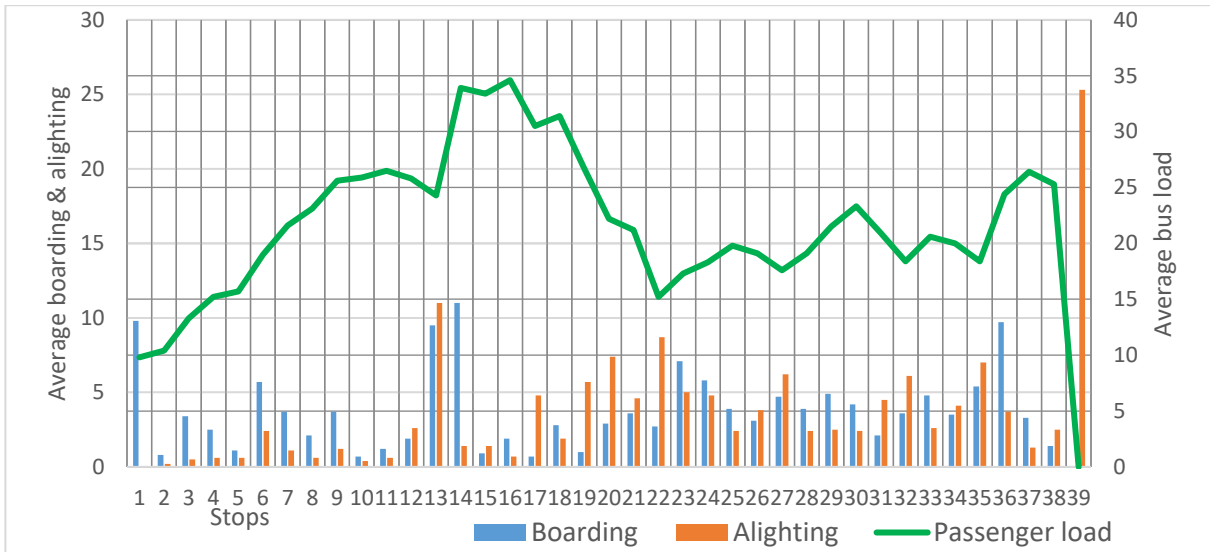


Figure 47. Peak period boarding, alighting and passenger load for January, February, and March 2015 along direction 2.

The horizontal line numbers in figure 47 stand for bus stop numbers along direction 2. The vertical values represent peak period (morning and afternoon peak) number of average boarding and alighting passengers. The blue bars represent boarding, the orange bars represent alighting and the green line represent passenger load. The period of distribution of boarding, alighting and passenger load was for the period January, February, and March 2015.

Dwell time

Average dwell time at the selected five stops was calculated. Furthermore, standard deviation of dwell time is also calculated. The vertical values in figures 48 and 49 stand for average dwell time in seconds. Dwell time is the length of time a bus takes at stops to serve passengers.

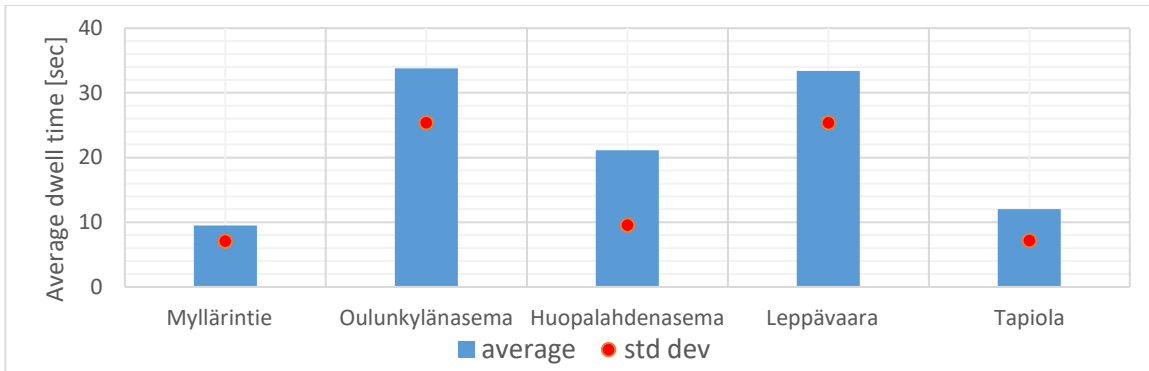


Figure 48. Average dwell time and standard deviation of dwell time at five selected stops for January, February, and March 2015 along direction 1.

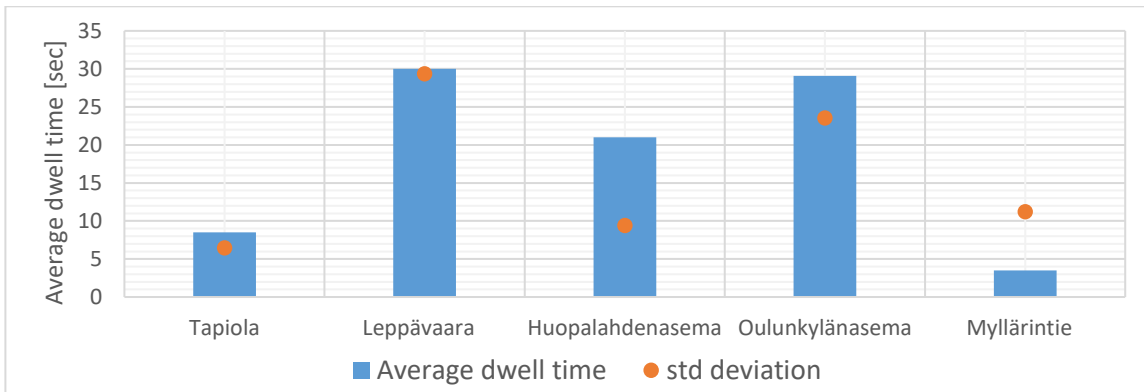


Figure 49. Average dwell time and standard deviation of dwell time at five selected stops for January, February, and March 2015 along direction 2.

Discussion

Distinct characteristics of passenger activity (boarding and alighting) and load values for both directions are discussed below. Furthermore, discussion on dwell time will also be followed.

Direction 1

The average passenger load was 26.6. The highest and lowest passenger load was 38.3 and 2.7 respectively. The passenger load value starts at 16 at the first stop and peaks to 38.3 at the 12th stop. The first half of the route is characterized by higher load values and decreases along the

second half of the route until it gets to zero at the final stop. The highest average boarding took place at the first stop (Myllärintie) of the route and the second highest at the 27th stop (Leppävaara). The highest recorded average alighting is at stop 27th (Leppävaara). Maximum average boarding or/and alighting took place at 1st and 27th stop. (See figure 44).

For the peak period, average loading was 23.6 with highest and lowest values of 37.2 (at 12th stop) and 2.6 (at 38th stop) respectively. Both average boarding and alighting values at each stop were 3.7. (See figure 46).

Dwell time is highest at Oulunkylänasema and Leppävaara with a duration of over 0.5 minute. (Refer to figure 48). Myllärintie and Tapiolansilta have the lowest dwell time compared to the other three stops, with about 10 second value. These stops are the 3rd and the 38th (out of 39th) stops of the route, which are located at the beginning and end of the bus route respectively. Smallest dwell time at these stops, therefore, is an indication of small passenger activity compared to the other three stops.

Direction 2

The highest and lowest passenger load was 35.3 and 10.4 respectively. The average passenger load value for the second half of the route was higher compared to the first half of the route, unlike along direction 1 where load peaked in the first half of the route. The highest passenger load occurred at the 32nd stop (Oulunkylänasema). The highest boarding was at the first stop (Westendinasema) and the highest alighting was at the last stop (Itäkeskus). There were all together 4 stops where the average number of passengers boarding/alighting were greater or equal to 10. These stops are the 1st, 13th, 35th, and 39th. (See figure 45).

For the peak period, average load was 21.4 with highest and lowest values of 34.6 (at 16th stop) and 9.8 (at 1st stop) respectively. Both average boarding and alighting values at each stop were 3.6. (Refer to figure 47).

Dwell time is highest at Leppävaara and Oulunkylänasema with a duration of about 0.5 minute. Myllärintie (37th stop) has an average dwell time of less than 5 seconds, a reflection of the low passenger activity at the stop. (See figure 49).

Summary of boarding, alighting and load characteristics along both directions is shown in the following table.

Table 12. Boarding, alighting and load characteristics along both directions.

		Whole period	Occurred at stop	Peak period	Occurred at stop
Average boarding at each stop (Passengers/bus)	Direction 1	3.7		3.7	
	Direction 2	3.6		3.7	
Average alighting at each stop (Passengers/bus)	Direction 1	3.7		3.7	
	Direction 2	3.6		3.7	
Average load on the line (Passengers/bus)	Direction 1	26.5		23.6	
	Direction 2	24.1		21.4	
Average lowest load (Passengers/bus)	Direction 1	2.7	38 th	2.6	38 th
	Direction 2	10.4	1 st	9.8	1 st
Average highest load (Passengers/bus)	Direction 1	38.3	12 th	37.7	12 th
	Direction 2	35.3	32 nd	34.6	16 th

It can be noted from table 12 that direction 1 has a higher average passenger load both during peak period and whole period compared to direction 2, an indication that there is more passenger activity along direction 1 compared to direction 2. Another noticeable trend was that average highest load for direction 1 is attained early in the first half of the route (12th stop) whereas for direction 2 load attained its maximum value at the second half of its route, that is at its 32nd stop. This shows that greater passenger activity at the first half of the route along direction 1 than the second half of the route along direction 2. Implementation of any reliability

improvement measures along both directions needs to consider passenger activity and load value characteristics of the route on both directions.

Dwell time comparison of the five stops for the two directions reveal that direction 1 has longer dwell times at all four stops compared to stops along direction 2. The exceptional stop is Huopalahdenasema where dwell time is equal for both directions, with a length of 20 seconds. (Refer to figure 48 and figure 49).

5.7 Service disruption

Results of service disruption data analysis is described in this section. The length of the disruption data lies within the period 19.02.2011–16.01.2015. The data was retried from HSL open data source.

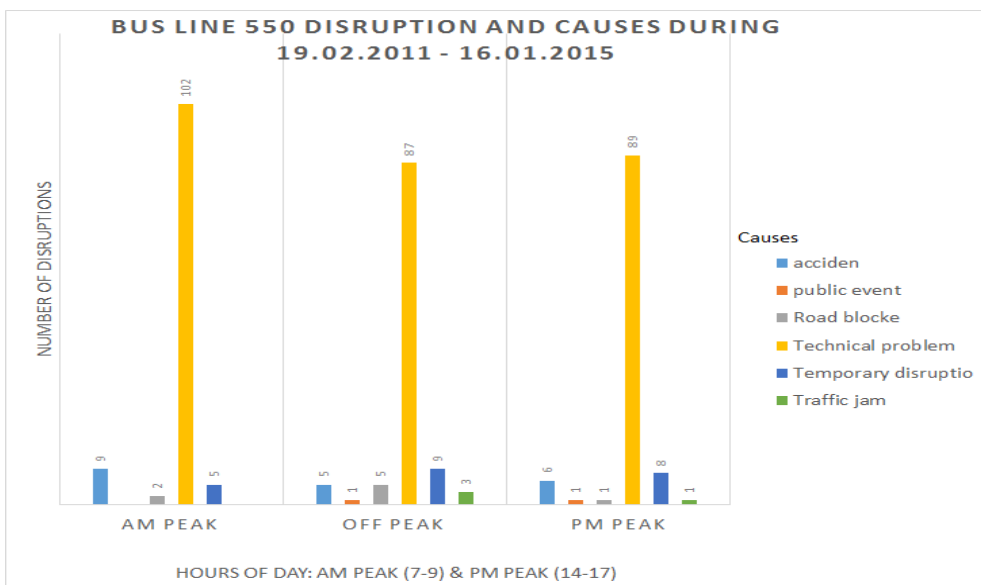


Figure 50. Causes of disruption (334 counts) to bus line 550 for four years of its operation (19.02.2011–16.01.2015). Figure is based on data obtained from HSL open source ‘pubtrans.it’.

In the following two figures (figures 51 and 52) illustrations of characteristics of disruption based on length of disruption and across different seasons will be provided.

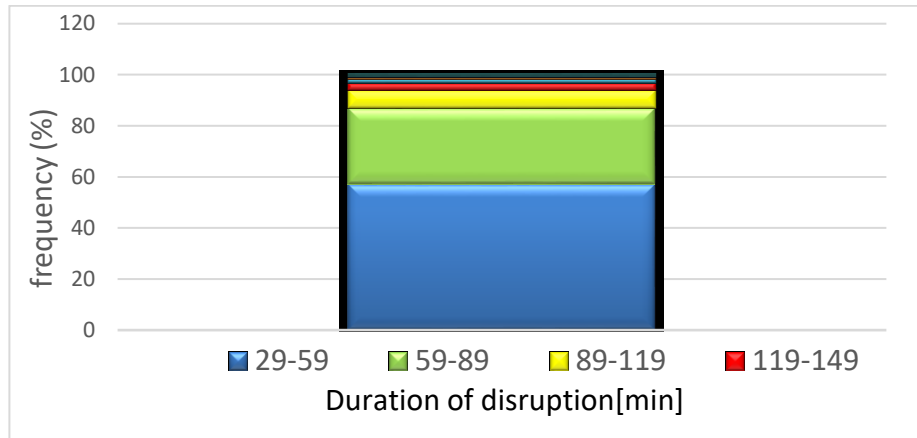


Figure 51. The length of disruption in service operation of bus line 550 over the period of 19.02.2011 – 16.01.2015.

Values along the horizontal axis in figure 51 represent duration of the disruption in minutes. The vertical values stand for percentage of disruption.

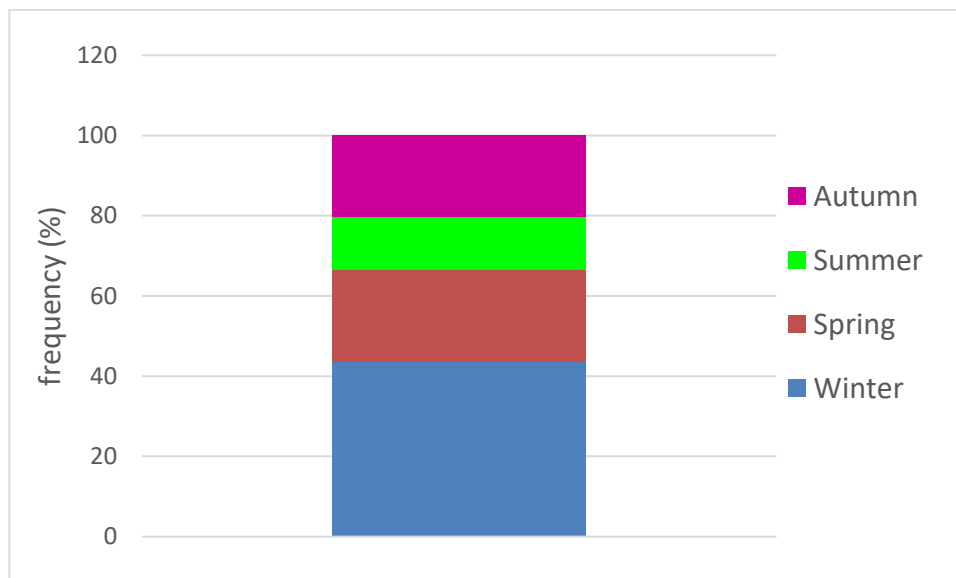


Figure 52. Disruption of service operation of bus line 550 at different seasons of the year over the period of 19.02.2011 – 16.01.2015.

Discussion

Disruption to service may be caused by several factors. Analysis of disruption data in section 6.7 showed that the number one cause of service disruption of operation along the bus line 550 is technical problem. Other major causes included accident, public event, road-block, traffic jam and temporary disruption.



Figure 53. Malfunctioning bus 550 being towed, seen in Otaniemi on 22.4.2014. Picture taken by Antero Alku. Source: (Kaupunkiliikenne 2016).

Service operation disruption data of bus line 550 over the period of 19.02.2011 – 16.01.2015 was analyzed. There were all together 334 disruption counts over this period. Level of disruption during morning peak, afternoon peak and off peak times over the entire period was analyzed. Distribution of disruptions over seasons of the year was also analyzed to shed light on effects of weather on service operation of the bus line. Winter season accounted for over 40% of all counts of disruption followed by Spring season. (See figure 52). Summer season accounted only for a little over 10% of all disruptions for the given period. Duration of disruptions is presented in a graph which indicated that over half of all the disruptions lasted between 30 minutes and an hour.

6 Conclusions and Recommendation

In this chapter conclusions of the study and recommendations for future work are presented. The main objective of this thesis was to analyze reliability of a high frequency bus line using different indicators of service performance measures. Data used in the analysis was obtained from Automatic Vehicle Location (AVL) and Automatic Passenger Counter (APC). HSL provided the automated data. The case study route was bus line 550 in Helsinki Capital Region. Five reliability indicators that reflect the interests of both public transport agencies and passengers were applied. These indicators are on-time performance, headway regularity, vehicle trip time/run time, passenger waiting time and passenger travel time. The first three of the indicators reflect agency reliability perspectives and the last two indicators represent passenger's perspective of reliability. Furthermore, dwell time, passenger activity and operational disruption data were analyzed to better characterize quality of service along the route.

- On-time performance of the line at the selected five stops based on the given on-time window revealed that along direction 1, about 60% of all departures were on-time, 39% late and 1% early. For morning and afternoon peak periods, percentage of on-time departures declined into 51.4% and 42.6% respectively. Along direction 2, the corresponding percentages for morning and afternoon peaks were 59% and 47% respectively. On-time performance of line 550 is based on a strict time window of 0.5-minutes early and 1-minute late, which makes comparison with international results difficult. Causes of late departures could be linked to late arrival, long dwell time, driver behavior or traffic behavior in the peak period. To address these possible problems and hence to improve on-time performance along the line, one or a combination of the following measures could be taken: optimizing schedule time table, acquiring low-floor bus fleets, providing driver training and inspection, provision of more traffic signal priorities at intersections, or exclusive bus lane provision. Furthermore, the policy of boarding through the middle door should be revised due to more passengers boarding through the middle door are crowding it while the front door getting underutilized. Early departures, which often occur at stops near the end of the route along both

directions can be minimized by a combination of implementing schedule-based holding at selected stops and driver training and supervision accompanied by making the job of the driver more attractive.

- Headway deviation increased consistently towards the end terminal at all five selected stops in both directions. The average headway deviation at the five stops was 84 seconds and 94 seconds for direction 1 and direction 2 respectively. From all the five analysis stops along direction 1, Oulunkylänasema has the highest percentage of headway regularity. That is, about 73% of all departures have a headway deviation of 60 seconds. This exceptional headway regularity performance at this stop could be the result of a control measure in the form of headway-based holding being implemented at this stop. Oulunkylänasema is one of the three time points on the route. Along direction 2, Tapiolansilta has the highest percentage of headway regularity, about 78% off all departures have a headway deviation of 60 seconds. This result could be due to the location of the stop being the second stop on the route. Headway deviations often propagate further down the line. Figure 27 shows how bunching occurs along the route. The figure shows that bunching becomes more frequent downstream along the line. The causes of headway irregularity along bus line 550 could be a result of longer dwell time, traffic conditions, or driver behavior. Implementation of headway-based vehicle holding could be an appropriate measure to improve service regularity along the route.
- The average additional vehicle trip time/run time per bus along direction 1 and direction 2 was 1.4 minutes and 0.2 minutes respectively. The standard deviation of actual vehicle trip time was 4.6 minutes and 3.2 minutes along direction 1 and direction 2 respectively. The variability in run times might be caused by several factors such as, non-optimal time-table, longer dwell time, traffic conditions, driver behavior, length of the route, number traffic signal priorities and exclusive bus lanes. To improve the variability of run times, hence to increase reliability of service on the route, each of the above factors should be improved.

- The average additional wait time over the five stops per passenger was 42 seconds and 74 seconds along direction 1 and direction 2 respectively. Average wait time at Tapiolansilta stop was the highest among the five stops, 270 seconds along direction 1. Tapiolansilta is at the end of the route (38th out of 39 stops). As literature also suggests, performance declines downstream. Along direction 2, the pattern is a more even distribution of average wait time in almost all the stops. Headway variability is a major cause of variability in wait time. Improving headway irregularity would minimize passenger wait times.

- The average additional passenger travel time per passenger along direction 1 and direction 2 was 1.7 minutes and 1.3 minutes respectively. The standard deviation of actual passenger travel time was 4.6 minutes and 3.2 minutes along direction 1 and direction 2 respectively. Improving additional passenger waiting time will minimize additional passenger travel time.

- The APC data analysis revealed that average passenger load was 26.5 passengers per bus. The average highest and lowest passenger loads were 38.3 passengers per bus (at Tuusulanväylä) and 2.7 passengers per bus (Tapiolansilta) respectively. Overall, Passenger activity over the first half of the route is characterized by high load which is about twice that of the second half of the route.

- During the period 19.02.2011–16.01.2015 there were altogether 334 service disruption counts of which winter season accounted for over 40% of all counts of disruption followed by Spring season. Summer season accounted only for a little over 10% of all disruptions. Over half of all the disruptions lasted between 30 minutes and an hour. The number one cause of service disruption along the bus line 550 is technical problem. Other major causes included accident, public event, road-block, and traffic jam.

Possible causes of unreliability could be linked to one or a combination of the following factors: line length of the route, driver behavior, not enough traffic signal priority at intersections, middle door boarding policy, vehicle design and other traffic.

In summary, the analysis of several important measures of bus service performance revealed that performance deteriorated further along the line in both directions. Agency oriented indicators showed that there is a gap in schedule and headway adherence and variability in run time. The vehicle trajectory illustrated the occurrence of bunching and how it propagated along the line. The passenger oriented reliability indicators in this study showed that passengers spend an additional waiting time at their first stop. Different studies in literature have shown that passengers perceive their wait time to be longer than their actual wait time. Winter temperatures such as the data period for this study (March 2015) could even lead to increased perceived wait time. Therefore, it is important to improve the headway regularity of the line in order to minimize passenger wait time.

Therefore, it is imperative that waiting time for passengers needs to be shortened. Keeping a regular headway along the line would shorten passenger wait time. The analysis also showed that variability in travel time along the line leading to more average additional travel time for passengers.

In conclusion, there is a room for improvement in both agency and passenger oriented measures of bus service performance. Keeping a regular headway on the route is very important than schedule regularity, especially for short headway services. Passengers perceive reliability mainly in terms of waiting and travel time. Improving these aspects of service increases passenger satisfaction which in turn affects the operating agency positively.

Further Research

The analysis in this study was based on data from AVL-APC system. Most of the analysis of bus service performance measures were carried out at selected stop level and using data over a duration of one month, due to limited time. It is suggested that future work could include similar stop-level analysis at all stops using longer data period to get a better result. Effect of seasons

of the year on service reliability could be investigated. For instance, how reliability is affected during winter time. Furthermore, the effect of middle door boarding policy on bus line 550 versus dwell time, and the relationship between line length of the route and reliability could be future research topics.

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Appendix

Table 13. Stop order and stop names along bus route 550 in 2016. Source: Journey Planner (HSL).

Stop order	Stop name	Stop order	Stop name	Stop order	Stop name	Stop order	Stop name
1	Itäkeskus	11	Mestarintie	21	Takomotie	31	Tietäjä
2	Roihupelto	12	Tuusulanväylä	22	Takkatie	32	Innopoli
3	Myllärintie	13	Maunula	23	Pitäjänmäen asema	33	Kemisti
4	Latokartano	14	Pirjontie	24	Vermo	34	Otsolahdentie
5	Viikin tiedepuisto	15	Pirkkola	25	Kalkkipellonmäki	35	Kontiontie
6	Viikinmäki	16	Hämeenlinnanväylä	26	Puustellinmäki	36	Sateentie
7	Veräjämäki	17	Ilkantie	27	Leppävaara	37	Tapiolansilta
8	Oulunkylän asema	18	Huopalahden asema	28	Säteri	38	Westendin asema
9	Mäkitorpantie	19	Vihdintie	29	Kurkijontie		
10	Käskynhaltijantie	20	Valimotie	30	Turvesuontie		