Centre for Geo-Information

Thesis Report GIRS-2011-01

Event recognition in public transport trajectories

A case study on Helsinki tram and bus movements

Aldo Bergsma

January 2011

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Event recognition in public transport trajectories

A case study on Helsinki tram and bus movements

Aldo Bergsma

Registration number 690430-057-070

<u>Supervisors</u>:

Ir. Ben Loke (Noldus Information Technology BV)
Dr. Ir. Ron van Lammeren (GRS, Wageningen University)

A thesis submitted in partial fulfilment of the degree of Master of Science
at Wageningen University and Research Centre,
The Netherlands.

January 2011
Wageningen, The Netherlands

Thesis code number: GRS-80436
Thesis Report: GIRS-2011-01
Wageningen University and Research Centre

Laboratory of Geo-Information Science and Remote Sensing

Preface/Acknowledgement

This report is written for the Master Thesis Geo-Information Science. The thesis is conducted as an integrated part in the PRONTO project. As such it is supervised by Ben Loke of Noldus Information Technology BV, which is one of the partners in the PRONTO project, and Ron van Lammeren of the Laboratory of Geo-Information Science and Remote Sensing of Wageningen University. Both I would like to thank for their patience and inspiring ideas to keep the subject going. I also would like to thank Rongmei Li, Leon Wiertz and Mike Kelia of Noldus Information Technology BV, for the comments and support on this thesis. Of course I would like to thank Arnold Bregt, Ron van Lammeren and my colleagues at the department of Geo-Information Science and Remote Sensing of Wageningen University for giving me the opportunity and time to study the Master of Geo-Information Science.

I would like to thank Mattersoft Ltd. for the supply and support they offered on the use of movement data of the Helsinki public transport on which this study is performed, without these this thesis research could not have been done.

Table of contents

Laboratory of Geo-Information Science and Remote Sensing Preface/Acknowledgement..... iii
Preface/Acknowledgement.....v
Table of contents vii
List of terms..... xi
Abbreviations and Acronyms xi
Summary 1
1. Introduction 3
1.1 Live! 3
1.2 PRONTO.....4
1.3 Objectives.....5
2. Background 7
2.1 Sensors 7
2.2 Location and environment.....7
2.2.1 GPS 7
2.2.2 Network triangulation 7
2.3 Sensor Networks 8
2.3.1 Sensor Web Enablement (SWE).....8
2.3.1.1 SOS.....9
2.3.1.2 SES 9
2.3.1.3 Complex Event Processing.....9
2.4 Object motion (tracking) 10
2.4.1 Camera registration.....10
2.4.2 GPS trajectories 10
2.4.3 Movement analyses.....10
2.5 Events definition 10
2.5.1 Low level events 11
2.5.2 High level events 11
2.5.3 TSO framework 11
2.5.4 Deterministic vs. Analytical 12
2.6 Concluding remarks 12
3. Methodology 13
3.1 Case study 14
3.1.1 Trajectory data 14
3.1.2 Stops data.....15
3.1.3 Traffic light priority data 15
3.1.3 Reference data.....15
3.2 Data preparation 16
3.2.1 Derived low level events.....17
3.3 Data exploration 18
3.3.1 Explorative trajectory analysis.....18
3.3.2 Explorative stop analysis 19
3.4 Analyses of high level events.....19
3.5 High level Event: Punctuality 20
3.5.1 Spatial analysis of aggregated vehicles on one line.....20
3.5.2 Spatial analysis individual vehicles on one line 21
3.5.3 Temporal analysis of aggregated vehicles on one line 21
3.5.4 Temporal analysis individual vehicles on one line 21
3.5.5 Spatiotemporal analysis of aggregated vehicles on one line.....21
3.5.6 Spatiotemporal analysis individual vehicles on one line 21
3.6 High level Event: Route problems 21
3.6.1 Traffic light priority 22

3.6.1.1 Spatial analysis of aggregated vehicles on one line 22
3.6.1.2 Spatial analysis individual vehicles on one line 22
3.6.1.3 Temporal analysis of aggregated vehicles on one line 22
3.6.1.4 Temporal analysis individual vehicles on one line... 22
3.6.1.5 Spatiotemporal analysis of aggregated vehicles on one line 22
3.6.1.6 Spatiotemporal analysis individual vehicles on one line 22
3.6.2 Road intersections 23
3.6.3 Traffic lights 23
3.6.4 Tram Stops 23
3.6.5.1 Spatial analysis on aggregated vehicles on one line 23
3.6.5.2 Spatial analysis on individual vehicles on one line 23
3.6.5.3 Temporal analysis of aggregated vehicles on one line 23
3.6.5.4 Temporal analysis individual vehicles on one line... 23
3.7 High level Event: Driving behavior and Passenger comfort 24
3.7.1 Spatial analysis of aggregated vehicles on one line 24
3.7.2 Spatial analysis individual vehicles on one line 24
3.7.3 Spatial temporal analysis of aggregated vehicles on one line 25
3.7.4 Spatial temporal analysis individual vehicles on one line 25
3.8 Concluding remarks 25
4 Data exploration 27
4.1 Implementation in SWE/SOS 27
4.2 Trajectory exploration 27
4.2.1 Tram line 1 27
4.2.2 Bus line 68 29
4.3 Stop exploration 30
4.3.1 Tram stops on tram line 1 30
4.3.2 Bus stops on bus line 68 32
4.4 Traffic light priority 33
4.5 Discussion and conclusions 33
4.5.1 SWE implementation 33
4.5.2 Trajectories 34
4.5.3 Stops 34
4.5.4 Traffic light priority 34
5 High level Event: Punctuality 35
5.1 Punctuality on tram line 1 35
5.1.1 Spatial analysis of aggregated vehicles on tram line 1 35
5.1.1.1 Punctuality of passing a stop 35
5.1.1.2 Status 37
5.1.2 Spatial analysis of individual vehicles on tram line 1 39
5.1.2.1 Punctuality 39
5.1.2.2 Status 41
5.1.3 Temporal analysis on aggregated vehicles on tram line 1 41
5.1.3.1 Punctuality 41
5.1.3.1.1 Punctuality Time of the day 41
5.1.3.1.1 Punctuality Rush-hours 42
5.1.3.2 Status 43
5.1.4 Temporal analysis on individual vehicles on tram line 1 43
5.1.4.1 Punctuality 43
5.1.4.1.1 Punctuality during the different hours of the day 43
5.1.4.1.2 Punctuality during the rush-hours 44
5.1.4.2.1 Status during the different hours of the day 44
5.1.4.2.2 Status during the rush-hours 45
5.1.5 Spatiotemporal analysis on aggregated vehicles on tram line 1 45
5.1.5.1 Punctuality 45
5.1.5.1.1 Punctuality during the different hours of the day 45

5.1.5.1.2 Punctuality during the rush-hours...46
5.1.5.2.1 Status during the different hours of the day..47
5.1.5.2.2 Status during the rush-hours...49
5.1.6 Spatiotemporal analysis on individual vehicles on tram line 1..............................49
5.2 Punctuality on bus line 68..49
5.2.1 Spatial analysis on aggregated vehicles on bus line 68 49
5.2.1.1 Punctuality...50
5.2.1.2 Status 52
5.2.2 Spatial analysis individual vehicles on bus line 68..53
5.2.2.1 Punctuality...53
5.2.2.2 Status 55
5.2.3 Temporal analysis on aggregated vehicles on bus line 68.....................................56
5.2.3.1 Punctuality...56
5.2.3.1.1 Punctuality during the different hours of the day 56
5.2.3.1.2 Punctuality during the rush-hours...57
5.2.3.2 Status 57
5.2.3.2.1 Status during the different hours of the day..57
5.2.3.2.2 Status during the rush-hours 58
5.2.4 Temporal analysis on individual vehicles on bus line 68 58
5.2.4.1 Punctuality...58
5.2.4.1.1 Punctuality during the different hours of the day 59
5.2.4.1.2 Punctuality during the rush-hours...59
5.2.4.2 Status 59
5.2.4.2.1 Status during the different hours of the day..59
5.2.4.2.2 Status during the rush-hours 60
5.2.5 Spatiotemporal analysis on aggregated vehicles on bus line 68 60
5.2.5.1 Punctuality...60
5.2.5.1.1 Punctuality during the different hours of the day 60
5.2.5.1.2 Punctuality during the rush-hours...64
5.2.5.2 Status 66
5.2.5.2.1 Status during the different hours of the day..66
5.2.5.2.2 Status during the rush-hours 68
5.2.6 Spatiotemporal analysis on individual vehicles on bus line 68 69
5.2.6.1 Punctuality...69
5.2.6.1.1 Punctuality during the different hours of the day 69
5.2.6.1.1.1 Punctuality during the different hours of the day in direction 1.........72
5.2.6.1.1.2 Punctuality during the different hours of the day in direction 2.........75
5.2.6.1.2 Punctuality during the rush-hours...78
5.2.6.1.2.1 Punctuality during the rush-hours in direction 1 80
5.2.6.1.2.2 Punctuality during the rush-hours in direction 2 82
5.2.6.2 Status 84
5.2.6.2.1 Status during the different hours of the day..84
5.2.6.2.2 Status during the rush hours 87
5.3 Discussion 88
5.3.1 Stop passage tram on line 1 88
5.3.1.1 Punctuality...88
5.3.1.2 Status 89
5.3.2 Stop passage on bus line 68 89
5.3.2.1 Punctuality...89
5.3.2.2 Status 89
5.4 Conclusions..89
5.4.1 Stop passage on tram line 1 89
5.4.2 Stop passage on bus line 68 90
6 High level Event: Route problems..91
6.1 Traffic light priority 91

6.1.1 Spatial analysis on aggregated vehicles on bus line 68 91
6.1.2 Spatial analysis on individual vehicles on bus line 68..93
6.1.3 Temporal analysis on aggregated vehicles on bus line 68....................................94
6.1.4 Temporal analysis on individual vehicles on bus line 68 94
6.1.5 Spatiotemporal analysis of aggregated vehicles on one line..................................95
6.1.6 Spatiotemporal analysis individual vehicles on one line 96
6.2 Possible stop locations 97
6.2.1 Spatial analysis on aggregated vehicles on tram line 1..97
6.2.1.1 Tram road crossings 97
6.2.1.2 Tram Traffic lights 98
6.2.1.3 Tram Stops 98
6.2.1.4 Aggregated stop locations (Crossings, traffic lights and stops) 98
6.2.2 Spatial analysis on individual vehicles on tram line 1 99
6.2.2.1 Road crossings...99
6.2.2.2 Traffic lights 99
6.2.2.3 Stops 100
6.2.2.4 Aggregated stop locations (Crossings, traffic lights and stops) 100
6.2.3 Temporal analysis on aggregated vehicles on tram line 1 101
6.2.3.1 Time of the day..101
6.2.3.2 Rush-hours...101
6.2.4 Temporal analysis on individual vehicles on tram line 1....................................101
6.2.4.2 Time of the day..101
6.2.4.2 Rush hours 103
6.3 Unexpected stops 104
6.4 Discussion 107
6.5 Conclusions 107
7 High level Event: Driving behavior and Passenger comfort 109
7.1 Spatial analysis of aggregated vehicles on one line 111
7.2 Spatial analysis individual vehicles on one line..111
7.3 Temporal analysis of aggregated vehicles on one line..113
7.4 Temporal analysis individual vehicles on one line 114
7.5 Discussion 119
7.6 Conclusions 120
8 Conclusions and further research 121
8.1 Conclusions 121
8.2 Further research...122
References 125
Wageningen University Thesis 126
Web References 126
Software & Tools 126
Appendix 1 Available Live! data.. I
Appendix 2 Transport lines IV
Appendix 3 Transport vehicles...V

List of terms

Tracking – Registration of object movements in space and time

Low level events - Observation of an objects position in space and time

High level events - Occurrence of “real world” phenomena in a movement context

Trajectory - Series of time-stamped position and orientation parameters

Trajectory nodes – Individual time-stamped locations on a trajectory (equal to a low level event)

Track – Connected sequence of trajectory nodes over time

Route – The path a vehicle travels to come from its start A to its end B

Segment – The path that connects two trajectory nodes

Line – Predefined route of a vehicles from start A to end B

Bus/tram stop – Scheduled stop on a line, where passengers can get on or leave a vehicle

HELMI – Project delivered a telematic tracking system of the Helsinki public transport

Mattersoft Live (previous WSP Live!) – Live operational implementation of HELMI

PRONTO – Research project on Event Recognition for Intelligent Resource Management

Abbreviations and Acronyms

FOI - Feature of Interest

GML - Geographiv Markup Language

HTTP - Hypertext Transfer Protocol

OGC - Open Geospatial Consortium (www.opengeospatial.org)

SOA - Service-oriented Architecture

SOS - Sensor Observation Service

SWE - Sensor Web Enablement

XML - eXtensible Markup Language

Summary

As a result of technical improvements in tracking technologies, location awareness of moving objects became more common fact. Objects are enabled with GPS and/or camera registration, for object motion. These objects can either freely move in space, or are restricted to a fixed network.

This study is part of the PRONTO project, which focus on Event Recognition for Intelligent Resource Management. WSP-Live! is the successor of HELMI, a technology driven project started in 1999, that implemented a telematic system (called Live!) for public transport tracking and management. movement measurements collected by the Live! system, are in this study defined as low level events, the most primitive registration of a location and a time.

In a case studies the low level events of vehicles of the Helsinki public transport are studied if these could be used to determine high level "real world" events. The vehicles are tracked during the first half of 2009. Three high level events are analyzed: punctuality, route problems and driving behavior and passenger comfort. Possibilities of the detection of these predefined high level events are studied by the detection of occurrences of low level events in the data supplied by the Live! system.

Results show that detection of low level events in trajectory data is possible, and that they can, to a certain degree, explain high level events. Punctuality in such is possible to be explained by the time of passing a stop together with the status of passage. Route problems can be largely explained by exclusion of expected stops made during a trip. Where expected stops can be at tram/bus stops, traffic lights and road intersections. Driving behavior and passenger comfort is in this study analyzed on basis of the low level events sharp turns in combination with a strong deceleration and/or high speed.

1. Introduction

During the last decade a rapid development of robust, real-time tracking techniques took place. The use of Global Navigation Satellite Systems, of which Global Positioning System (GPS) is the most common known, in consumer electronics, more and more objects (entities) can register their position in an outdoor environment. In the past, location data was mainly collected manually by Survey and Mapping agencies. Which was a specialized job, as the equipment was far from easy to be used.

Today location determining equipment ranges from individual devices like cell phones and cameras, but are also introduced in professional logistics of ships and vehicles which are part of complex navigation management systems for fleet control and traffic planning. Where NASA is the supplier of GPS, an inventory of these location aware applications is supplied at the NASA website [1].

Another large technological step forward is the fact that measured data becomes available in a fast and reliable way by means wireless or wired networks which are connected to the internet. Altogether these technologies made real-time automated surveillance and event recognition of moving objects possible (Johnson and Hogg, 1996).

1.1 Live!

As a spinoff from a project called HELMI [2], in 1999 a sophisticated telematic system was introduced in the Helsinki Public Transport. The system is a clear example of an implementations of the above introduced technologies to support several public transport services like real time passenger information, bus and tram priority at traffic signals and schedule monitoring. It is based on the wireless communication with radio modems.

Key in the telematic system is the location of the vehicles, which is determined in three different ways (see figure 1.1):

- GPS-satellite navigation measuring the tracks of the vehicles.
- sensors at the tram/bus stops that locate a vehicle's exact position along the route.
- The location of a vehicle along the route is based on an odometer counting the accurate distance of the vehicle from the preceding tram/bus stop.

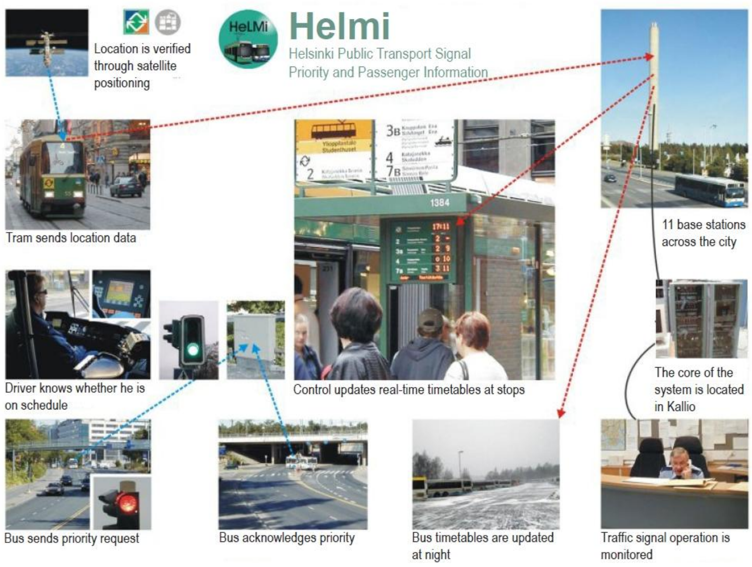


Figure 1.1: Implementation of the HELMI telematic system.

The observation of object positions in space and time are defined as a low level event. A low level event is the most primitive registration of location, together with a time-stamp. On basis of these low level events, several controls can be performed. In the Helsinki case, the schedule is permanently monitored, arrival and departure times are updated as real time passenger information at the tram/bus stops. As the successor of HELMI, the information is now implemented in a public transport tracking website [3] Live! (currently known as Mattersoft Live!) (see figure 1.2). Besides this public information, it also supplies vehicle information to the fleet manager.

Another feature in the Live! system is the Traffic Signal Priority request a vehicle can send when reaching a traffic light. In case a vehicle is behind on its original schedule, a message is send when the vehicle reaches a traffic light at a distance of 150-250 meter. The signal controller is called to get the green light. When the vehicle has passed the traffic light another signal, that the vehicle has passed, is send to the controller.

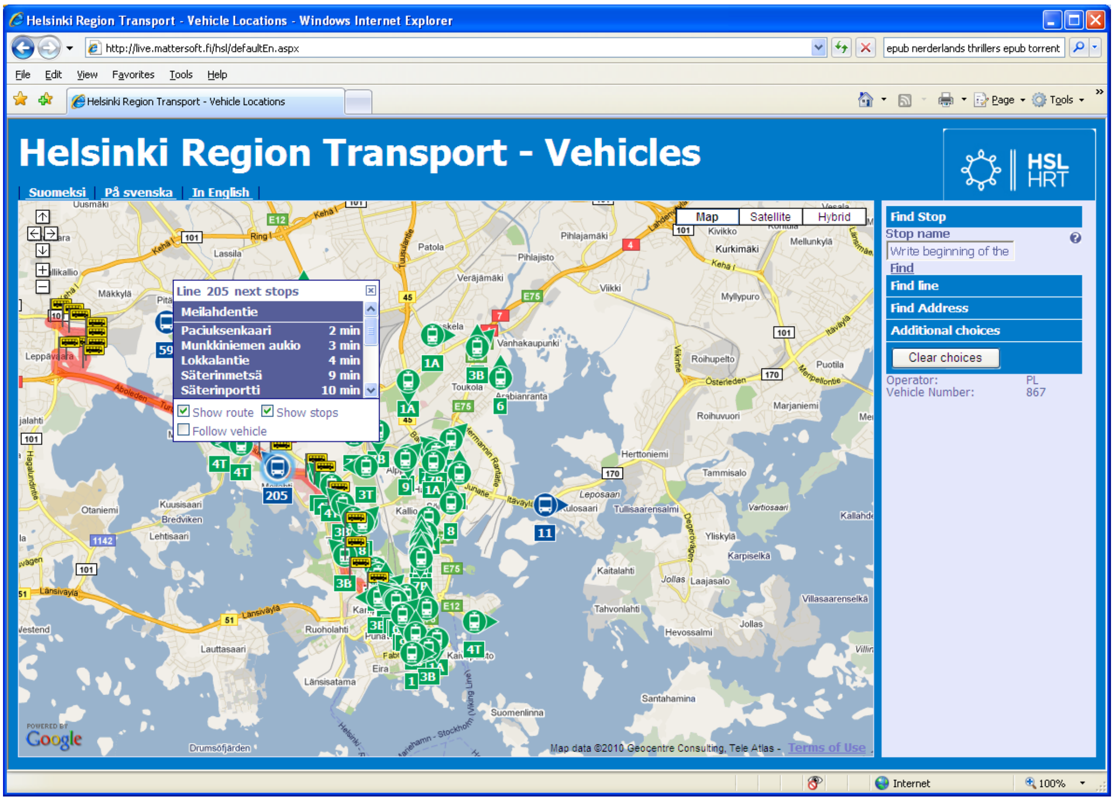


Figure 1.2: Real time Helsinki public transport vehicle tracking

1.2 PRONTO

As Live! is meanly the technical implementation of a registration system for low level events (observations in place and time). A following up the PRONTO project has been defined, where low level events will be used to determine a number of predefined "real world" high level events. These high level events will tried to be explained on basis of a series spatial-temporal explicit data driven low level events.

As such, the PRONTO project [4], is a research project financed by the European Community, with a focus on Event Recognition for Intelligent Resource Management.

PRONTO emphasizes the role of event recognition in intelligent resource management. The project proposes a methodology for fusing data from various sources, analyzing it to extract useful information in the form of events. The resulting knowledge will be delivered for *decision making, through a user-friendly intelligent resource management (IRM) service including a digital map interface (MAP)* [4].

One of the aims of the PRONTO project is to develop a sustainable framework for solving the difficult task of real-time, accurate recognition of high level events for resource management.

1.3 Objectives

In this study an evaluation of the Live! data, available from the real-time tracking application of Mattersoft [3], will be made. The evaluation will be performed to verify if the collected low level events of the Live! system can be used to explain the high level events as defined in the PRONTO project.

The following predefined high level events, as described in the PRONTO projects will be examined on basis of the collected low level events of busses and trams in a case study of the Helsinki public transport:

- Punctuality
- Route problems
- Driving behavior / Passenger comfort

It is assumed that the setup of Live! is representative for comparable public transport settings of tram and busses. To perform the evaluation of low level events for recognition of high level events in a public transport setup, the following research questions will be answered:

1. Can low level events of stop status and passage explain the high level event Punctuality?
2. Can low level events of expected and unexpected stops explain the high level event Route problems?
3. Can low level events sharp turn in combination with strong deceleration or high speed be used to explain the high level event Passenger comfort?

There is a systematic hierarchy in the predefined high level events. Punctuality is based on the time a vehicle passes a stop and the predefined schedule. Results of non-punctuality can be caused by Route problems, for example a stop can always been reached too late, as on the way before the stop there is a road intersection, traffic light, or other delaying events. As a result of non-punctual stop passage and route problems, a driver can change its driving behavior, by speeding up to reach a stop punctually on time. This could result in high speeds at places where a lower speed is preferred, and could result in strong decelerations at locations where a low speed is required.

Based on this systematic hierarchy, low level events occurring in the Live! data will be examined. Although the hierarchy is present in the event definition, non occurrence of one of the events will not automatically exclude the occurrence of other high level events.

The next chapter deals with the background and terminology on the subject, starting form possible measurements towards event detection. The methodology is describe in chapter 3. The results and conclusions will start with a brief exploration of the collected data in chapter 4. The defined research questions for the predefined high level events will be dealt with in separate chapters 5, 6, and 7. Some of the questions will be studied for both bus and tram vehicles, others will be limited to one of them. Chapter 8 describes the findings of this study, together with recommendations on further research.

2. Background

In the next part the available techniques of data capture and supply of moving objects are described. The last paragraph deals with the detection of event occurrences in the movements of objects. These movements can differ location and time.

2.1 Sensors

Since a few years the use of instruments that measure all kinds of phenomena is growing rapid. These measuring devices can be part of a closed system, like the inside climate control of large buildings, which measure dedicated parameters necessary to control the system. On the other hand, sensors can measure parameters for more general purposes, for example for reasons of environmental monitoring. For these purpose, several parameters can be measured at different locations, preferably in a large spatial coverage, so more reliable judgments can be made at locations without any measurements, based on interpolations of the measured locations.

Looking at the location aspect of a sensor, two different types can be determined. In the first case the sensor is placed at a fixed location, in the second, the sensor is attached objects that can freely move in space. The second group can next be split in sensors moving through a continuous physical space, and those that only can move through a structured physical space (e.g. road net works) (Andrienko et al., 2008).

2.2 Location and environment

A spatial sensor not only measures a phenomena in its surrounding, but is one that can also measure its position on earth. This location can be measured by different means, all with their specific advantages and disadvantages. The most common used techniques, are discussed below.

2.2.1 GPS

The first category is the Global Navigation Satellite Systems, of which the Global Positioning System (GPS) is the most known. To derive the position of a user, GPS makes use of 24 satellites of which the first was launched in 1978 (Leick, 1990), and became available free of charge in 1984. In 1993 all 24 satellites became successfully operational. GPS satellites circle the earth twice a day, transmitting low power radio signals to the earth. Using these signal information, the system calculates the time it takes for the signal to travel from the satellite to the earth. Using the time-difference, the distance of a satellite to the earth surface is known. When 3 or more satellites are "visible" to the GPS-receiver, the exact position of the GPS receiver can be triangulated. As the signal travels by line of sight, the signal cannot pass through solid objects, and should be visible by the GPS-receiver, which makes this technique only usable in an outdoor setting. The accuracy of 5 to 10 meters mainly depends on the number of satellites taken into account by the position calculation.

2.2.2 Network triangulation

Network based positioning like GSM, local radio-signal based networks, Wireless Local Area Networks (WLAN) or RFID (Kushki et al., 2010) can be used to locate a users position. Network based location makes use of triangulation of network-cells of which the device makes use (Sadoun and Al-Bayari, 2007). Triangulation is based on signal strength of the device to its surrounding ground based base stations. The accuracy is between 50 and 500 meters, and highly depends on the concentration of base station cells in the neighborhood of the device. Whereas the technology makes use of signal strength of its base stations, it can be both used indoor and outdoor.

On smart phones, currently GPS and Network triangulation are often combined, meaning when GPS position is not available the device switches to the less accurate positioning of network triangulation.

2.3 Sensor Networks

A sensor is a device that captures physical phenomena of its focused surrounding. The captured measurements will be converted into electrical signals that can be interpreted by the user. Sensor measurements of the same phenomenon at different locations can be included in a so called sensor web. The term sensor web was first introduced at the NASA/Jet Propulsion Laboratory (JPL) (Delin et al., 2005). A sensor web is a type of sensor network, in which the measurements of the sensors nodes can be combined using a communication network to directly transmit the collected data. So a sensor in a sensor network needs to contains two modules: (1) a transducer module that would interact with the environment to gather the desired data and (2) a communication module (Delin, 2002). In this sense, a networks of several sensors is very suitable for monitoring systems, like the environment, traffic and others.

Sensor networks can be build from a set of sensors with a fixed position, wireless mobile sensors that can theoretically freely move around in space, or from an orbital origin (Delin, 2002). As location is one of the key-features in a sensor network, for fixed sensors its location should only be measured ones at the time of installation. From that moment on, the position is known, and as it is a fixed sensor, it should not change. For wireless mobile sensors, the location should be measured permanent with each measurement done, as the sensor can freely move in space. So in the latter, besides the measured *phenomenon,* also the *position* of the sensor at a certain moment in *time* is registered.

An example of a dedicated large sensor networks is used in the setup of a mobile participatory sensing network, in which independent sensor are carried by everyday citizens on for example a cell phone(Burke et al., 2006). In a case study of (Paul et al., 2009), the independent environmental air quality sensors are placed at street sweeping vehicles. These vehicles supply their measurements direct to the network, where they can immediately be used in monitoring and tracing systems. Advantage of this form of sensing is the large spatial coverage of independent measurements, which could never be reached by institutional data collection

2.3.1 Sensor Web Enablement (SWE)

Recent developments in the field of sensor networks, involve the standardization of services for fixed and mobile sensors that both own a location component by their known position. The work of the Open Geospatial Consortium [5] on Sensor Web Enablement (SWE) describes the standard implementation of a framework for the supply and management of sensor based spatial data via the internet (Chu and Buyya, 2007). At the moment of writing, the SWE service model comprises of four services [6]:

- Sensor Observations Service (SOS) – a standard web service interface for requesting, filtering, and retrieving observations and sensor system information.
- Sensor Planning Service (SPS) – a standard web service interface for requesting user-driven acquisitions and observations, to (re-)calibrate a sensor or to task a sensor network.
- Sensor Alert Service (SAS) – a standard web service interface for publishing and subscribing to alerts from sensors.
- Sensor Event Service (SES) - an enhancement and the further development of the SAS.
- Web Notification Services (WNS) – a standard web service interface for asynchronous delivery of messages or alerts from any other web service.

The goal of OGC's Sensor Web Enablement (SWE) is to enable all types of Web and/or Internet-accessible sensors, instruments, and imaging devices to be accessible and, where applicable, controllable via the Web [7]. An example of transport control in a SWE environment is demonstrated at the Data Fusion Research Center, where an air traffic control is implemented in SWE. The mash-up [7] demonstrates the Processing Services and Service Chaining of the current locations of departure and arriving planes for given airports. In the next part, the two services most related to this study will be described.

2.3.1.1 SOS

As part of Sensor Web Enablement, the Sensor Observation Service provides an interface that makes archives of sensors and sensor data available in an interoperable web environment. The interface foresees in a primary requests to get the capabilities of the service. It makes it possible to retrieve (meta) information on the registered sensors and their observations, and to register new sensors that will deliver their observations to the service.

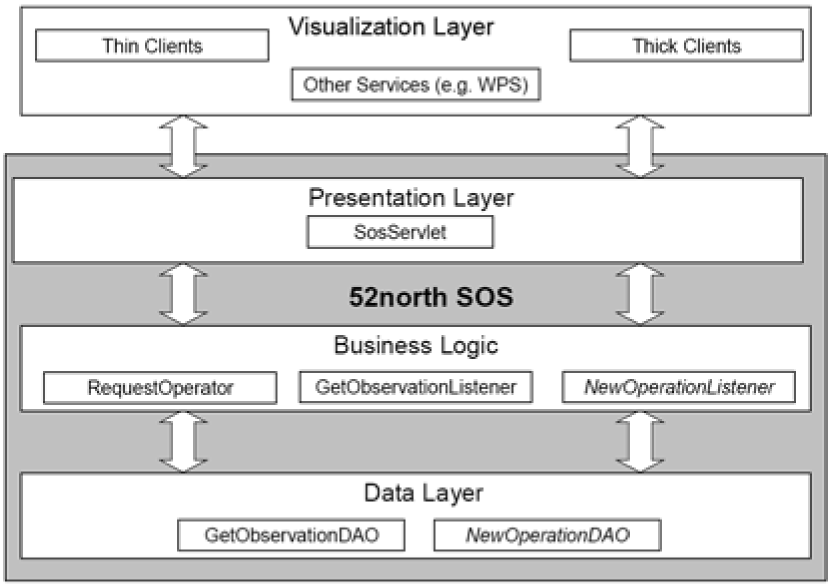


Figure 2.1: SOS interface implementation

2.3.1.2 SES

The Sensor Event Service provides an interface to filter sensor information, it allows a user to send filter request to determine events occurring in a senor web environments. The service can send notifications in response on a request. Tree filtering levels are defined, each allowing more complex filtering:

- Level 1: Filters based on the syntax of the incoming observations allowing definition of filters to only receive data from certain phenomenon.
- Level 2: Uses Event Pattern Markup Language (EML) for filters definition, it allows combination of logical, spatial, temporal, arithmetic and comparison operators.
- Level 3: Based on EML and uses Complex Event Processing (CEP). In contrast to level 1 and level 2 filtering level 3 can handle queries on data streams. They do not only operate on one incoming notification at a time but on series of events arriving at the SES.

2.3.1.3 Complex Event Processing

Complex Event Processing (CEP) studies the relations between multiple events (Luckham, 2008). It is use to derive higher level information. Complex events can be based on spatial, temporal, causal or any other type of relation that can be applied to events. These event represent objects describing a complex real world phenomenon that consists of multiple sub-phenomenon.

2.4 Object motion (tracking)

As positions of moving objects became available by location sensors, possibilities to study movements in space and time were growing rapid. Object motion tracking is originating from a large range research disciplines using different kinds of sensing techniques, (Bashir et al., 2006) mentions tracking results from video trackers, sign language data measurements gathered from wired glove interfaces fitted with sensors, Global Positioning System (GPS) coordinates on smart phones, cars using Car Navigation Systems (CNS), animal mobility experiments, etc.

2.4.1 Camera registration

Camera registration uses a video camera as a movement sensor. It is often used to analyze movements in a small space. Examples are the study of (Howarth and Buxton, 1992), who analyzed the traffic movements on a German roundabout and (Mohnhaupt, 1991) studied logic-based reasoning, together with analogical representation in the form of spatiotemporal buffers of traffic and pedestrian movements. All studies principally use the same technique, which is based on the determination of differences in the image registration. For the analysis fixed objects can be defined, in case the object is crossed by another object, a move is detected. Movement categories are defined on irregularities in differences in the image over time.

2.4.2 GPS trajectories

Trajectories are series of time-stamped position and orientation parameters, they are often collected using a GPS as location sensor. Trajectories consists of a series of time-stamped position and orientation parameters. They describe the travel history of individual moving object (Andrae, 2005). Trajectories are complex objects which behavior over time and space can be captured as a sequence of interesting events. These complex moving objects cover a wide range of movements like human movements (GonzÃ¡lez et al., 2008), animals (Calenge et al., 2009) and vehicle tracking (Kane et al., 2008)

2.4.3 Movement analyses

Analyses of movements obvious start by visualizing their position in space and time(Andrienko et al., 2008). One of the first known visualization of movements is the well known representation of Napoleon’s Russian Campaign of 1812, as produced by Charles Joseph Minard in 1861. The map is one of the first that describes movement as a combination of space, time and its surrounding. (HÃ¤gerstrand, 1970) introduced a three dimensional representation of movements in space and time in a so called space-time-cube.

2.5 Events definition

Events are interesting occurrences in a time varying scene, bounded to a certain spatial extend and time-interval (Neumann and Novak, 1983). Events are particularly important pieces of knowledge, as they represent the temporal nature of the processes taking place in an organization. Therefore, the recognition of events is of outmost importance in resource management [1].

(Kane et al., 2008) proposes visualization tools to help spatial-temporal queries to answer event occurrences. (Schmid et al., 2009) explains the determination of events along a vehicle trajectory. They recognize events like origin, destination, street intersections and public transport stops. A series of successive events are defined as spatial chunks.

Based on camera registration, (Mohnhaupt, 1991) describes events as a hierarchy ranging from primitive events, with the most general event: "exists", to increasingly complex events. In this study nineteen primitive object motions (events) like 'turn off', 'overtake' and 'walk' events are determined, several of these primitive events can together form complex events.

2.5.1 Low level events

Spatiotemporal low level events can be defined as occurrences in space and time (Andrienko et al., 2008) that can be distinguished in a large set of continues "virtual" measurements of phenomena. This definition clearly covers the scope of low level events, which are defined as all observations of an objects position in space and time, together with is derived variables like speed, acceleration etc.

As events differ at certain locations, (Howarth and Buxton, 1992)first define the region in which an object currently moves (objects can freely move in space or are restricted to a network). Depending on this region or zone, certain events can be determined. As an example the movement of a person in a house is given. Activities done in a kitchen are most likely different from those done in a sitting room. Depending in which region an object is, different occurring events can be detected. In this way the number of searches, to detect certain events, are reduced. So the extent in which an event takes place is the spatial boundary for the search.

(Andrienko et al., 2008) mentions several movement characteristics like time, position, direction and speed which are described as low level events. Besides the characteristic itself, changes in direction and speed can be determined, as well as accumulated time and distance can be derived. Besides examining single trajectories, comparisons of trajectories can be made. They could be examined on equality, order distance and topological relations.

As described, low level events are events that take place at a certain moment in space and time. It is restricted by a spatial boundary, and time constrained. This means when low level events should be detected, spatial boundaries should be defined, and temporal differences should be examined.

2.5.2 High level events

High level or complex events are occurrences of "real world" phenomena. Within the scope of this study they the term high level evens will be used. High level events can be derived from a series of these low level events (Mohnhaupt, 1991). They can occur at a certain place or at a certain moment in time, depending on the measurements taken at the object itself, and on measures taken at objects in its close surrounding.

2.5.3 TSO framework

From the previous event descriptions, it becomes clear that space and time are crucial in movement analysis. One of the basics of spatial analysis is described by Tobler's First Law of Spatial Analysis: "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). Which means when analyzing *trajectories* to determine spatial and temporal *events*, this should be done at different distances and time intervals. Locations closer to each other have a stronger relation with each other than locations further away.

The Time-Space and Object framework has it's origin in the field of Time-Geography, a science field first studied by the Swedish geographer Hägerstrand. It studies the spatial temporal factor of human activities. (Peuquet, 1994) introduces the TRIAD framework to study space-time and objects, that explains real world phenomena the high level events (what) on basis of low level events (where and when).

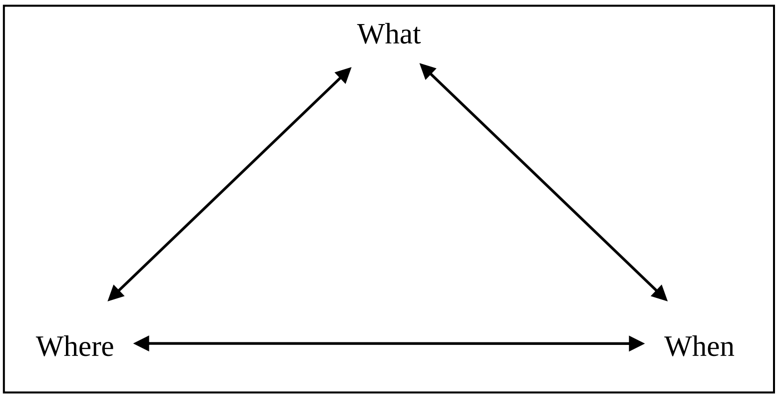


Figure 2.2: The basic components of the TRIAD framework.

Following the TRIAD framework the next categories can be determined:

- Spatial analysis of aggregated phenomena
- Spatial analysis of individual phenomena
- Temporal analysis of aggregated phenomena
- Temporal analysis of individual phenomena
- Spatial temporal analysis of aggregated phenomena
- Spatial temporal analysis of individual phenomena

2.5.4 Deterministic vs. Analytical

Several studies have been done to analyze event occurrences in trajectories. Far often, trajectories derived from camera registrations were used as a source. But in principle same methods can be used for both camera oriented as GPS oriented measures. As for both measurements, the analytics are performed on the derived trajectories.

A known case study of camera registrations of sport events are used for analysis. (Rea et al., 2004) investigated the retrieval of semantic events that occur during the broadcast of a snooker game. A color filter used to determine the different balls in the game. When the white ball is played, the position of this ball is used to determine the high level semantics of events that occur during the movement. When the white ball hits one of the other balls in the game, a separated new track is initiated, resulting in a low level pot or foul event. This result will accomplish the event in progress. On basis of this analysis, six high level semantics (plays) are distinguished. (Bashir et al., 2006) developed activity recognition algorithms based on statistical techniques to classify trajectories in types of activities. Based on these statistical methods, trajectories are segmented in different classes/activities.

2.6 Concluding remarks

Movements can be studied using different capture techniques for individual or aggregated objects, with different time settings. Data can be supplied in a standardized way, using a SWE architecture.

3. Methodology

As explained in chapter 2 background, events can be from different types: The first are low level events, that are easily traceable as they are the most elementary registration of an objects place and time. The second type are high level events, which are the result of a combination, or sequences of low level events.

In this study, the case of the Helsinki public transport is used, using the recorded low level events of the Live! telematic system. The implementation of low level event registration can be seen as a generic process, as only position and time are to be registered. For this reason it is valid to analyze possible occurrence of high level events by determination of sequences of low level events based on a this case study. Low level events (a vehicles location at a given time), are used to determine high level events as formulated in the PRONTO project.

In this study the analysis will focus on the visual analysis of events occurrences (Kane et al., 2008). For the three high level events low level events and derived parameters will be determined. The data of the case study will be used to analyzed if the defined low level events supplied by the Live! system can consistently be determined, and if they can explain the occurrence of the predefined high level events.

For reasons of possible real-time recognition of high level events on basis of low level events, a brief exploration of the use of a sensor web implementation (SWE) will be performed.

Assumptions:
The following assumptions are made on the definition of high level events:

Punctuality means that a vehicle is exactly on time at a stop as it was planned to be in the fixed predefined time-schedule. Non punctual arrival are vehicles which are to early or to late at a stop. Within the scope of this study, a punctual arrival is defined as being on time within an range of one minute from the actual schedule. It can also occur that vehicles do not stop at a stop at all, but are just passing the stop, as no passengers are to be left or enter the vehicle.

Route problems can be determined at places where vehicles stop during their travel. Stops can be expected, such as at tram- and bus stops, but can also be incidental stops at road intersections, and traffic lights. Stops that do not belong to the previously mentioned categories, are defined as being route problems.

Passenger comfort and *driving behavior* are strongly related. Reduced passenger comfort is defined at locations where irregularities in a route occur (e.g. turns). A combination with the driving style (e.g. strong deceleration/acceleration or a high speed), can be experienced as reduced passenger comfort.

All analysis will be performed in a hierarchical sequence using a Time-Space and Object framework (TRIAD):

- Spatial analysis of aggregated objects
- Spatial analysis of individual objects
- Temporal analyses of aggregated objects
- Temporal analysis of individual objects
- Spatial temporal analysis of aggregated objects
- Spatial temporal analysis of individual objects

3.1 Case study

3.1.1 Trajectory data

For this study, transportation trajectories of the Helsinki public transport, collected for a long period of time are used. The provided project data covers a time span of the first half year of 2009, during which trams and busses were tracked. The logs contain registrations of 52 trams on 12 fixed lines (see figure 3.1) and 15 busses on 37 lines (see figure 3.1 and appendix 2).

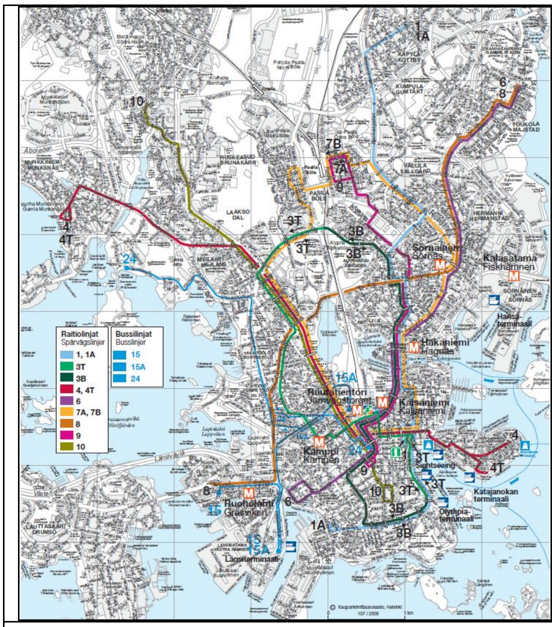
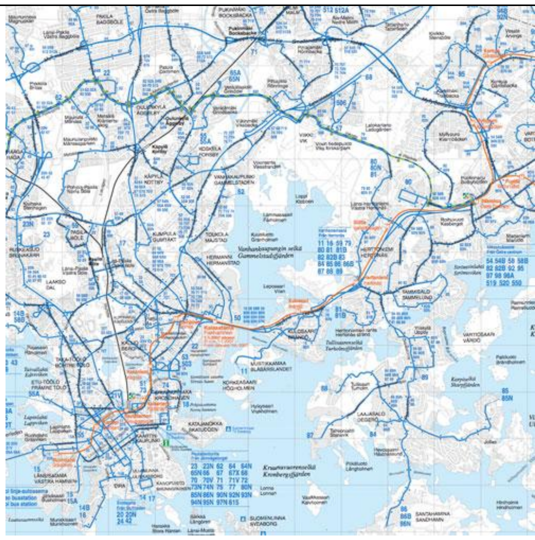
	
Helsinki tram lines	**Helsinki bus lines**

Figure3.1: Helsinki tram and bus lines

From these collected vehicle locations, trajectories can be derived, as a trajectory is defined as a predefined fixed route that the public transport vehicle passes to come from the start (A) of its route (where start time and distance to the start point are 0) to the end of the route (B). This definition limits the time constrain of a trajectory to the time it takes to come from (A) to (B). Trajectories on the same route but with a reversed start and end (from A to B and from B to A) are treated as being the same trajectories, and will also be dealt with separately (by means of direction).

In the analyses, the two kinds of vehicles are tracked. Busses and trams, will be Handled separately, as trams can only follow a fixed route along their track, whereas busses could leave there route following different roads available along the road network.

For the tram trajectories, twelve fixed lines are present, and can be identified by a line code together with a vehicle identifier for the tram that is serving. Besides the measurement of the vehicles position, derived parameters on acceleration, bearing and distance from its starting point are registered. All these parameters are determined on basis of low level event collected by GPS registration. Besides these dynamic measures, also time of departure and direction are available, obvious these should not differ during one single trajectory.

In the analyses, only vehicles were a line code is known are selected. Those with a lacking line code are excluded, as these can be registered tracks that were made when an object moved to reach the start of its route (e.g. from the tram garage).
Trajectories are limited to the registrations where a distance from the start is given. This excludes the recordings when an object is waiting at the start (e.g. to start its route at the scheduled start time) or the end of a line. So the trajectory starts at the moment an object

starts to move on its route. This will also exclude cases in which the driver has switched on the registration system, while still not driving on its route.

Trajectories collected on busses contain daily records low level events of the time-stamped bus locations, together with measurements on acceleration and distance from the starting point of a route the vehicle travels. Busses follow a fixed scheduled route. A routes can be identified by line code. The same as for the tram lines, busses with a missing route are left aside in the analysis.

In scope of this study, we select one tram and one bus line to be analyzed. For the tram line, line 1 with a total length of 13900 meters and 41 scheduled tram stops is selected, the route has an estimated travel time of 30 minutes [9a]. For busses line 68 with a length of 13400 meters and an estimated travel time of 35 minutes is selected [9b]. This bus line passes along 32 scheduled bus stops. Both lines are chosen as they pass through the city center of Helsinki. The bus-line has one start/end in the city center, and the other start/end out of the city boundaries.

3.1.2 Stops data

Each moment a vehicle is passing a stop on its line, several parameters together with a timestamp, the vehicle identifier and route code are collected. Every stop has a unique stop code. In combination with the timestamp and vehicle identifier, each stop registration can unique be identified, which makes it possible to link a location to the stops based on the trajectory datasets. Besides these identifiers, the status of the vehicle is registered, which gives information on the vehicle's location regarding to stops (e.g. entering a stop, or leaving a stop or just passing a stop without stopping). Also the time difference from timetable is registered.

3.1.3 Traffic light priority data

Vehicles back on their schedule send an priority request when reaching a traffic light. For these requests a timestamps together with an identifier for the junction, the traffic light number of that junction and the departure time of the vehicle are stored. Combining the time stamp and the vehicle identifier to the trajectories dataset, the exact location of a traffic light request at a certain moment in time can be retrieved.

3.1.3 Reference data

Locations of collected trajectory data depends on the accuracy of the measurement devices, which is currently around 5 to 10 meter. To link these measurements to the real road and tram network, exact locations of these lines should be known in advance. A reference for these data to track the locations of tram lines, roads, tram- and bus stops, are taken from the OpenStreetMap [8] project. OpenStreetMap is a project, that creates and provides free geographic data such as street maps to anyone who wants them. Data are collected by voluntary data collectors, and brought together in a widely covered dataset including roads, point objects and several other features.

The study on trams uses available tram lines, which contain detailed locations of the rail (where applicable) in both directions, tram stops, intersections and locations of traffic lights.

For busses, the reference data of the OpenStreetMap is used to locate and analyze the collected trajectory data of busses. Together with the bus line data, bus stops, road intersections, traffic light locations can be retrieved from the OpenStreetMap dataset.

3.2 Data preparation

Data collected by the Live! system on locations of the Helsinki public transport vehicles are supplied as ASCII format containing the daily GPS logs of the transportation vehicles. Per vehicle, the position, line number, direction, and its status (including derived parameters on acceleration, distance from the start point and bearing) are stored in separate files. The time interval of the measurements is one second. Trams or Busses can be identified by a vehicle code.

Besides the status of a vehicle, stop passages, tracking status, off route distance and traffic light priority are collected.
These registrations can all be linked to the status files containing the location of a vehicle using the timestamp in combination with the vehicle identifier.

For the analysis of the trajectories, all data are aggregated in a large dataset containing all the individual trajectory nodes (low level events) collected during the first half year of 2009. To be able to perform analysis on turn angles, and speed, the trajectory points are converted into line segments, that connect the trajectory nodes over time into a continuous track. From these tracks the turn angle and speed can be derived.

The imported trajectories will be analyzed in a GIS environment, as measurements are done by GPS, the measured location can differ from the exact location, with a difference depending on the equipments accuracy, which is currently around 5-10 meters. Another factor that plays an important role in the accuracy is the surrounding of the vehicle. In high density buildup areas, the accuracy will be far less then in open space.

As the data should be easily reusable within the PRONTO project, it is preferred to use as much as possible open source tools and databases. For this reason PostgreSQL [a] is chosen as the storage platform, a database that can store spatial information, which can next be represented using the open source geographical information system QuantumGIS [b]. Data is converted from the ASCII files into a PostgreSQL database using the GDAL/OGR [c] library. For analysis where metric measures need to be done, the data is re-projected to a metric projection in UTM using zone 34 North, the zone that covers the city of Helsinki. Visualizations are made in ArcGIS [d].

OpenStreetMap data is available in different export formats. Not all of these export formats include all the available data. For this reason, it is chosen to use the raw OpenStreetMap XML export format, to ensure the latest data of all available layers is included.

From the OpenStreetMap XML file, the layers needed for the study are selected. This resulted in a layers with information on:

- tram/bus lines
- tram/bus stops
- roads and their intersections
- traffic lights

OpenStreetMap selections can be made using the different relations that are available within the OpenStreetMap database. A line segment has for example a relation with a tram- or bus line on basis of a unique identifier. Using these relations identifiers, selections can be made to retrieve all the objects belonging to the related element:

Below, an example is given that will retrieve the data for bus line 68, which has a unique relation identifier of 70409. By specifying a full data retrieval is requested, all line segments that are part of the relation will be retrieved. The data will be returned in the OpenStreetMap XML format, which can be used in Quantum GIS.

http://api.OpenStreetMap .org/api/0.6/relation/70409/full

Figure 3.2: Example of a relational data request using the OpenStreetMap API

Traffic lights are stored as nodes, belonging to a line segment. As they are stored as part of a line segments, they are not treated the same as individual points elements. So, they should be retrieved from the raw OpenStreetMap XML format, where lines are build from a sequence of nodes.

For this study only those traffic lights which are on tram/bus lines are of importance. Which means they can be retrieved from the datasets that belong to the relation of the tram line 1 and bus line 68.

3.2.1 Derived low level events

Low level events are defined as the most primitive observations of locations and time. From these events, other low level event parameters like speed and acceleration can be derived.

Trajectories are converted to line segments, that connect trajectory nodes over time into a continuous track. Over these segments the length, duration, speed and bearing are calculated.
Speed can be described in two different ways, the first is the actual speed in meters per second. The second is based on the acceleration or deceleration and describes the state of the vehicle, determining three possible different states: speeding-up, slowing-down and steady state. The speed of the line is generated over complete trajectories, to determine regular locations where a common speed is met.

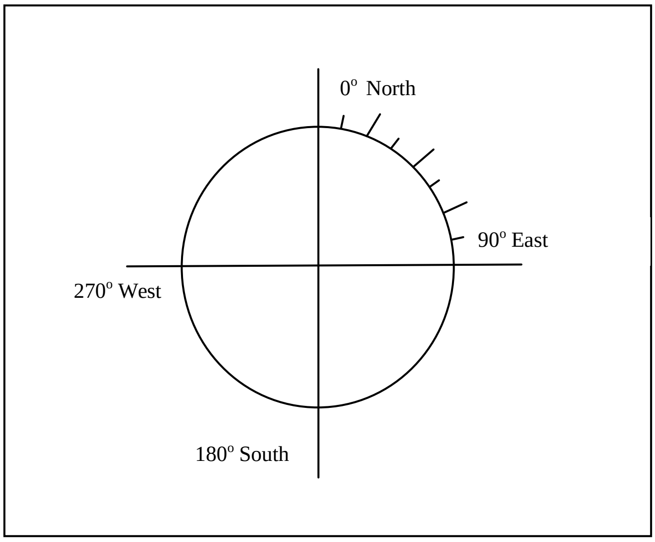


Figure 3.1: Determination of segment directions

Beside speed, the direction of a line segment is determined. The direction describes the angle starting from north (0°) to south (180 °) and returning back to north (360 °).
From these moving directions of the vehicles, turn angles can be calculated, where a turn describes the difference in direction of two line segments.

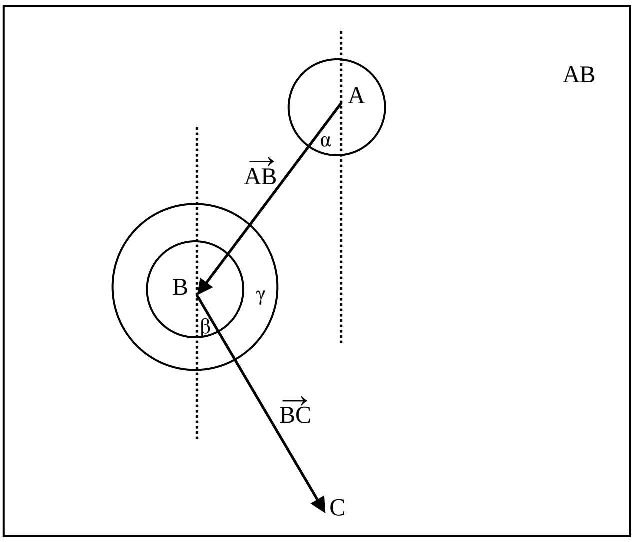


Figure 3.2: Determination of turn angles

From these parameters, different low level events will be derived, on basis of speed, an abrupt acceleration, and abrupt deceleration can be determined. Using the angles α and β of the line segments (AB and BC), it is possible to determine locations where sharp turns (angle γ) occur. A sharp turn is described as a turn which smaller than 135 degrees (which is chosen arbitrary).

3.3 Data exploration

The analysis starts with an exploration of the available collected Live! data. This exploration is done determining outliers, based on duration and length of a trajectory. Individual trajectories and tram/bus stops are explored.

3.3.1 Explorative trajectory analysis

To be able to determine low level events in the available trajectories, they are first analyzed on similarities and irregularities. This is done by comparing the trajectories of selected public transport lines for the two different vehicle types (tram line number 1 and bus line 68) on several characteristic parameters like length and travel duration. Trajectory length and duration can be calculated from UTM34N re-projected trajectory data in the PostgreSQL spatial database. Also the number of vehicles that were used on a line using the first half of 2009 can be derived.

Trajectories that differ from the average are analyzed visually, plotting a space-time-cube. This represents the movements in a 3 dimensional plot, where the x and y axes present the movement in space, and the z axis contains the difference in time.

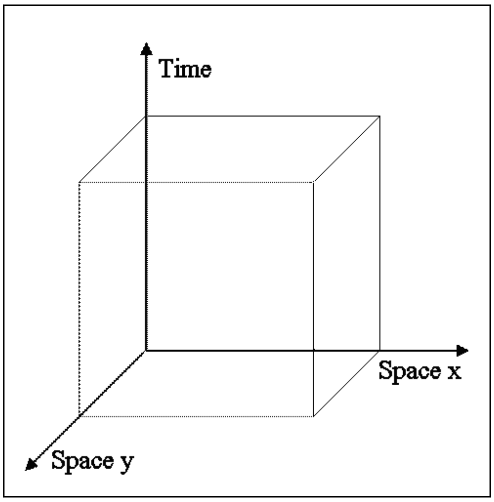


Figure 3.2: Time-space-cube

3.3.2 Explorative stop analysis

Stops can be of two different origins, those that are planned/fixed like tram- and bus stops, and those which are incidents like traffic lights or road crossings.

Recorded information on stops are linked to the locations of the trajectories. The stop information can be determined in the trajectories on basis of the date/time stamp together with the vehicle identifier. In this way for each registered stop of a vehicle, the exact location and time of passing the stop is known. As the positions of the stops are based on GPS measurements, they will obviously differ from the "real world" position, forming clustered point clouds around a stop. The central point feature of these point clouds around the stops will be calculated, and compared with the locations of the stops available in the OpenStreetMap sources dataset. As for the spatial analysis one position for each stop along a line is needed, it is decided that when the average positions (on basis of calculated central features) of the recorded data matches with the stop positions in the OpenStreetMap locations, the OpenStreetMap locations will be used for these spatial analysis. In case they don not match, the calculated central point features will be used.

The locations of traffic lights priority requests are compared with the locations of traffic lights in the OpenStreetMap source dataset. The priority request belong to a certain junction in the route. These junctions are different for the traffic lights along a route.

3.4 Analyses of high level events

From the PRONTO project three predefined high level events are explored:

- Punctuality
- Route problems
- Driving behavior and passenger comfort

For these three high level events, low level events are determined that can explain the occurrence of the given high level event at a certain place and time. To be able to study the spatial and temporal components, it is chosen to perform all the analysis following a fixed scheme:

Table 3.1 Analysis scheme following the TRIAD framework

<table>
<tr><td>Aggregated vehicles</td><td rowspan="2">Space</td><td rowspan="3">Space-time</td></tr>
<tr><td>Individual vehicles</td></tr>
<tr><td>Aggregated vehicles</td><td>Time</td></tr>
</table>

Individual vehicles		

A Spatial analysis of aggregated vehicles, which are all vehicles that were used on the line during the first half of 2009, will be carried out. In the next phase a distinction to the individual vehicles that were used during the first half of 2009 on the line to be studied is made.

The same study is done for the temporal component, by splitting the day in four different compartments: Morning (6:00 - 11:59), Afternoon (12:00 – 17:59), Evening (18:00 – 23:59) and Night (0:00 – 5:59). Also the day will be split in two possible different transport pressure settings: within the rush-hours, during from 8:00-9:30 in the morning and 17:00-18:30 in the evening [12] and the hours out of the rush-hours.

In the last phase a combination of the spatial and temporal components (space-time) are studied, again for aggregated and for individual vehicles.

In the next part the methodology for each predefined high level event will be explained.

3.5 High level Event: Punctuality

Punctuality is analyzed on basis low level events (recorded of the movements) on stops registrations that are available for vehicles on the Helsinki tram- and bus-lines.

The collected stop data contains information on the status of passing a stop, and on time difference from the schedule. Both parameters are used in the analysis.

The analysis will be performed for tram line 1 and bus line 68 and follows the Time-Space and Object framework that is distilled from the components of the TRIAD framework:

- Spatial analysis of aggregated vehicles on one line
- Spatial analysis individual vehicles on one line
- Temporal analysis of aggregated vehicles on one line
- Temporal analysis individual vehicles on one line
- Spatial temporal analysis of aggregated vehicles on one line
- Spatial temporal analysis individual vehicles on one line

3.5.1 Spatial analysis of aggregated vehicles on one line

Stops will be analyzed on spatial similarities. For every stop along a line, parameters on the status of the vehicle passing a stop (entering a stop, leaving a stop, or just passing a stop) will be derived.

Besides the stop status, the stops can be analyzed on punctuality, as a time difference from the original schedule is registered with every stop passage. These measurements are classified in three categories: passed too early, punctual on time, or too late. A punctual passage is being defined as a passage between one minute early, and one minute late (-60 seconds, +60 seconds). The analysis will be performed using the registered stops of all vehicles.

The same analysis will be done taking the direction in which the vehicle passed the line into account. Within the dataset a driving direction 1 and 2 are defined.

Differences will be analyzed visually on basis of the spatial distribution op the stop passages along the line.

3.5.2 Spatial analysis individual vehicles on one line

Once the aggregated stops information of the line are subtracted for all vehicles that were used during the first half of 2009, the analysis is continued among the different vehicles, to find differences and similarities for vehicles.

Vehicle information is available in the trajectory data. By selecting the stop information of the individual vehicles from the trajectories, it is exactly known at which time and by which vehicle the stop was passed.

The differences in stop status, and stop passage will be compared visually, to find if there is a relation between the vehicle and the stop parameters.

3.5.3 Temporal analysis of aggregated vehicles on one line

Once the spatial variability and similarities are known, the stop parameters can be analyzed on temporal components. For this reason the day is split into four compartments: Morning (6:00 - 11:59), Afternoon (12:00 – 17:59) Evening (18:00 – 23:59) and Night (0:00 – 5:59). After analyzing the differences and similarities of punctuality and stop passage during the different periods of the day, the heavy traffic periods of the day will be included. In Helsinki the rush-hours last from 8:00-9:30 in the morning and 17:00-18:30 in the evening [12]. These will be grouped as one, to find if there is a difference between tracks travelled during the rush-hours and those made outside the rush-hours.

The stop passages are grouped into the above described time categories on basis of the departure time of a vehicle. This means that if a vehicle has a departure time starting at 11:55, all its stops made belonging to that trajectory are classified to the morning group. Those with a departure time of 9.25, all stops made during the complete trajectory are treated as being made in the rush hours.

3.5.4 Temporal analysis individual vehicles on one line

Depending on results of the previous visual analysis on punctuality and the number of vehicles that passed a stop without stopping (stop status), the same analysis will be performed on basis of individual vehicles, to determine if the found differences are influenced by the vehicle used.

3.5.5 Spatiotemporal analysis of aggregated vehicles on one line

A combination of spatial and temporal analysis on aggregated vehicles will be made to determine if there are difference in locations and the moment of the day, or if the stops were passed within and out of the rush-hours.

3.5.6 Spatiotemporal analysis individual vehicles on one line

Depending on results of the previous visual analysis on punctuality and status (the number of vehicles that passed a stop without stopping), the same analysis will be performed on basis of individual vehicles and time of the day (including rush-hours) a stop was passed.

3.6 High level Event: Route problems

Route problems can be determined on basis of stops made during a route. A stop is defined as a moment in time where the vehicle has a deceleration, resulting in a speed of zero.

Stops can be planned or unexpected. Planned stops are defined as stops made at the tram stop entries. Unexpected stops are stops that occur during a travel that can not be exactly planned in advance of the travel. Unexpected stops can be differentiated in stops that occur occasionally at given locations and those that occur completely random (e.g. accidents). Stops that occur occasionally at fixed locations can be selected as traffic light locations, and road crossings and tram stops from the OpenStreetMap source data. Randomly made stops can be determined based on the recorded trajectories, they are the places that are left after filtering the stops that occur at known locations.

A possible expected stop are traffic lights. In the Live! system, there is a possibility to influence the passage of these possible stops, by sending a traffic light priority request in case a vehicle is back on its schedule. As the request are closely related to the punctual passage of a vehicle, the explanation of route problems will start with the analysis of traffic light requests.

The further analysis will be done by the individual stop types, and continued with the aggregated stops (all possible stops made during a travel) for tram line 12. The stops that occur out of the fixed stop locations are analyzed in more detail, to find explaining factors for these stops.

3.6.1 Traffic light priority

A similar analysis to explain punctuality can be done on traffic light priority. Traffic light priority is given to vehicles that are back on their schedule. The analysis will only be performed for busses only. The registered traffic light priority request are stored as a paired request. The first opens the request, the second is closing it.

3.6.1.1 Spatial analysis of aggregated vehicles on one line

The analysis of traffic light requests is done on basis of the number of requests at certain junction along the route. The spatial distribution will be studied on difference in the request type (opening and closing the request) and if the difference in driving direction of the vehicle making the requests.

3.6.1.2 Spatial analysis individual vehicles on one line

Next the priority request are studied for the individual vehicles, to find if there is a difference in the spatial distribution of the priority requests that depends on the vehicles that were used on the line. The request will be plotted in spatially.

3.6.1.3 Temporal analysis of aggregated vehicles on one line

To find out if there is a temporal difference in the priority requests, the day will be divided into four different parts: Morning (6:00 - 11:59), Afternoon (12:00 – 17:59) Evening (18:00 – 23:59) and Night (0:00 – 5:59). The same will be done for request during (between 8:00-9:30 and 17:00-18:30) and outside the Helsinki rush-hours.

3.6.1.4 Temporal analysis individual vehicles on one line

If a difference is found in the temporal analysis, the same can be done for the individual vehicles used on the line.

3.6.1.5 Spatiotemporal analysis of aggregated vehicles on one line

A combined analysis on space and time is performed for all the aggregated vehicles that made a traffic light priority request on the line during the first half year of 2009.

3.6.1.6 Spatiotemporal analysis individual vehicles on one line

A combined analysis on space and time is performed for the individual vehicles that made a traffic light priority request on the line during the first half year of 2009.

3.6.2 Road intersections

Expected places where stops can occur are road intersections. Road intersections are place where the tram line is crossing another road. When a vehicle has a low speed at these locations, a route problem is counted.

Road intersections are selected from the OpenStreetMap source dataset. A distance of 30 meters around the road intersections is computed. Low speed occurrences in a distance of 30 meters from a road intersection are selected and counted. Locations with a high count of these occurrences are used to determine route problems. Low speed is being defined as a speed less than 0.1 m/s. Standing still can not be only defined as a 0.0 m/s movement, as the GPS signal of an object is still moving around its position, although the actual position does not change (see paragraph 3.2 Data Preparation).

3.6.3 Traffic lights

The same analysis as for road intersections is performed for traffic light locations. Traffic light locations are located at several places along the tram line. Occurrences of high deceleration, or low speed near these pedestrian crossings are counted. Locations with a high count are defined as a route problem.

Traffic lights are available in the OpenStreetMap source dataset. They are selected and the areas of interest, with a distance of 30 meters from a traffic lights are computed. These areas of interest are used to select low speed (less than 0.1 m/s) occurrences from the trajectory data. These occurrences are counted and compared.

3.6.4 Tram Stops

Tram stops are locations where a vehicle is expected to stop where passengers can enter or leave the vehicle. The locations of tram stops are selected from the OpenStreetMap. A 30 meter influence zone is created, to be able to gather all the trajectory nodes that were registered as a tram stop. All occurrence with a lower speed then 0.1 m/s are selected as a stop. The trajectory nodes will be counted as stops made at these locations.

3.6.5.1 Spatial analysis on aggregated vehicles on one line

The analysis of route problems is done based on the count of possible occurring stops. All low speed occurrences of all aggregated vehicles that were used on tram line 1 during the first half year of 2009 are taken into account. The possible stops are analyzed individual and as an aggregated group of possible stop locations (discussed in the three previous paragraphs).

3.6.5.2 Spatial analysis on individual vehicles on one line

The next analysis take all individual vehicles that were used during the first half of 2009 into account. Differences in the number of stops made by the vehicle are compared.

3.6.5.3 Temporal analysis of aggregated vehicles on one line

The possible stops of all the vehicles are analyzed on the moment of occurrence over the day. For this reason the day is separated into four compartments: Morning (6:00 - 11:59), Afternoon (12:00 – 17:59) Evening (18:00 – 23:59) and Night (0:00 – 5:59). The same will be done for stops made during (between 8:00-9:30 and 17:00-18:30) and outside the Helsinki rush-hours.

3.6.5.4 Temporal analysis individual vehicles on one line

Next, the possible stops are analyzed on the temporal aspects, as mentioned in paragraph 3.6.3 for the individual vehicles. Stops made by the individual vehicles during these time intervals are counted and compared.

3.7 High level Event: Driving behavior and Passenger comfort

Low level events that could explain driving behavior and passenger comfort are studied on bases of passage of sharp turns in combination with a high speed or a strong deceleration.

To analyze the high level event driving behavior and passenger comfort, on trams, sharp turns occurring in the “source track” are derived. For trams, the source of the track is taken as the lines are at fixed locations, and do not depend on the path the driver chooses.

The locations where sharp turns occur in the tram line are taken form the OpenStreetMap. Detection of sharp turns in the source data is first done visually, and next derived in the way as described in paragraph 3.2.1. As the source data is already build from a line structure, the line is split in segments of 5 meters, which approximates an average speed of a little less then 20 km/h. From these resulting line segments, direction and turn angles are calculated.

The chosen length of a line segment highly influences the number of sharp turn to be found. At a 5 meter distance, it is rather unlikely to determine a lot of sharp turns, as the travelled distance is rather short, on the other hand a lot of artifacts of objects that stand still are determined as sharp turns, as the GPS signal used to start jumping around the object. At a point distance of 100 meter, the occurrence of sharp turns could be more realistic, and artifacts will disappear. To determine the best segmentation interval, different intervals will be examined. This will be done by dividing the source data as taken from the OpenStreetMap in pieces of 5 meter (which is comparable with registering a GPS location every second at an average speed of 18 km/h) followed by 10, 25, 50, 100 meter segments.

The turns of the most appropriate segmentation are used to analyze the speed and (acceleration) deceleration. As the GPS recorded tracks do not exactly fit the original lines, it is chosen to explore the low level events of all registered measurements within a distance of 30 meters of the sharp turns.

A Combination of the described low level events (sharp turn, speed and acceleration) can be used as a measure for driving behavior and passenger comfort. For example a sharp turn in combination with a high speed will be experienced as a reduced passenger comfort.

3.7.1 Spatial analysis of aggregated vehicles on one line

The sharp turns are analyzed in more detail, first averaged for all vehicles that were used on tram line 1. The average speed of Helsinki trams is at given at 14.3 km/h (3.97 m/s) [10]. The analysis is selecting an speed of the vehicles of two standard deviations. These are combined with the determined sharp turns locations in the OpenStreetMap.

After, acceleration is divided in three categories: strong acceleration (smaller then -1.8), normal (between -1.8 and 1.8) and strong deceleration (larger than 1.8). At web sources emergency deceleration rates for comparable transportation are given between 1.8 and 3.0 m/s^2 [11]. Vehicles with a strong deceleration in the sharp turns are counted. Finally a combination of sharp turns with high speed and strong deceleration are determined.

3.7.2 Spatial analysis individual vehicles on one line

To see if there is a difference in driving behavior between the vehicles, the same analysis will be performed for the individual vehicles that were used on tram line 1 during the first half of 2009. This analysis is done using all the recorded trajectories of a vehicle on the tram line 1 during the first half of 2009. A difference in the number of times a vehicles is used during this half year is not made. Average deceleration and speed will be derived. Besides the averages, extremes will be analyzed.

3.7.3 Spatial temporal analysis of aggregated vehicles on one line

Next the analysis on sharp turns in combination with speed and deceleration is expanded with a time constrained. The day is split into four compartments: Morning, Afternoon, Evening and Night. After the determination of low level events speed and deceleration during the different hours of the day, the heavy traffic periods of the day will be included. The rush hours lasts in Helsinki from 8:00-9:30 in the morning and 17:00-18:30 in the evening. These will be grouped as one, to find if there is a difference between tracks travelled during the rush-hours and those made outside the rush-hours.

3.7.4 Spatial temporal analysis individual vehicles on one line

Depending on the number of vehicles that passed a sharp turn with a high speed, or with a strong deceleration, the registrations of the individual vehicles will be split in the same time classes, as mentioned above.

3.8 Concluding remarks

Each of the predefined high level events, will be explored on explaining factors occurring in recorded low level events of the Live! telematic system. Occurrences will be studied using the TRIAD framework introduced in the previous chapter. When differences can be found for the different individual vehicles, and for the different time intervals defined, the low level events will be accepted to be able to explain a high level event.

4 Data exploration

4.1 Implementation in SWE/SOS

The large amount of data collected on the Helsinki public transport, where traveling object are traced with a frequency of one measurement per second, is currently not stored in a standardized manner. This means for common use, a dedicated system needs to be implemented. Data used for analysis are first exported from the system into per vehicle and per day organized ASCII files. To be able to design a more generic system, possible implementation of data delivery in a SWE environment has been explored. In such an environment, each vehicle is treated as an individual sensor that delivers its time and location, together with several derived parameters like speed and acceleration. Besides these continues object specific measurements, there are a set of incidental measures, like stop passage and status, traffic light priority etc.

4.2 Trajectory exploration

To get a first impression on the trajectories, the collected trajectories of the first half of 2009 on the same public transport line (tram line number 1 and bus line 68) are compared on duration and length.

4.2.1 Tram line 1

Tram line 1 has two driving directions, the first in a south-north direction, with the start in the city centre of Helsinki, and ends in the north at Käpylä. The second direction goes from north to south. The line (see figure 4.1) has a total length of 13900 meters. The length is measured as a total along the line, which means, it is including in both directions. The line has a clear start and end, in the south, where trams can turn around a small square. In the north, the turn is situated as a small loop in the other (road) infrastructure.

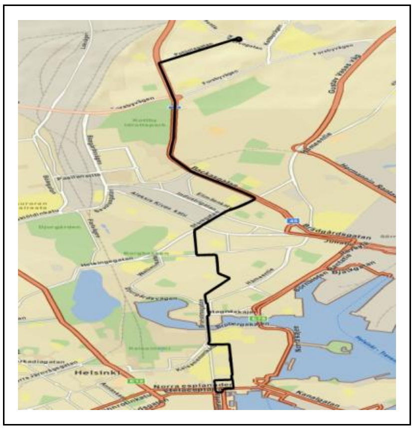


Figure 4.1: Location of tram line 1

During the first six month of 2009 there were 570 trajectories recorded on tram line 1. In this period 32 vehicles were counted on the line. The trajectories are build from 964,606 trajectory nodes. From these nodes 489,171 (50.7%) were in a south to north direction. The other 475,435 (49.3%) in a north to south direction. The minimum duration that was registered is 0 seconds, the maximum 41009 seconds (11 hours 23 minutes and 29 seconds). The average duration of the recorded trajectories on tram line 1 is 2225 seconds (≈37 minutes), with a median of 1784 seconds (≈30 minutes).

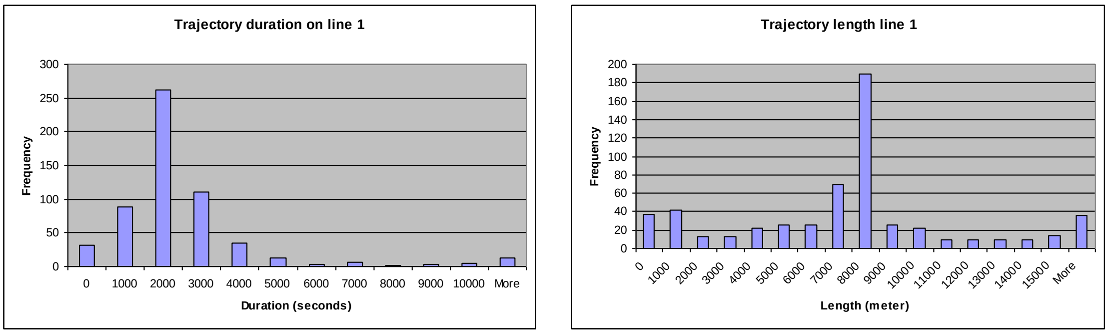


Figure 4.2: Trajectory duration and length on tram line 1

In figure 4.2 it can be observed that the distribution of the duration is clearly positive skewed (7.04), with σ=3073. The distribution of the trajectory length has a normal distribution, where σ=6588 and γ_1=4.01 For tram line 1 the extremes with a smaller duration then 6 hours and larger then 2 hours listed below.

Table 4.1: Extreme trajectory duration of vehicles recorded on tram line 1

TransID	Departure	StartTime	EndTime	SecDiff	TimeDiff	TrajLength
CEENG1074300168	1042	18-02-2009 10:42	18-02-2009 12:51	7773	02:09:33	15230.71
CEENG1074300246	1115	26-02-2009 13:02	26-02-2009 15:18	8175	02:16:15	9856.03
CEENG1074300248	939	25-03-2009 09:37	25-03-2009 11:56	8343	02:19:03	30872.23
CEENG1074300248	1458	08-01-2009 14:43	08-01-2009 17:08	8686	02:24:46	4090.66
CEENG1074300180	1404	22-01-2009 13:51	22-01-2009 16:24	9191	02:33:11	9272.70
CEENG1074300198	910	07-04-2009 06:46	07-04-2009 09:23	9409	02:36:49	10004.96
CEENG1074300168	939	12-01-2009 09:35	12-01-2009 12:13	9441	02:37:21	35795.35
CEENG1074300227	939	16-03-2009 09:35	16-03-2009 12:13	9450	02:37:30	35883.90
CEENG1074300248	939	16-04-2009 09:35	16-04-2009 12:15	9638	02:40:38	35765.82
CEENG1074300186	1218	02-01-2009 12:05	02-01-2009 15:07	10896	03:01:36	42140.90
CEENG1074300167	1320	12-03-2009 13:17	12-03-2009 16:21	11007	03:03:27	40074.98
CEENG1074300167	926	12-02-2009 09:26	12-02-2009 12:37	11508	03:11:48	13750.51
CEENG1074300168	951	02-01-2009 06:50	02-01-2009 10:19	12517	03:28:37	9070.65
CEENG1074300186	910	02-01-2009 08:24	02-01-2009 12:05	13286	03:41:26	47371.63
CEENG1074300227	926	31-03-2009 06:02	31-03-2009 09:49	13672	03:47:52	7591.36
CEENG1074300167	1320	24-02-2009 13:13	24-02-2009 17:01	13689	03:48:09	27261.59
CEENG1074300176	926	17-03-2009 08:57	17-03-2009 13:02	14665	04:04:25	21574.72
CEENG1074300225	951	26-05-2009 05:53	26-05-2009 10:00	14773	04:06:13	14603.72
CEENG1074300230	1136	25-02-2009 10:00	25-02-2009 14:15	15330	04:15:30	30459.34
CEENG1074300246	1042	26-02-2009 07:08	26-02-2009 12:42	20050	05:34:10	27264.03

From the extremes, it can be note, that there are several trajectory node registered far from the original tram line, and lots of registrations were made on the same location where the vehicle stand still for a longer period of time.

4.2.2 Bus line 68

Bus line 68 is situated in a south-west to north-east direction (see figure 4.3), with one of its start/ends in the city centre of Helsinki, and the other start/end located out of the city centre, near the Helsinki University Campus in Vikkii. The line is passed in two directions. The total length of the line is 13436 meters, which is measured in one direction.

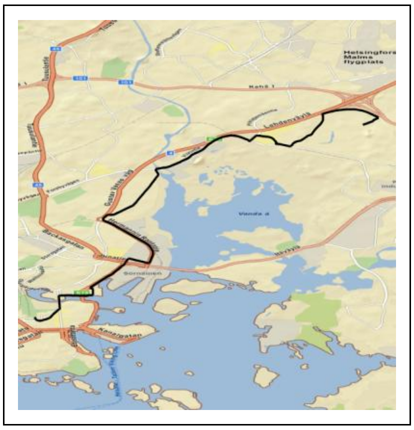


Figure 4.3: Location of bus line 68

On bus line 68 there were 9023 trajectories recorded during the first half of 2009. There were 17,553,564 trajectory nodes registered during this period. From these nodes 8,599,620 (49.0%) were in a south-west to north-east direction. The other 8,953,944 (51%) were travelled in a north-east to south west direction. The duration ranges from a minimum of 0 seconds to a maximum of 86399 seconds (23 hours 59 minutes and 59 seconds). The average trajectory duration that a vehicle travelled on line 68 is 3402 second (≈57 minutes), and the median is 2157 second (≈36 minutes).

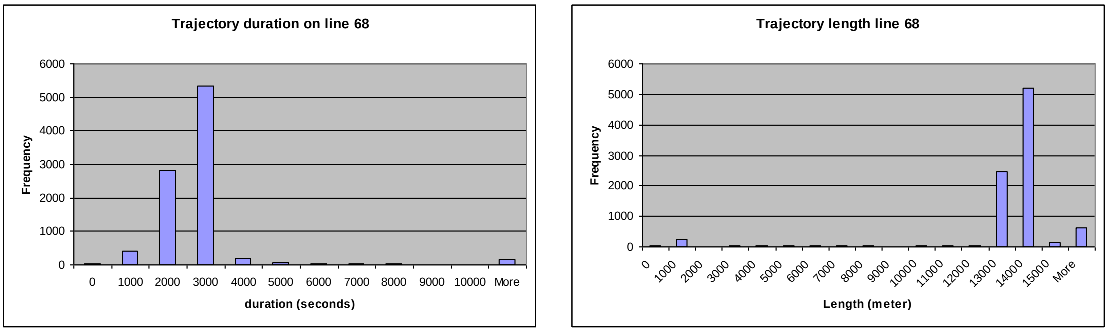


Figure 4.4: Trajectory duration and length on bus line 68

For bus line 68 the below listed extremes of trajectories with a smaller duration then 7 hours, and larger then 3 hours were studied in more detail.

Table 4.2: Extreme trajectory duration of vehicles recorded on bus line 68

TransID	Departure	StartTime	EndTime	SecDiff	TimeDiff	TrajLength
EFENG1061900267	20	04-03-2009 00:20	04-03-2009 03:22	10949	03:02:29	86766.05
EFENG1062200066	100	17-04-2009 00:47	17-04-2009 03:50	11006	03:03:26	76276.29
EFENG1061000067	528	03-01-2009 02:40	03-01-2009 05:52	11550	03:12:30	18675.03
EFENG1061900267	1034	11-03-2009 10:33	11-03-2009 13:47	11654	03:14:14	67771.92
EFENG1061000067	600	16-01-2009 03:13	16-01-2009 06:35	12123	03:22:03	18013.01
EFENG1061000067	600	17-04-2009 02:55	17-04-2009 06:24	12544	03:29:04	18125.92
EFENG1061900267	1034	17-03-2009 10:32	17-03-2009 14:27	14064	03:54:24	48274.69
EFENG1061000067	600	10-03-2009 02:42	10-03-2009 06:40	14226	03:57:06	18185.54
EFENG1061900267	1430	22-04-2009 14:26	22-04-2009 18:43	15372	04:16:12	74327.45
EFENG1061000067	1942	22-04-2009 19:39	22-04-2009 23:57	15471	04:17:51	406866.1
EFENG1061000067	45	29-01-2009 00:37	29-01-2009 05:24	17204	04:46:44	14344.48
EFENG1061000067	658	10-04-2009 02:23	10-04-2009 07:29	18359	05:05:59	18232.39
EFENG1061900267	750	09-05-2009 03:06	09-05-2009 08:16	18599	05:09:59	18210.6
EFENG1061900267	1110	29-01-2009 06:06	29-01-2009 12:29	23008	06:23:28	29015.63
EFENG1061000067	750	27-06-2009 01:51	27-06-2009 08:19	23265	06:27:45	18502.4

Similar to the tram trajectories, further exploration of the extremes in the bus trajectories, show that most of the long durations are due to the fact that the vehicles is registering its position, but does not move on its route. In most cases this occurs at the beginning of the route, they can be recognized as the distance to the start of the line is registered as 0. In the analysis of the events, these registrations will be left aside.

Some other trajectories follow a path out of the original route, e.g. a vehicle traveling to the garage. These also will be excluded from the continuing analysis by limiting the range of analyzed trajectory nodes to a 30 meter distance around the bus/tram line.

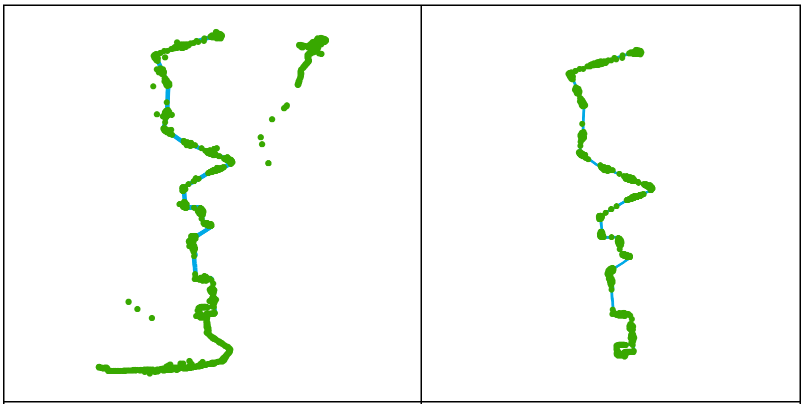
4.3 Stop exploration

4.3.1 Tram stops on tram line 1

As said before, tram line 1 is crossing the centre of Helsinki in a north-south and south-north direction. It has a total length of 13900 meters with 41 stops (figure 4.5) along its route. Stops are measured as a total along the line, which means, it is including stops of both directions.

Figure 4.5: Locations of tram stops along line 1

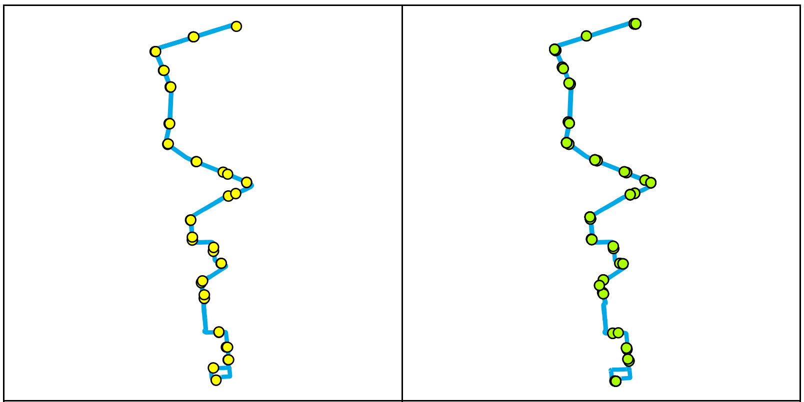
During the first six month of 2009, 20808 stops were recorded on tram line 1. As a lot of recordings clearly do not belong to tram line number 1 (figure 4.6a), a subset was defined on basis of a 30 meter maximum distance to the actual line (figure 4.6b). From all recorded stops, 18723 (90%) fall within the distance of 30 meters from the line.



a) All recorded stops	b) Selected stops within 30m of the line

Figure 4.6: Recorded stops on line tram 1

The central point of the recorded stops along line 1 (figure 4.7b) are calculated and compared with the stop locations in the OpenStreetMap source dataset (figure 4.7a).



a) Original locations of tram stops	b) Central points of the recorded stops

Figure 4.7: Stop locations on tram line 1

From all the calculated central features, 79.8% are within a distance of 30 meter from the original OpenStreetMap stop locations.

4.3.2 Bus stops on bus line 68

Bus line 68 has its start/end in the centre of Helsinki and leaving the city in a north eastern direction, with a total length of 13436 meters and 33 stops (see figure 4.8) along its route. The line is passed in two directions. The stops are located on the line as intersections of the road, stops are used in both directions.

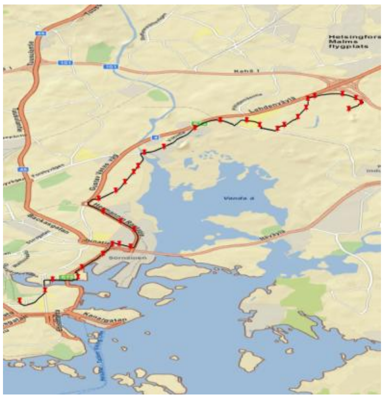
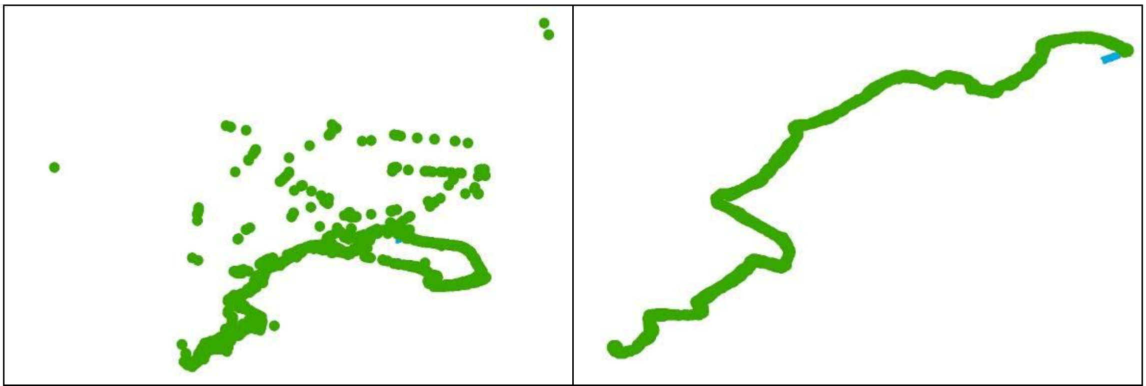


Figure 4.8: Location of bus stops along line 68

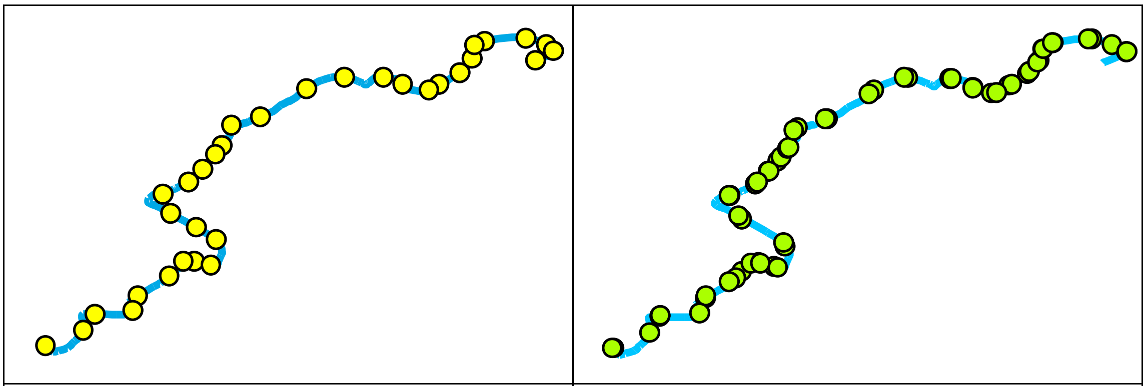
During the first six month of 2009 617,835 stops were recorded on bus line 68.
As could also be noticed on the tram stops, a lot of recordings obvious do not belong to bus line number 68 (see fig 4.9a). Those stops that were within a distance of 30 meter from the actual line are selected (figure 4.9b). This reduces the number recorded stops use for further analysis to 525,357 (85%).



a) All recorded stops | **b) Selected stops within 30m of the line**

Figure 4.9: Recorded stops on line 68

The central point of the recorded stops along line 68 are calculated and compared with the stop locations in the OpenStreetMap source dataset (figure 4.10b). The original source contains 33 bus stops. There are 61 stops retrieved from the recorded trajectories (figure 4.10a). This difference occurs due to the difference in stop codes used for the two driving directions in the trajectories. In the source data these the stops for both directions are present as one stop. Only one of the recorded stops (1020118) is used in both directions.

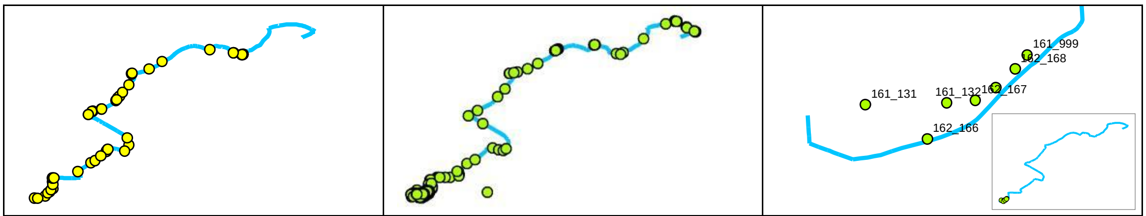


a) Original locations of bus stops | b) Central points of the recorded stops

Figure 4.10: Stop locations on line 68

4.4 Traffic light priority

The source locations of the traffic lights, as they are available in the OpenStreetMap data are compared with the registered locations of the traffic light priority requests.



a) OSM traffic lights | b) All traffic light priority requests | c) Central feature Junctions

Figure 4.11: Locations of the traffic lights in the OpenStreetMap source dataset (a), the recorded traffic light priority request locations (b) and the central features of the recorded requests (c).

The locations of the traffic lights in the OpenStreetMap and the recorded locations do visually match. When the central features are calculated on basis of the junction code, which is the unique identifier of a request, the locations do clearly not match the locations of the traffic lights. There are only seven junction identifiers registered for traffic light requests, although many more traffic lights are located along the route. The central points of the junctions are all located near the south-western start/end of the line.

4.5 Discussion and conclusions

4.5.1 SWE implementation

With the start of this study, the idea existed to implement the measurements done by the Live! telematic system in a SWE environment. But after the first exploration, and for reasons explained below, the implementation was not carried out further.
SWE is mainly designed for an easy web based control of sensor based data. SWE could be implemented in a public transport setting, to help to easily manage the registration of observations. In this sense two services are of interest, the SOS, for the registration and retrieval of observations, and SES, for the definition and detection of events.

The large difficulty of implementing SWE in a public transport setting, is the extreme high frequency in which the observations are measured. A large disadvantage of an SOS is that it is only capable to store one measured parameter per request. In the measurement of Live! telematic system, combined measures among which are acceleration, and distance from the starting point need to be stored. Storing these combined measurements in a SWE environment, will result in a lot of redundant information to be stored. For this reason implementation of the Live! data in SWE is not continued.

4.5.2 Trajectories

During the first half of 2009 52 trams on 12 fixed lines and 15 busses on 37 lines were tracked. The collected trajectories were used to analyze the possibilities of determining predefined high level events on bases of the delivered low level events of the Live! system.

A first exploration was performed to define which trajectories can be used for the above mentioned determination of high level events.

On tram line 1, compared to the estimated scheduled travel time (30 minutes), the median duration of the trajectories is the same.

On bus line 68, compared to the estimated scheduled time (35 minutes), there is a small difference of one minute with the median (36 minutes).

In general it can be concluded that the collected low level events of the Live! system can not directly be used for high level event determination. As the collected observations fluctuate strongly in space and time. For example vehicles keep on tracking their route, even if they do not actively follow the scheduled route of their line. This could be in case of movement to a garage or just the intermediate waiting time between two services.

The Live! telematic system should clearly keep track on the start and end of the movement of vehicles along a line, and close the recording automatically when a vehicle reaches the end of the line.

4.5.3 Stops

For tram line 1 the calculated central features of the by Live! recorded tram stops do match the locations of the stops available in the source OpenStreetMap dataset. For further exploration of events, the locations of the stops in the OpenStreetMap will be used.

On bus line 68 there is a difference between the locations of bus stops available in the OpenStreetMap dataset and the bus stops recorded by the Live! system. The main reason of this difference lies in the fact that the OpenStreetMap localizes the stops as intersections of roads, which means the stops of both directions are located at the same position. From the recorded stops, it can be concluded that the source data does not describe reality, as stops along the different directions of the line are not located at the same location, but differ for the direction traveled.

For this reason it is decided to use the calculated central features of the by Live! measures locations for the exploration of events.

4.5.4 Traffic light priority

Location of the original recorded position where a traffic light request is made correspond to the positions of traffic lights in the OpenStreetMap. When the unique identifier of junctions is included the locations of traffic lights do clearly differ between the two sources. As traffic light priority requests all belong to a certain junction, the recorded locations of the junctions should match the location of traffic lights at these junction.

It can be concluded that the junction registration does not correspond with the location of the requests. This mismatch will clearly influence the results of the analysis of events on traffic light priority requests.

In the next three chapters the results, conclusions and discussion of the analysis on three different high level events will be presented.

5 High level Event: Punctuality

5.1 Punctuality on tram line 1

5.1.1 Spatial analysis of aggregated vehicles on tram line 1

Punctuality is analyzed on basis on low level events recorded by Live!. For each stop a punctuality compared with the original schedule time and a stop status are known. Both these parameters are analyzed separately to find if they do have a value in explaining the high level event of punctuality.

5.1.1.1 Punctuality of passing a stop

Low level events on punctuality are recorded by Live!. Punctuality is explained by the difference between actual time and the time which was scheduled for an object to pass a stop. This part of the analysis focuses on the punctuality of planned tram stops. In such, a stop can be reached too early, too late or exactly on time in relation to the predefined schedule. Locations of these occurrences are compared. From the 18,723 registered stops on tram line 1, on average there was a delay compared to the schedule of 222.7 seconds, with a median delay of 14 seconds. It can be noticed, there are several large outliers at the beginning, and some at the end of the graph (figure 5.1).

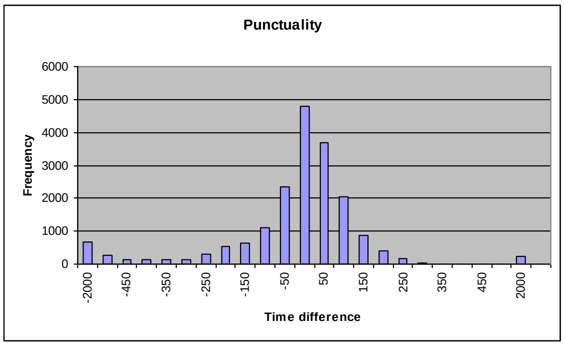


Figure 5.1: Punctuality as a difference in time to the schedule of aggregated vehicles traveling on tram line 1.

From 18,723 observations, 5768 (30.8%) passed too late (more then 60 seconds behind schedule), 3,295 (17.6%) passed too early (more then 60 seconds in front of the schedule) and 9,660 (51.6%) were passed punctual on time (between 60 seconds to early and 60 seconds to late of the schedule).

When looking to the spatial variability, it can be observed that a late- and early arrival at a stop occurs more often at the beginning and the end of the tram line. Passing a stop behind schedule occurs at both ends/starts of the line. At the southern start/end of the line, stops are passed a bit more often behind schedule then at the northern start/end. During the travel across the line, the overall number of punctual passages does not largely vary. Two stops in the southern part of the line are passed punctually on time with a higher percentage then the other stops.

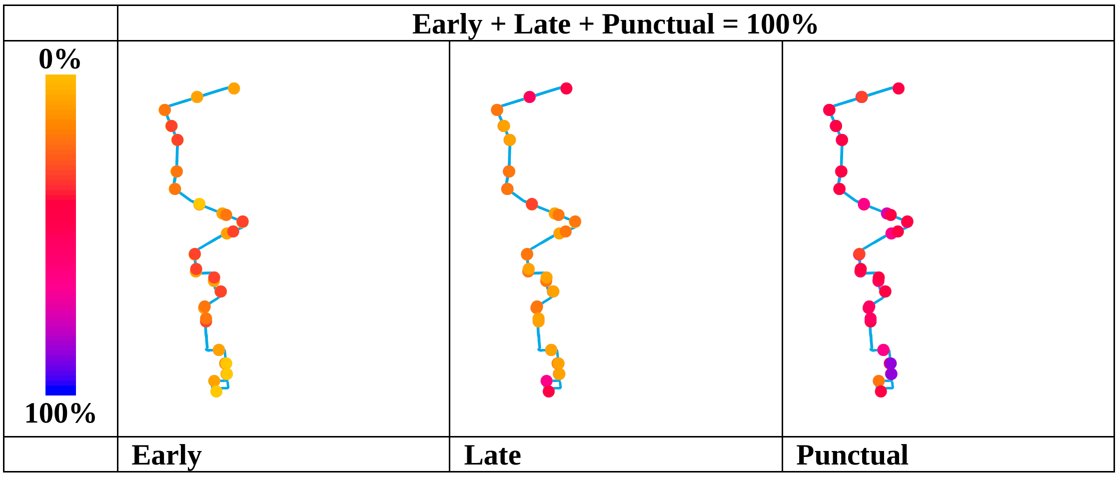


Figure 5.2: Categorized punctuality (percentages) of aggregated vehicles traveling on tram line 1 over the whole period.

When the direction is taken into account, it can be observed that for driving direction 1 (south-north), there are 9786 observations, for the opposite driving direction 2 (north-south) there are 8937 observations. For driving direction 1 the average delay is 168.9 seconds with a median of 0, driving direction 2 has an average delay of 281.7 seconds passing a stop, with a median delay of 29 seconds.

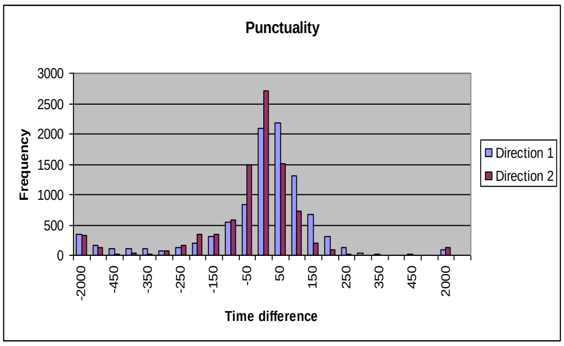


Figure 5.3: Punctuality as a difference in time to the schedule of vehicles traveling on tram line 1 in a south-north direction (direction 1) and a north-south direction (direction 2).

Although the average delay of vehicles traveling in direction 2 is higher, it be noticed from figure 5.3, that the peek of vehicles passing the line in direction 2, is higher and more located around 0 then the peek for vehicles traveling in direction 1. In both directions, there are outliers at the beginning and end of the graph.

From the 9,786 stops recorded at vehicles passing the line in direction 1 (south to north), 49.2% were punctual on time, 23.4% passed to early and 27.4% were to late. In direction 2 (north to south), 54.2% were punctually on time, 11.2% to early and 34.6% passed a stop to late.

The locations of the measurements divided in driving directions are compared, using the same punctuality classification as mentions above.

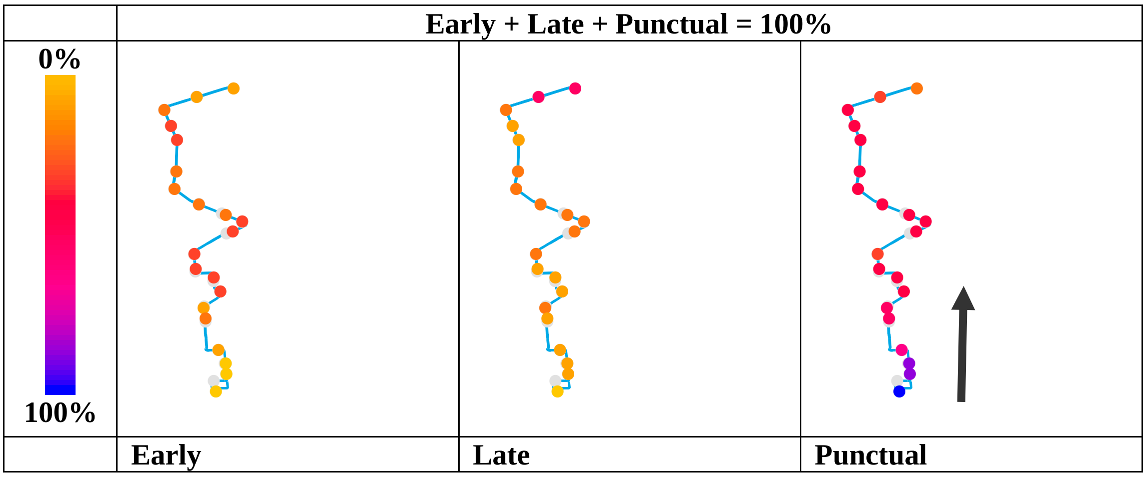


Figure 5.4a.: Categorized punctuality (percentages) of vehicles traveling on tram line 1 in a south-north direction (direction 1).

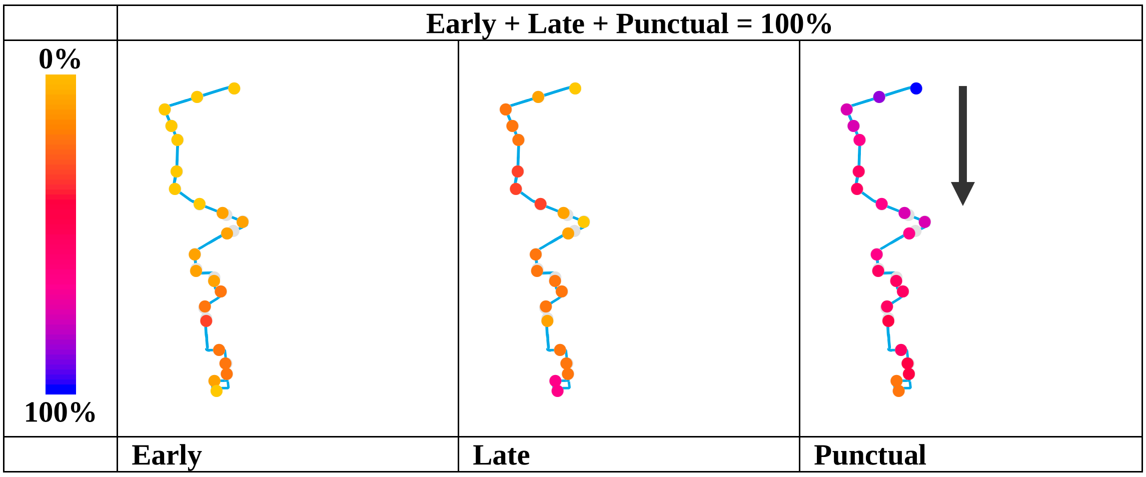


Figure 5.4b: Categorized punctuality (percentages) of vehicles traveling on tram line 1 in a north-south direction (direction 2).

When looking at the punctuality of the vehicles on line 1, it can be observed that, on average, in both directions, most vehicles start there track punctually on time. During the track the delay is fluctuating, although most of the stops are still passed punctual on time. The last two stops at the end of the line (in both directions) are passed less punctual than the other stops.

5.1.1.2 Status

The status of a vehicle passing a stop can be of three different types, a vehicle can enter, leave or just pass a stop without stopping. The 18,723 stops located within a distance of 30 meters from the tram line are used for further analysis. From these 18,723 stops, a status of passing a stop without stopping was recoded 170 times (which is less then 1% of the total), 9,260 (49.4%) times a stop enter was recorded, and 9,293 (49.6%) times a stop.

Although in nearly all occasions a stop was registered as stopped, the location of the stops that were passed without stopping are analyzed in ore detail. The stop at the southern beginning/end of the line is passed far more often without stopping then the other stops, 5 tram-stops were never passed without stopping. The highest number of stop enters and stop leaves can be found at the beginning and the end of the line. It can be observed that the stops recorded with a high number of stop enters are not the same as the ones with a high number of stop leaves.

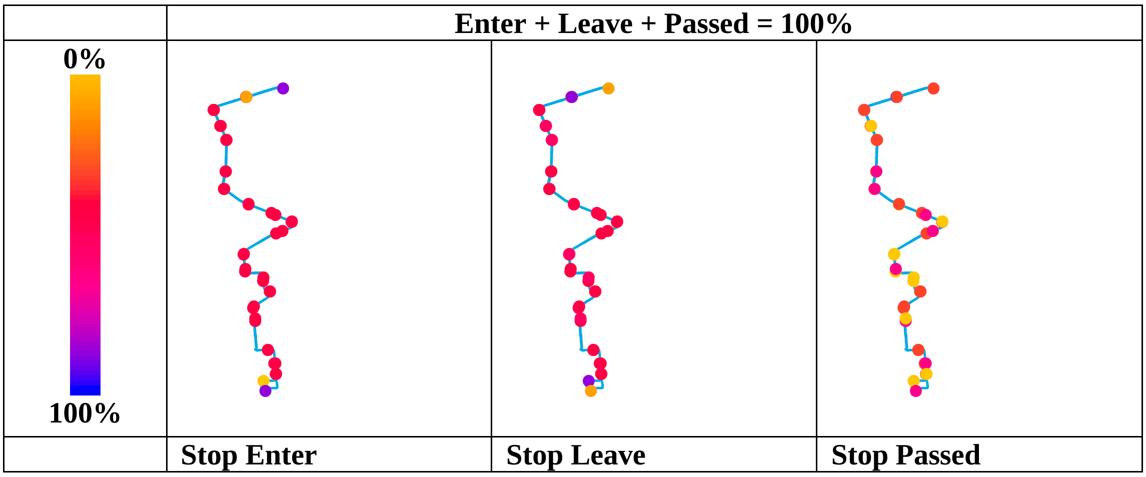


Figure 5.5: Status (percentages) of vehicles traveling on tram line 1.

The stop enters and stop leaves are spread equally, both show around 50% of the stops are entered and left again, except form the stops at the start and the end of the line. Stops are passed randomly without stopping, for the average of all vehicles, no clear passages of stops can be determined.

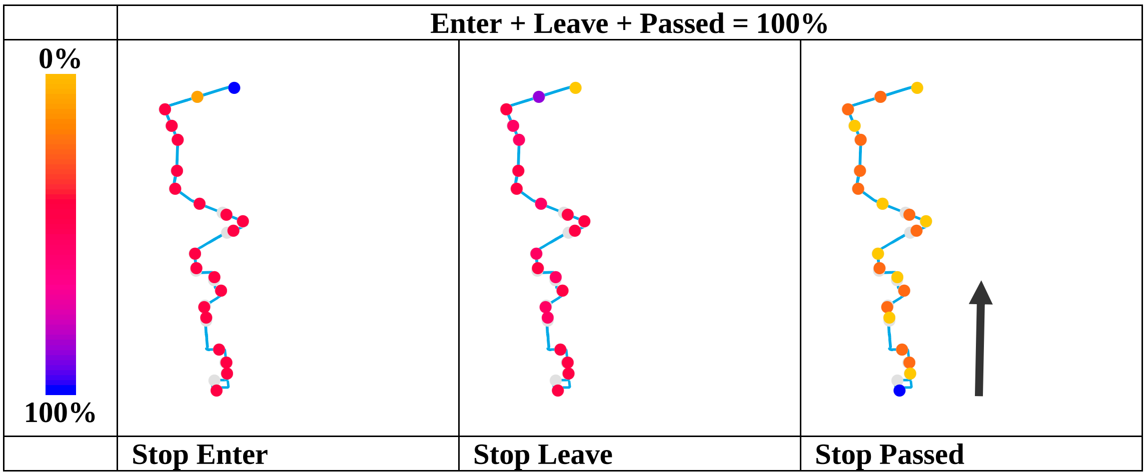


Figure 5.6a: Status (percentages) of vehicles traveling on tram line 1 in a south-north direction (direction 1).

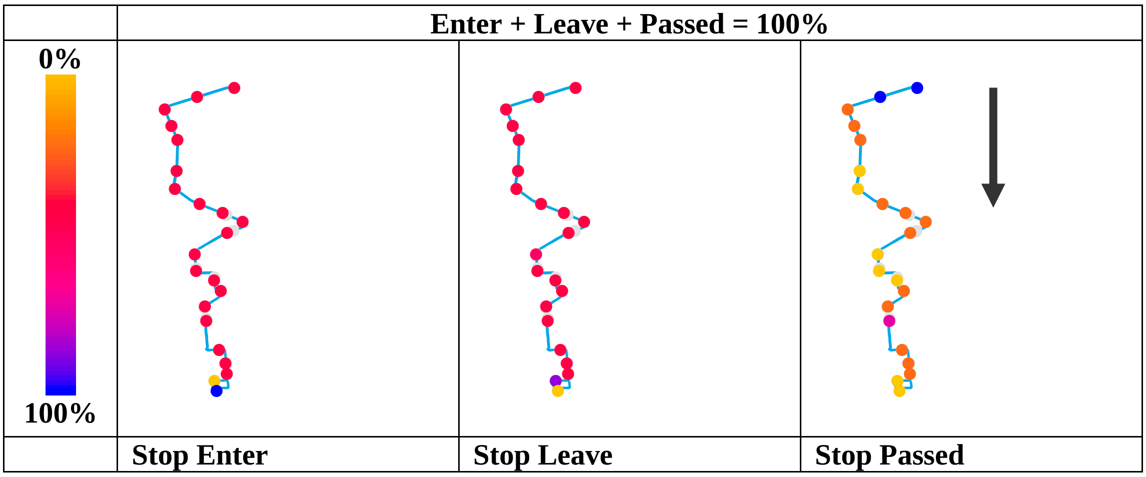


Figure 5.6b: Status (percentages) of vehicles traveling on tram line 1 in a north-south direction (direction 2).

As observed for the punctuality of the stops passage, direction plays an important role. Also the status is further explored on stops being passages without stopping for the both different directions.

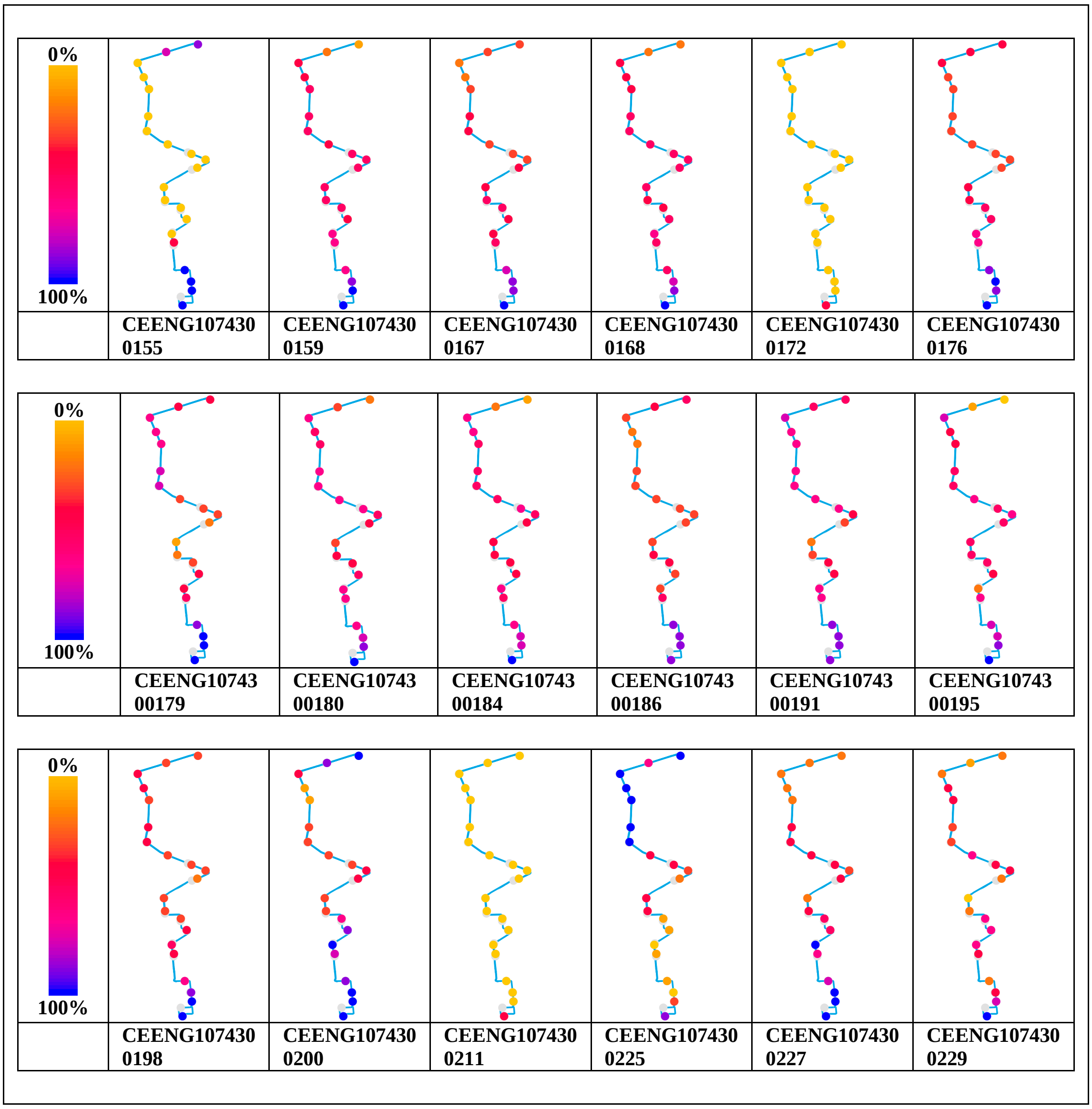
The number of stop passages where a vehicle did not stop are low; 1.04% passed without stopping in direction 1, 0.76% passed a stop without stopping in direction 2.

Both directions show identical figures as when direction is not taken into account. The start and end of the line can clearly be determined. Stop passed without stopping are higher at the stops near the start and end of the line compared to stops further along the stops.

5.1.2 Spatial analysis of individual vehicles on tram line 1

5.1.2.1 Punctuality

The same analysis is performed taking into account the individual vehicles that were used on tram line 1 during the first half of 2009. During this period, 23 different vehicles were used in a south-north direction (direction 1), and 18 vehicles in north south direction (direction 2). From all these vehicles the punctuality is compared. As there is a difference between the two directions on the aggregated vehicles, results are directly separated into these two categories.



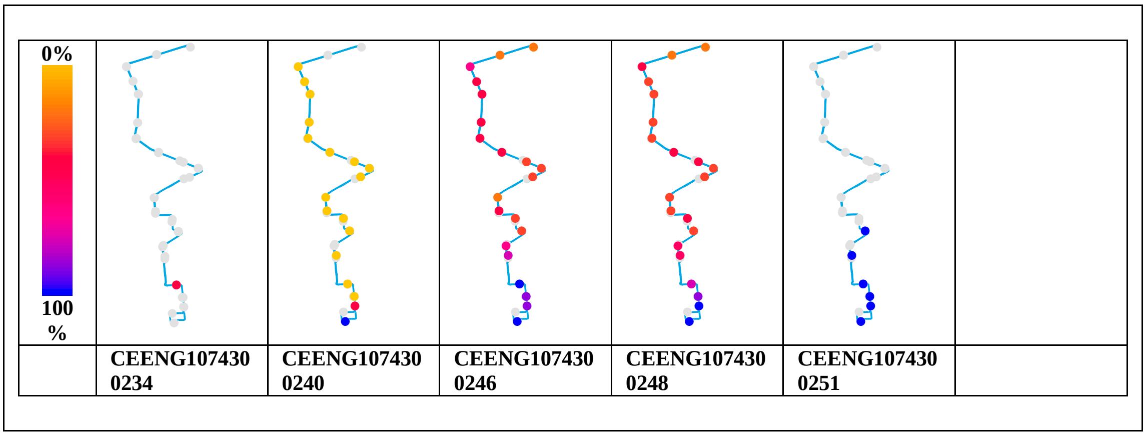
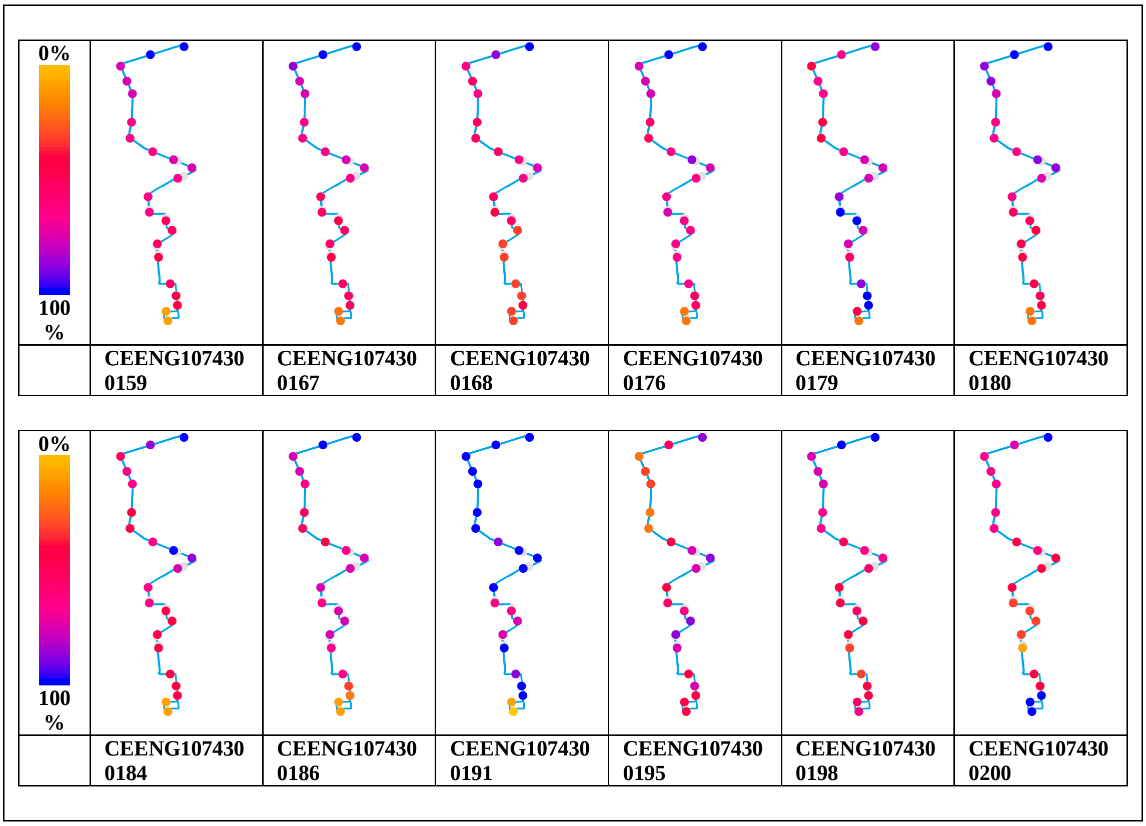


Figure 5.7a: Categorized punctuality (percentages) of individual vehicles passing a stop punctual on time, traveling on tram line 1 in a south-north direction (direction 1).

Most vehicles, except vehicles CEENG1074300172 and CEENG1074300211 started their track punctual on time. One of the vehicles CEENG1074300234 only registered a single stop. Stops of vehicle CEENG1074300251 were only recorded at the start of the track. During the track most of the vehicles, except vehicles CEENG1074300155, CEENG1074300172, CEENG1074300211 and CEENG1074300240 show a high percentages (> 50% of all passages) of punctual passages of the stops. The four mentioned exceptions show very low percentages of punctual passage of the passed stops. Vehicle CEENG1074300200 and CEENG1074300229 show respectively two (5^{th} and 4^{th} stop before the end of the line) and one (near the centre of the line) stops that differ from the other punctual passed observations at the other stops. The two stops at the end of the line were compared to the other stops more often registered as less punctual.



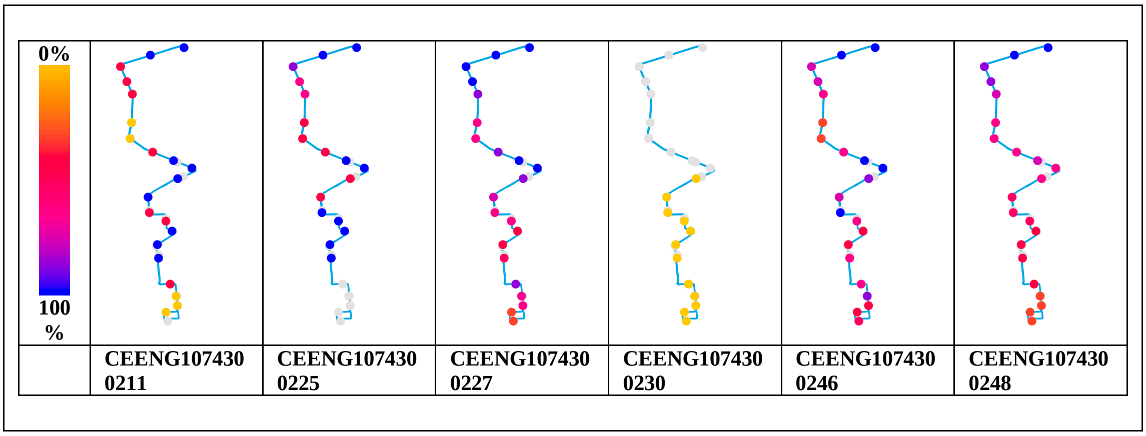


Figure 5.7b: Categorized punctuality (percentages) of individual vehicles passing a stop punctual on time, traveling on tram line 1 in a north-south direction (direction 2).

The same as mentioned for vehicles driving in a south north direction, counts for the north south direction; vehicles start punctually on time at their route, further along the route, stops are passed little less punctual, but still most (> 50%) of the stop passages are made punctually on time. Two vehicles (CEENG1074300225 and CEENG1074300230) did not register a full track. Registrations made for vehicle CEENG1074300230 were all not punctual (<10% of all recorded stop passages). Twice two stops of vehicle CEENG1074300211 were recorded as not punctual (one pair in the north of the line, another pair at the end of the line). The two stops at the end of the line were compared to the other stops made, more often registered as not punctual.

5.1.2.2 Status

As the stops that are passed without stopping are a very low percentage (les than 1%), and are spread randomly for the aggregated vehicles. They are not analyzed for the individual vehicles.

5.1.3 Temporal analysis on aggregated vehicles on tram line 1

The analysis is performed splitting the day in morning (6:00 - 11:59), afternoon (12:00 - 17:59), evening (18:00 - 23:59) and night (0:00 - 5:59) passages. Tram line 1 only contains trajectories that were recorded in the morning and the afternoon. These trajectories had registered departure times ranging between 8:57 and 14:58.

5.1.3.1 Punctuality

Punctuality analysis are performed based on aggregated vehicles.

5.1.3.1.1 Punctuality Time of the day

From all stop passages 52.1% were registered in the morning from which 49.1% were punctual on time, 16.9% to early, 34.0% to late. From all stops 47.9% were recorded during the afternoon, from which 54.3% were punctual on time, 18.4% to early and 27.4% to late.

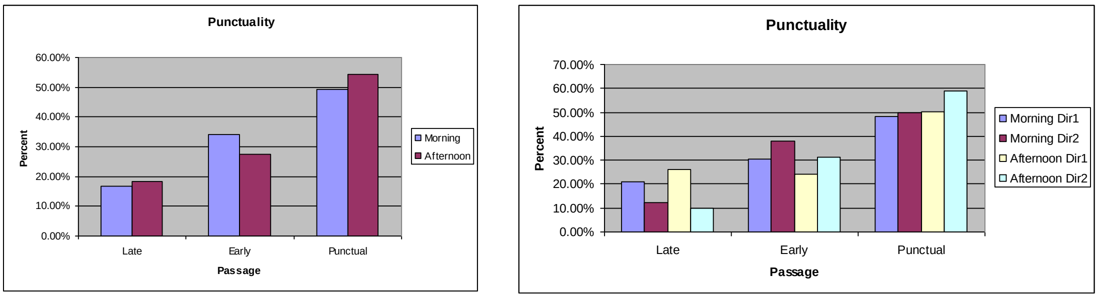


Figure 5.8: Categorized punctuality of vehicles traveling on tram line 1 during different hours of the day and for different directions, where direction 1 travels in south-north direction (left), and direction 2 in a north-south direction (right).

When direction is taken into account, during the morning 21.0% of the stops were passed early, 30.5% passed late and 48.4% passed punctually on in direction 1. In direction 2, 12.3% passed to early, 37.8% to passed to late and 49.9% passed punctually on time during the morning hours.

During the afternoon, in direction 1, 26.0% passed to early, 23.9 passed to late and 50.0% passed a stop punctually on time. In the afternoon, in direction 2, 10.0% passed a stop to early, 31.1% to late and 58.8% of the stops were passed punctually on time.

Overall it can be said that the punctuality of vehicles driving in direction 2 are highest during the afternoon. Late passage is for both directions higher during the morning than in the afternoon.

5.1.3.1.1 Punctuality Rush-hours

As the latest departure time on tram line 1 is 14:58, the rush-hours only exists of the stops that were passed during the morning rush from 8:00 to 9:30.

From all the stops that were passed during the rush hours, 22.0% were passed late, 31.6% passed to early and 46.4% were punctual on time.

From the stops that were passed outside of the rush-hours, 17.0% passed to late, 30.7% were passed to early and 52.3% were punctual on time.

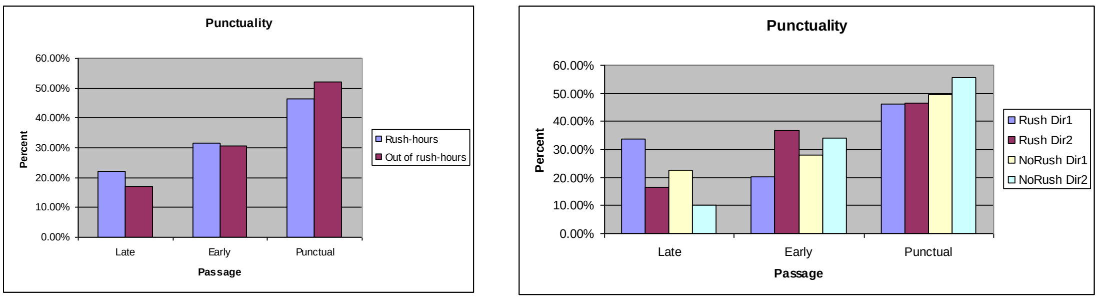


Figure 5.9: Categorized punctuality of vehicles traveling on tram line 1 during different hours of the day and for different directions, where direction 1 travels in south-north direction (left), and direction 2 in a north-south direction (right).

When the direction is taken into account, during the rush-hours, in driving direction 1, 33.7% of the vehicles passed a stop to late, 20.2% passed to early, and 46.1% passed punctually on time.

In direction 2, 16.6% passed a stop to late, 36.8% passed to early and 46.6% passed a stop punctually on time, during the rush-hours.

Out of the rush-hours, 22.7% passed a stop to late, 27.9% passed to early and 49.4% passed a stop in direction 2 punctually on time.

During the rush-hours in direction 1 the highest number of stops were passed to late. Out of the rush-hours, in driving direction 2, the punctuality is highest. The late passage is lower in direction 2 for both time intervals. Early passage is a little higher for both time intervals in direction 2. There is a large difference between the late and early passage in direction 1 and direction 2. In direction 2 there are more vehicles passing a stop to early during the rush hours then out of the rush hours.

5.1.3.2 Status

From the stop passages that a vehicle passed a stop without stopping, 41.8% took place in the morning, and 58.2% in the afternoon.

From the stop passages that a vehicle passed a stop without stopping, 9.4% were during the rush-hours, and the other 90.6% took place outside the rush-hours.

As in the previous analysis of stop status no directional difference was found, so they are not analyzed further.

5.1.4 Temporal analysis on individual vehicles on tram line 1

The temporal differences between the individual vehicles are analyzed.

5.1.4.1 Punctuality

Punctuality analysis are performed based on individual vehicles.

5.1.4.1.1 Punctuality during the different hours of the day

During the morning hours, most of the vehicles were punctually on time. One vehicle passed all of its stops to early or punctually on time. All the other vehicles passed at least once a stop to late. Nine vehicles had more then 50% of it passages punctually on time. Four vehicles had more then 50% of their stop passages to late.

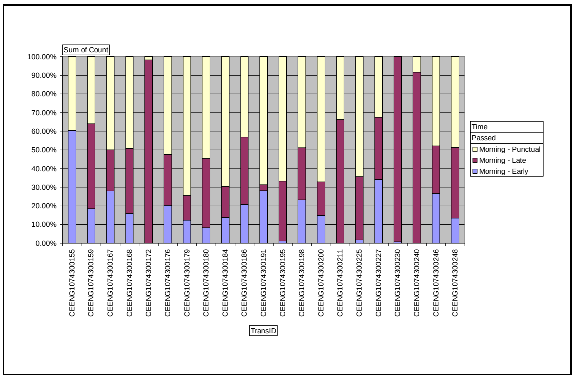


Figure 5.10a: Punctuality as a difference in time to the schedule of vehicles traveling on tram line 1 during the morning hours.

In the afternoon one vehicle had all of it's stop passages punctually on time. Two vehicles had more then 50% of their passages to late. Fourteen vehicles had more then 50% of it passages punctually on time. Four vehicles had more then 50% of their stop passages to late.

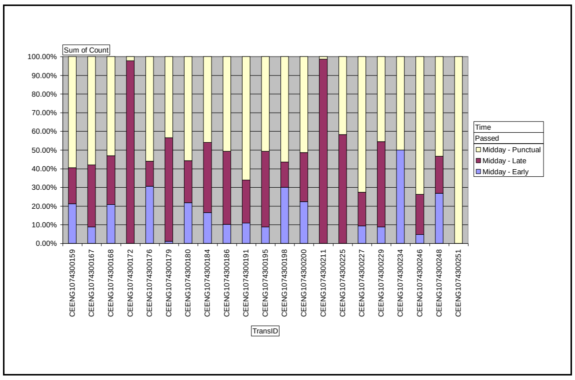


Figure 5.10b: Punctuality as a difference in time to the schedule of vehicles traveling on tram line 1 during the afternoon hours.

5.1.4.1.2 Punctuality during the rush-hours

During the rush hours, one vehicles always passed its stops punctually on time. One vehicles only passed punctually or to early. Four vehicles had more then 50% of their stop passages to late. Seven vehicles had more then 50% of their stop passages punctually on time.

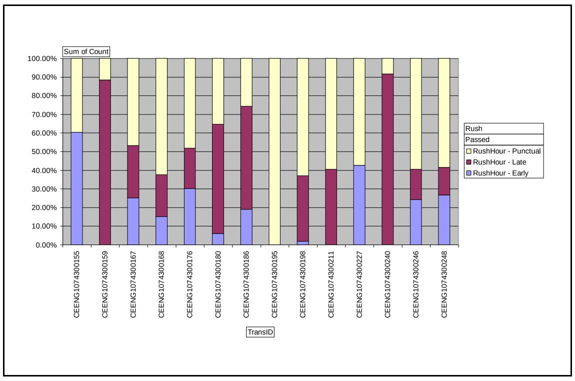


Figure 5.11a: Punctuality as a difference in time to the schedule of vehicles traveling on tram line 1 during the rush-hours.

Out of the rush-hours fourteen vehicles had a punctual stop passage of 50% or higher. One vehicle always passed punctually on time. One vehicles always had a to late passage. Two vehicles had more then 99% of their stop passages to late.

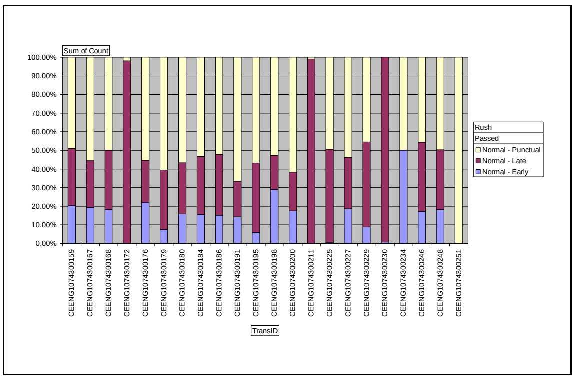


Figure 5.11b: Punctuality as a difference in time to the schedule of vehicles traveling on tram line 1 out of the rush-hours.

5.1.4.2.1 Status during the different hours of the day

One vehicles had all of its stop passages without stopping during the morning hours. Five vehicles had all of their stop passages without stopping during the afternoon. Most of the vehicles had a higher stop passage without stopping during the afternoon, then during the morning hours.

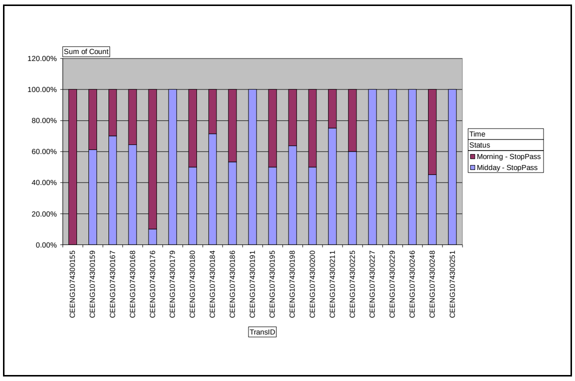


Figure 5.12a: Status (passed a stop without stopping) of vehicles traveling on tram line 1 during the different hours of the day.

5.1.4.2.2 Status during the rush-hours

One vehicle had all of its stop passages without stopping in the rush-hours. Ten vehicles had all the stop passages without stopping out of the rush-hours. All the other vehicles except one had more then 80% of all their stop passages that they did not stop out of the rush hours.

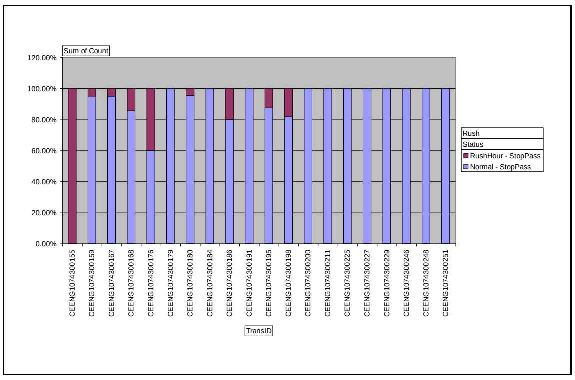


Figure 5.12b: Status (passed a stop without stopping) of vehicles traveling on tram line 1 during the different in and out of the rush-hours.

5.1.5 Spatiotemporal analysis on aggregated vehicles on tram line 1

5.1.5.1 Punctuality

Punctuality analysis are performed based on aggregated vehicles.

5.1.5.1.1 Punctuality during the different hours of the day

The analysis is done splitting the day in morning (6:00 - 11:59), afternoon (12:00 - 17:59), evening (18:00 - 23:59) and night (0:00 - 5:59) passages. Tram line 1 contains only trajectories that were recorded in the morning and the afternoon.
From all stop passages 52.1% were registered in the morning of which 49.1% were punctual on time, 16.8% to early, 34.0% to late. 47.9% Of all stops were recorded during the afternoon, from which 54.3% were punctual on time, 18.4% to early and 27.4% to late. The spatial distribution of these stop passages is shown below.

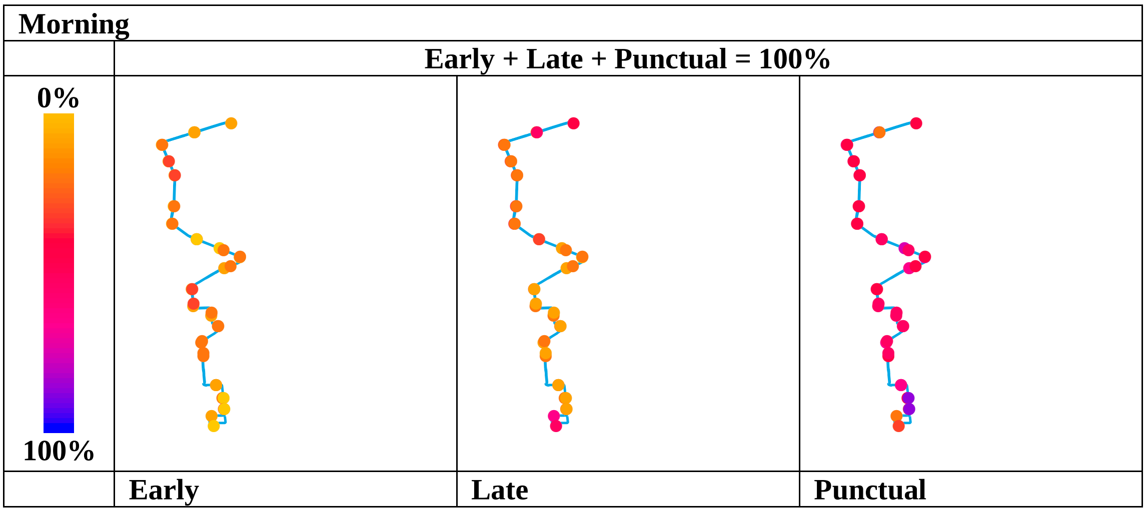


Figure 5.13a: Categorized punctuality (percentages) of vehicles traveling on tram line 1 during the morning hours of the day.

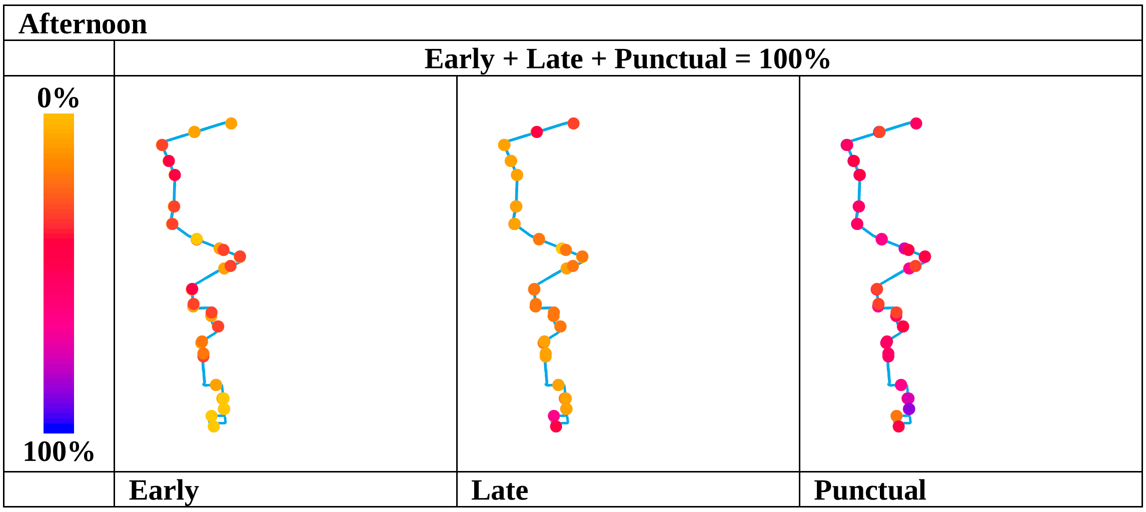


Figure 5.13b: Categorized punctuality (percentages) of vehicles traveling on tram line 1 during the afternoon hours of the day.

Hardly any difference between the morning and afternoon passages can be observed. Stops passed in the morning are a bit more punctual at the stops located in the south then those passed during the afternoon.

5.1.5.1.2 Punctuality during the rush-hours

Next the stops are analyzed on passing during the rush-hours (8:00-9:30 and 17:00-18:30) and out of the rush-hours.

From all the stop that were recorded, 16604 (88.7%) were registered out of the rush-hours, the other 2119 (11.3%) were registered within the rush-hour. Line 1 is only used during the morning (rush-hours), so none of the registrations were made during the evening rush.

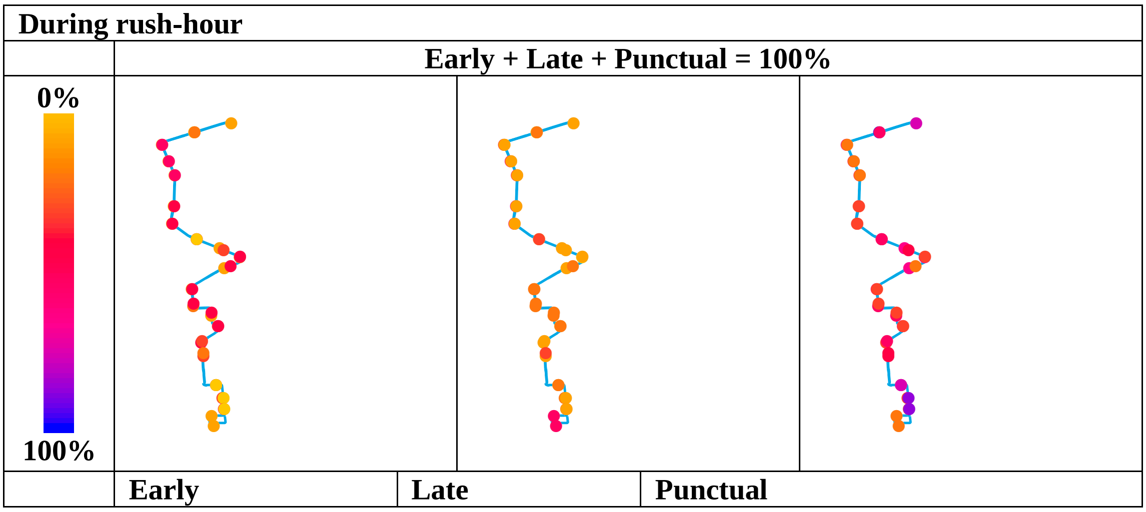


Figure 5.14a: Categorized punctuality (percentages) of vehicles traveling on tram line 1 during the rush-hours.

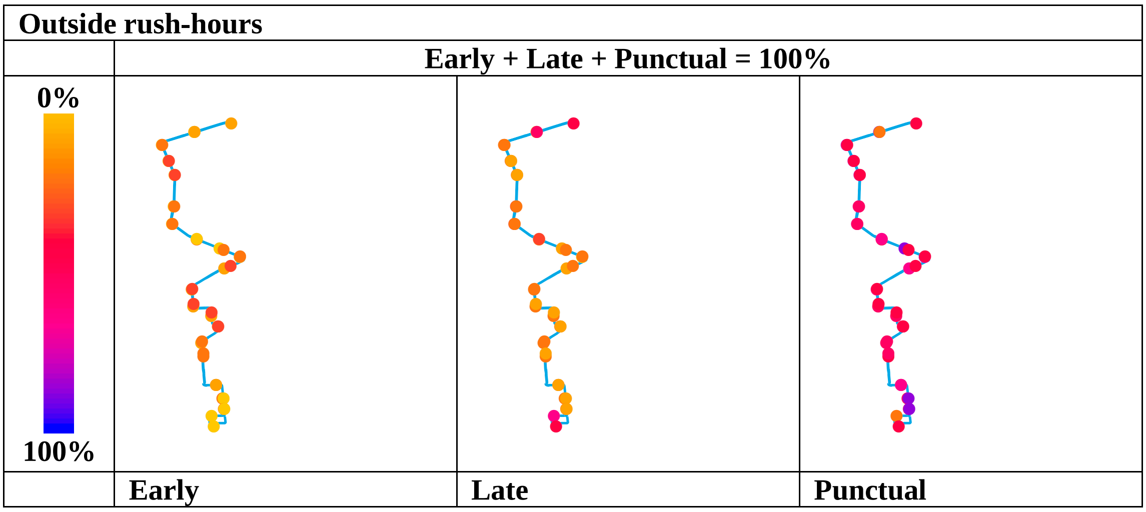


Figure 5.14b: Categorized punctuality (percentages) of vehicles traveling on tram line 1 out of the rush-hours.

It can be observed that during the rush-hour, the percentage of punctual passages is along the complete line a little lower then during the other hours of the day. It can also been observed that during the rush-hour more early passages along the complete line are registered compared to the other hours. The difference for arriving to late is very small, only a few stops in the north of the line show a higher percentage of passing late.

5.1.5.2.1 Status during the different hours of the day

Although there is no clear difference in the stop status of the vehicles (stop enter, stop leave and stop passed), they are further analyzed on difference in time of the passage. Again the time of the day are separated in morning and afternoon and rush-hour and outside rush-hour.

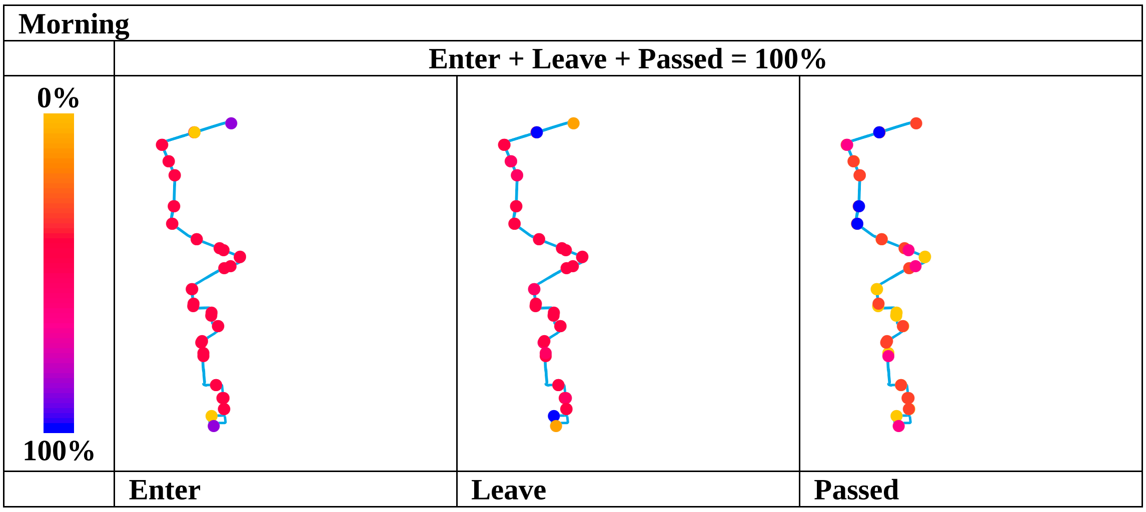


Figure 5.15a: Status (percentages) of vehicles traveling on tram line 1 during the morning hours of the day.

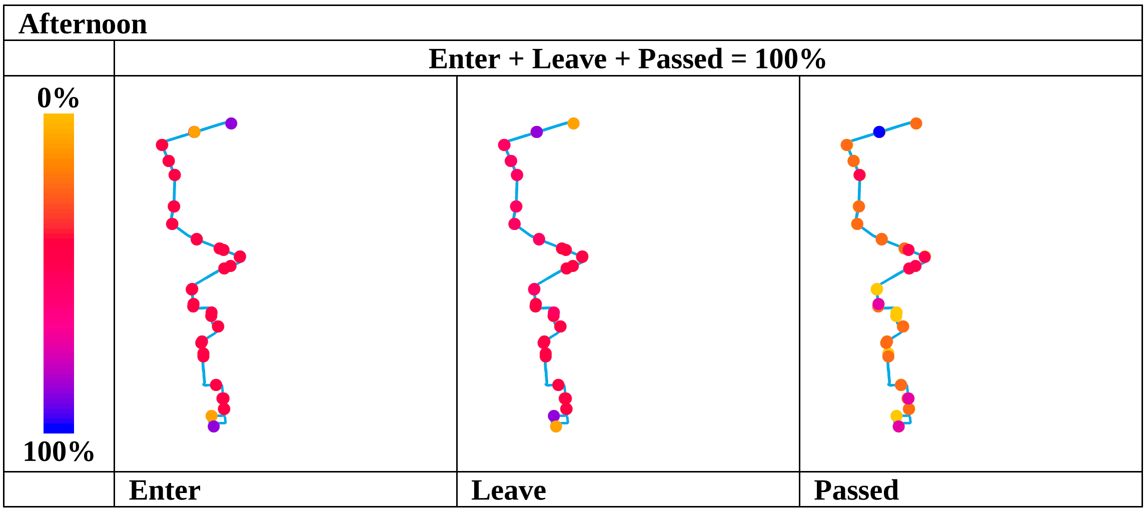


Figure 5.15b: Status (percentages) of vehicles traveling on tram line 1 during the afternoon hours of the day.

In the morning, only 0.73% of the stops were passed without stopping. In the afternoon, 1.1% of the vehicles are passing a stop without stopping. The locations of the stops that were passed without stopping are randomly spread along the line. In the morning, two stops (around 100% of the passages) in the northern part of the line are far more often passed without stopping then during the afternoon. The second stop from the north is passed without stopping more often then the other stops, this can be observed for both the morning and the afternoon. Stop enters en stop leaves are both above 49% in the morning and in the afternoon, the two stops at the start and end of the line show differences.

5.1.5.2.2 Status during the rush-hours

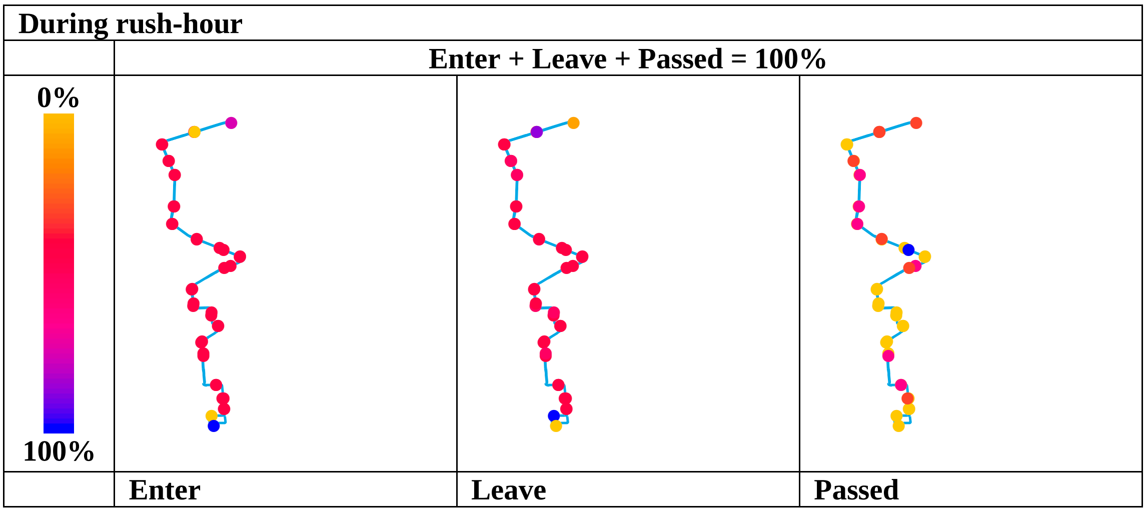


Figure 5.16a: Status (percentages) of vehicles traveling on tram line 1 during the rush-hours.

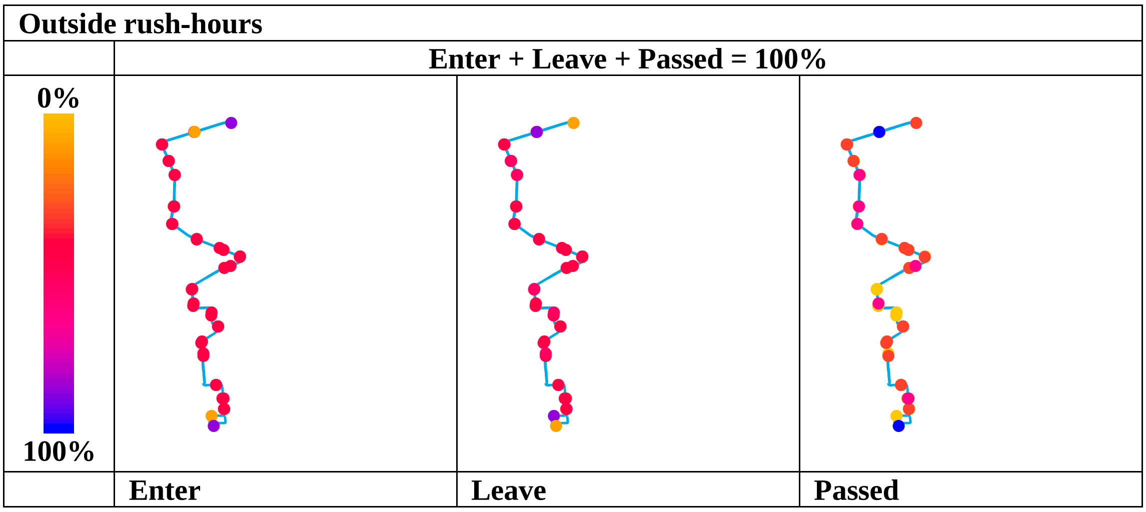


Figure 5.16b: Status (percentages) of vehicles traveling on tram line 1 out of the rush-hours.

The rush-hours show a stop passage of 0.76% while the other hours show 0.93% stop passages. Stop enters en stop leaves are both above 49%. Also here, the two stops at the start end of the line show differences.

5.1.6 Spatiotemporal analysis on individual vehicles on tram line 1

As there are no clear differences being found in the separate spatial and temporal analysis of individual vehicles, the spatiotemporal analysis of individual vehicles during the different hours of the day, and during and outside the rush-hours are not continued.

5.2 Punctuality on bus line 68

5.2.1 Spatial analysis on aggregated vehicles on bus line 68

As for the tram, the first analysis focuses on the punctuality of the planned stops. In such, a stop can be reached to early, to late or punctually following the time in the schedule. Locations of these occurrences are compared. From the 525,357 registered stops made on bus line 68 during the first half of 2009, on average there is a delay of 184.7 seconds on the original schedule. The median passage of a stop is 83 seconds behind schedule. There are several large outliers at the beginning of the graph.

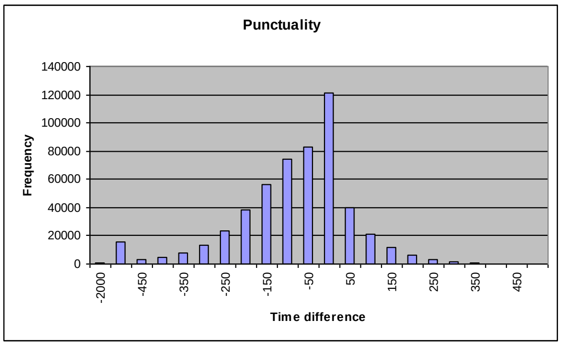


Figure 5.17: Punctuality as a difference in time to the schedule of vehicles traveling on bus line 68.

5.2.1.1 Punctuality

From 525,357 observations, 301,883 (57.5%) passed to late (more then 60 seconds behind schedule) 39,568 (7.5%) passed to early (more then 60 seconds in front of the schedule), 184,417 (35.1%) passed punctual on time (in a range of 60 seconds to early and 60 seconds to late of the schedule).

When looking to the spatial variability, it can be observed that stops in the north east are passed more punctual then the rest of the route, the other stops show a higher rate of late passage. Only a few times stops were passed to early, they are equally distributed over the stops along the complete line.

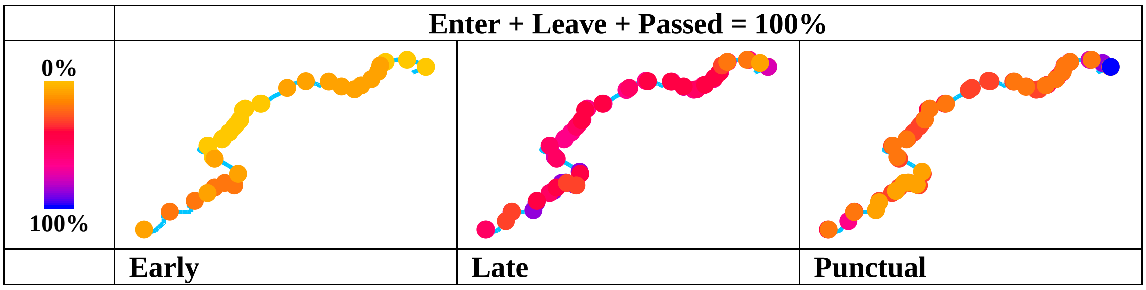


Figure 5.18: Categorized punctuality (percentages) of vehicles traveling on bus line 68.

When direction is taken into account, it can be observed that in driving direction 1, there are 263,302 observations, in the opposite direction, driving direction 2, there are 262,055 observations. For driving direction 1 the average delay is 215.3 seconds with a median delay of 111 seconds. Driving direction 2 has an average delay of 153.9 seconds passing a stop and a median delay of 59 seconds.

From the 263,302 stops recorded on vehicles passing the line in direction 1 (south-west to north-east), 28.1% were punctual on time, while 6.8% passed to early and 65.1% were to late. In direction 2 (north-east to south-west), 42.0% of the vehicles passed punctually on time, 49.8% were to late and 8.3% passed to early.

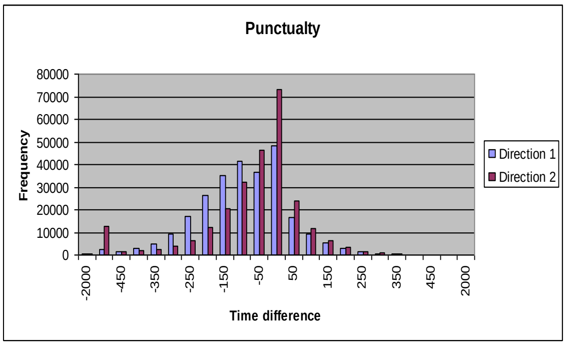


Figure 5.19: Time difference with the scheduled time at stop passage, for two directions, direction 1 is from south-west to north-east, direction 2 from north-east to south-west.

It can be noticed from the above figure, that the average distribution of all vehicles passing the line in direction 2, had less delay then vehicles passing in direction 1. In direction 2 more vehicles passed a stop punctually on time then stops recorded on vehicles passing in driving direction 1. In direction 2 (north-east to south-west), there are large outliers (strong delay) at the beginning of the graph, which influence the lower average delay in direction 2 than in direction 1.

The locations of the measurements divided on driving directions are compared, using the same classification as mentions above.

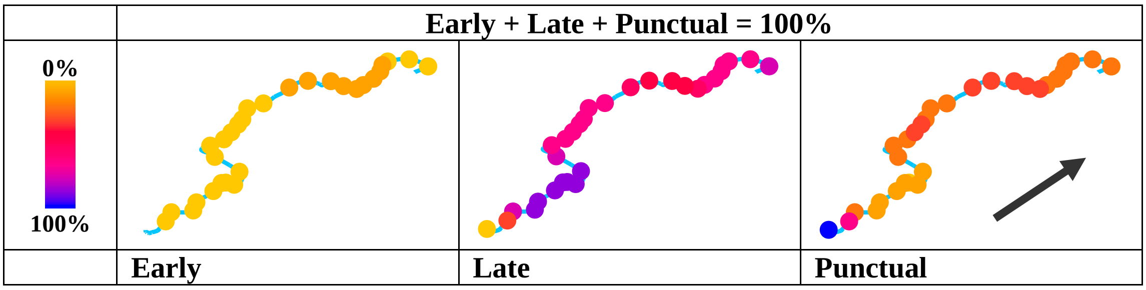


Figure 5.20a: Categorized punctuality (percentages) of vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1).

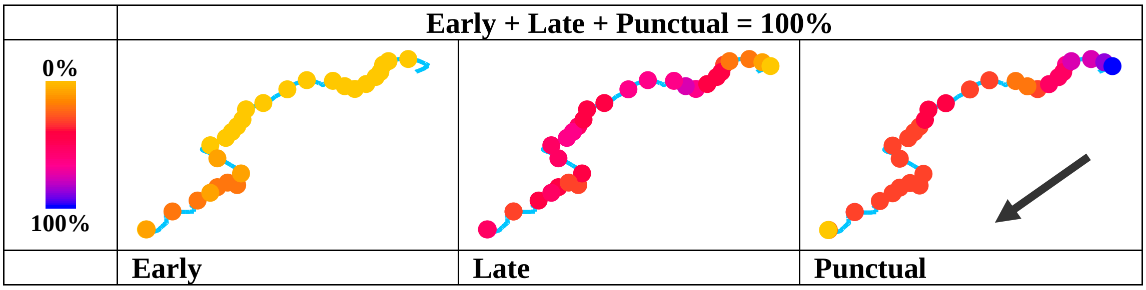


Figure 5.20b: Categorized punctuality (percentages) of vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2).

When looking at the punctuality of the vehicles on line 68 in the different directions, it can be observed that, in direction 1 the punctuality of passing a stop is lower then in direction 2. Vehicles starting their route in the south-east (direction 1) are passing a stop more often to late then in direction 2. The vehicles driving in direction 1 start their route more often late then in the opposite direction. In direction 1, the percentage of vehicles passing a stop to late is decreasing during the continuation of the route. In direction 2 the percentage of vehicles passing a stop to late is increasing after the first four stops, and stays around 50% of the vehicles after. Early passage of stops occurs more often during the second half of the line.

5.2.1.2 Status

525,357 Stops located within a distance of 30 meters from the tram line are used for the analysis. The status of a vehicle passing a stop are registered as three different identifiers, a vehicle can enter, leave ore pass a stop without stopping. During the first half of 2009, the number of stops registered as stop enters (251,905, which is 47.9% of the total) is approximately the same as the number of stop leaves (251,952, which is 48.0% of the total). At the individual stops there is a difference between the number of registered stop enters and stop leaves, as some stops are only used to drop of passengers, and some are only used for passengers to enter the vehicle. Stops were passed without stopping 21,500 times (4.1%). Although the number of stop passages without stopping is low, they are analyzed further to explore if these passed stops are always located at the same location.

The four stops, two at the south-west and two at the north east of the line are recorded far more often then the others. One stop was only recorded 5 times during the first half of 2009, it was always passed without stopping. The highest number of stop enters and stop leaves can be found at the beginning and the end of the line. It can be observed that the locations of the stops recorded with a high number of stop enter are not the same locations as the ones with a high stop leave. Stops at the beginning and at the end of the line are used as start (where stops are only recorded as stop leaves) or end (where stops are only recorded as stop enters) of the line.

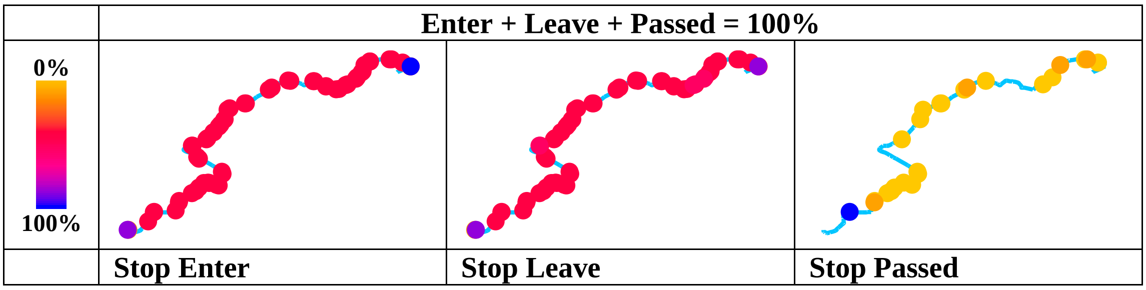


Figure 5.21: Status (percentage) of vehicles traveling on bus line 68.

The stop enters and stop leaves are spread equally, both show around 48% of the stops are entered and left again, except form the stops at the start and the end of the line. Note that the stops with the high percentage of stop enters and stop leaves at the beginning and the end of the line are not the same. These stops overlap, but are different stops used for the two directions of the line.

Stops which are passed without stopping are located along the complete line. One stop at the south-east that is always passed without stopping. It needs only to be said, that this stop was only registered 5 times during the first half of 2009. The other stop passing's without stopping range from 64 to 952 times.

As seen in the overall explanation and punctuality analysis of the stops, direction plays an reasonable role, the status will be further analyzed on stops passed without stopping for the different directions.

The number of stop passages where a vehicle did not stop at a bus stop are rather low, 4.58% were passed without stopping in direction 1, and 3.7% passed a stop without stopping in direction 2.

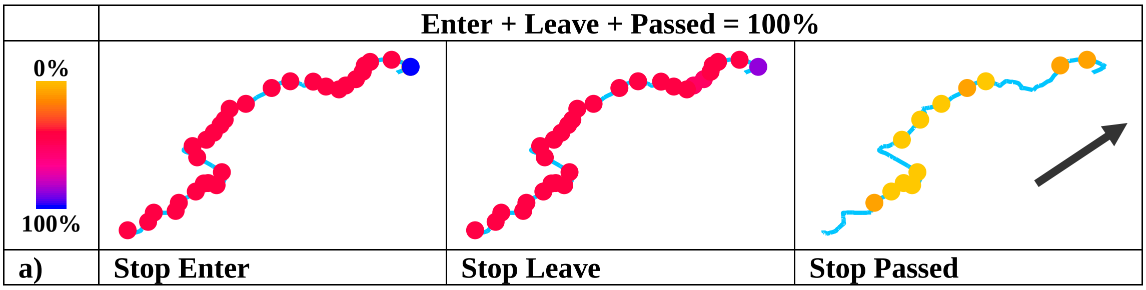


Figure 5.22a: Status (percentage) of vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1)

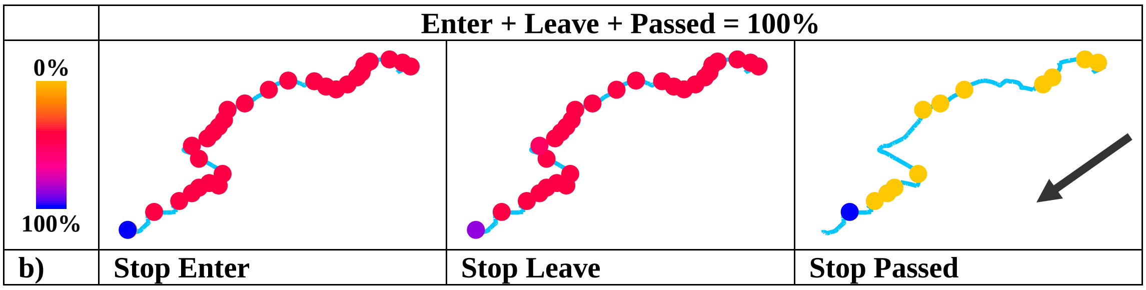


Figure 5.22b: Status (percentage) of vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2)

Both directions show identical figures as if the direction is not taken into account. The start and end of the line can clearly be determined, as at these stops, locations only have a stop enter or a stop leave. Stop passages are equally spread over the complete line. The stop at the south-west of the line was always passed without stopping in direction 2 (it includes only 5 stop passages).

5.2.2 Spatial analysis individual vehicles on bus line 68

During the first half of 2009 three individual vehicles were used on bus line 68. As there is a clear difference between the punctuality in the two directions, a comparison between the vehicles is made using this directional information.

5.2.2.1 Punctuality

The punctuality is compared for the three different vehicles used during the first half of 2009 on line 68.

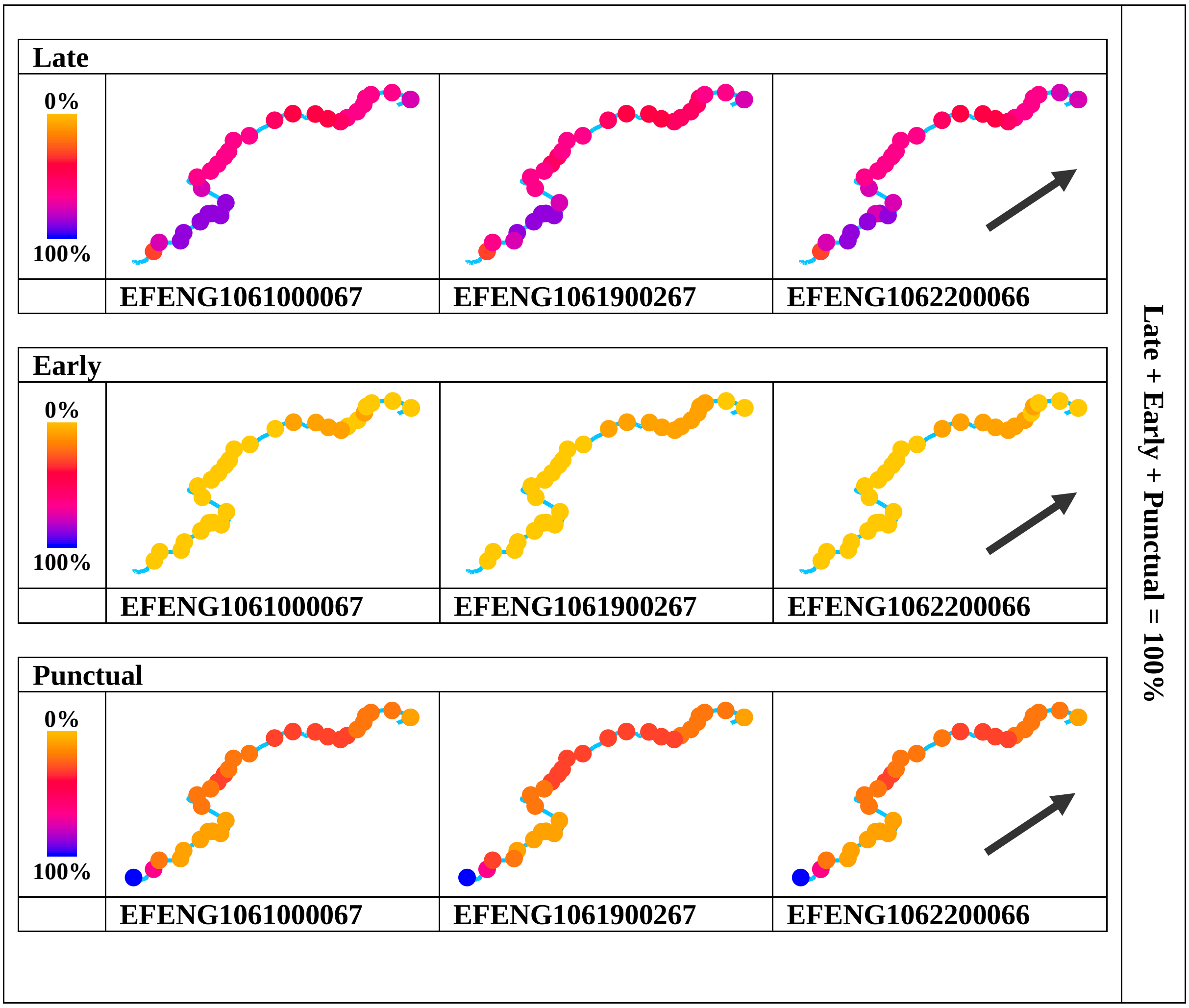


Figure 5.23a: Categorized punctuality (percentages) of individual vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1)

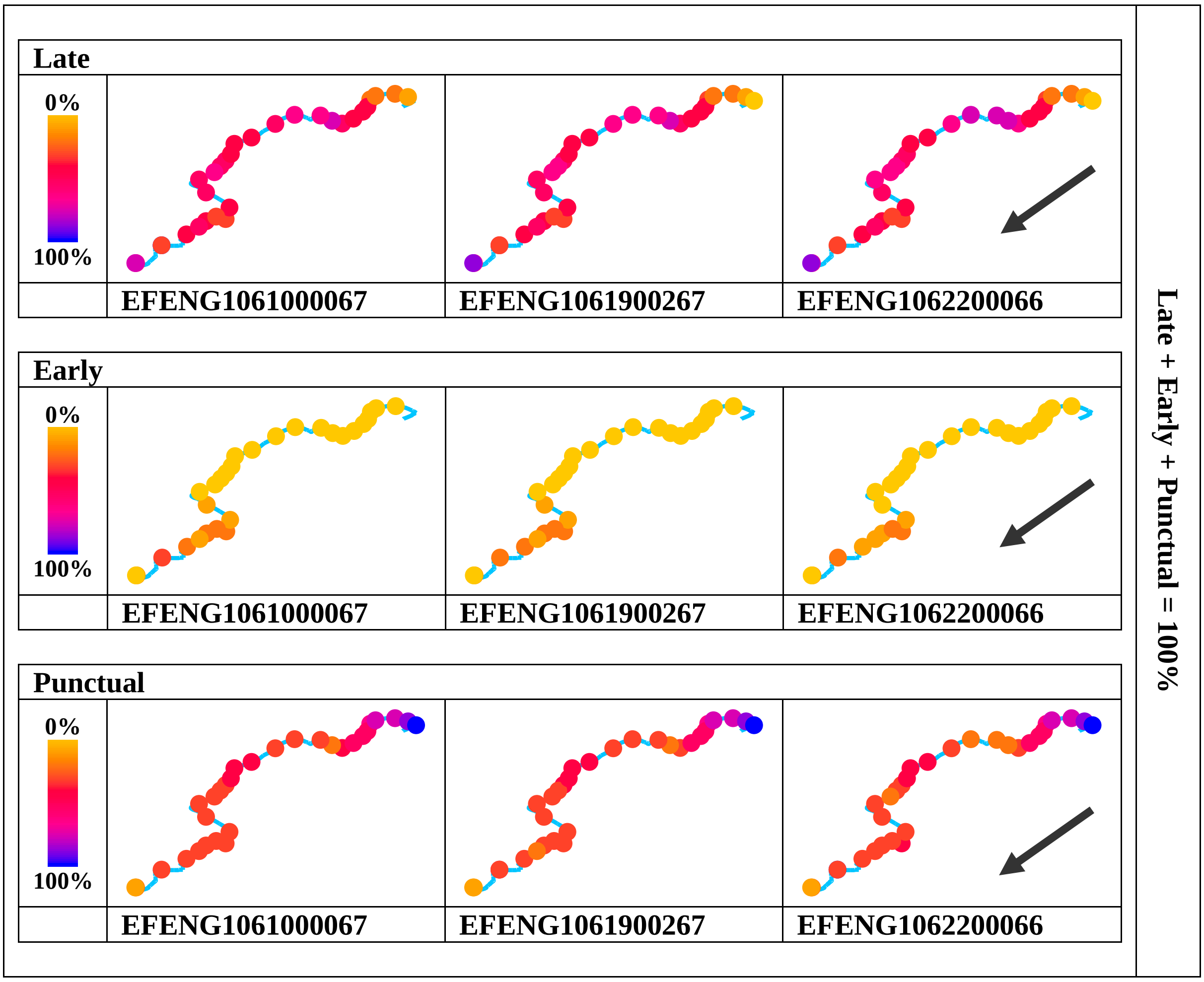


Figure 5.23b: Categorized punctuality (percentages) of individual vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2)

No clear differences between the three vehicles can be observed. They all follow the general trend of starting punctually at the beginning of their travel, and passing late from the stops further on their route. In direction 1, the stops direct after the start of the line in the south-west, are very often passed late by all the vehicles. In the opposite direction this observation does not occur.

5.2.2.2 Status

The rest of the analysis on status are done only for stop passages without stopping, as the other two categories stop enter and stop leave have both contributions of around 48%. For this reason it is only interested to see if there is a spatial difference in stops that were passed without stopping.

As the observations are all classified from 0 to 100%, differences in stops that were passed without stopping can not be clearly be observed. For this reason, the stop status of passed is reclassified in different categories: 0.5, 1, 1.4, 1.7, 2, 2.4, 2.8, 3.6, 4.4, 50.

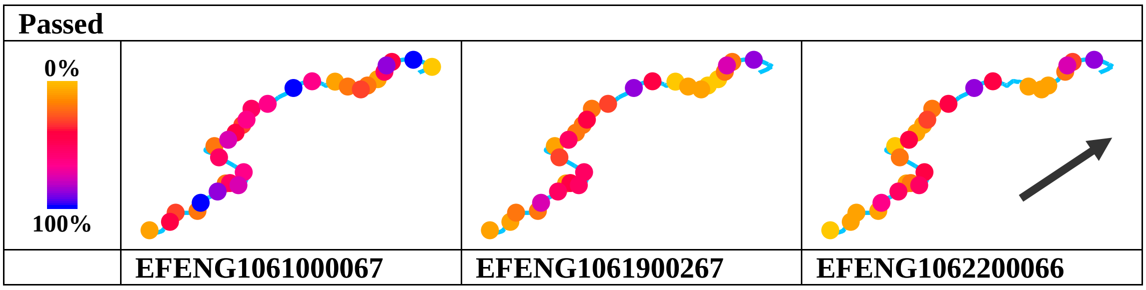


Figure 5.24a: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1), with class-breaks at 0.5, 1, 1.4, 1.7, 2, 2.4, 2.8, 3.6, 4.4, 50.

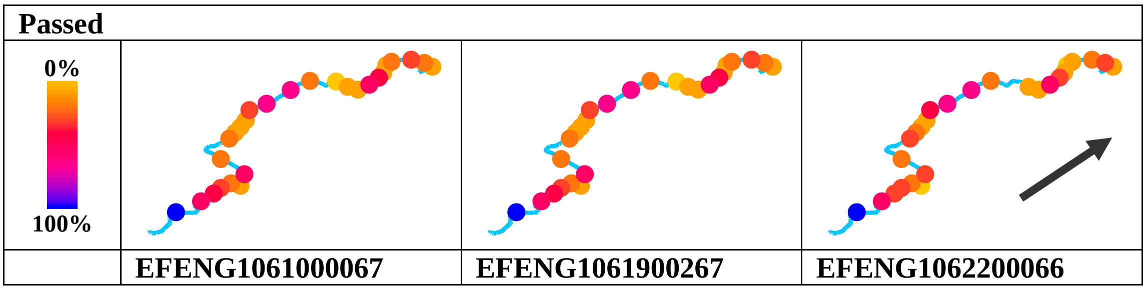


Figure 5.24b: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2), with class-breaks at 0.5, 1, 1.4, 1.7, 2, 2.4, 2.8, 3.6, 4.4, 50.

The spatial distribution of the stops passed in direction 2 are almost equal. In the opposite direction, direction 1, vehicle EFENG1061000067 shows higher percentage in stop passage, then the other two vehicles. The distribution of the stops passed without stopping is equal for all vehicles.

5.2.3 Temporal analysis on aggregated vehicles on bus line 68

Bus line 68 was used during all time intervals defined (also including evening and night). The hours defined as rush-hours cover both the morning and afternoon rush.

5.2.3.1 Punctuality

Punctuality is analyzed on aggregated vehicles for the different hours of the day and during rush-hours and out of the rush-hours both combined with the driving direction.

5.2.3.1.1 Punctuality during the different hours of the day

Of all the stop passages that were made on bus line 68, the ones during the afternoon were a little more punctual then those made during the other hours. During the night the passages were least punctual and the highest percentage of being late can be observed (differences are relative small between the divined intervals).

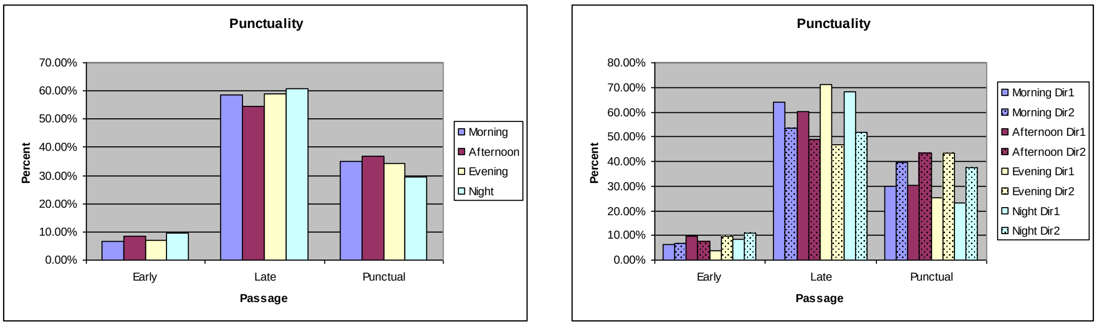


Figure 5.25: Categorized punctuality of vehicles traveling on bus line 68 during different hours of the day and for different directions, direction 1 travels in a south-west to north-east (left) and direction 2 in a north-east to south-west direction (right)

During the evening hours, in direction 2, there were the least early passages. For the evening stops that were passed to early, there is a directional difference between the stops made in direction 1 and those in direction 2. The late passed stops in direction 2 are always a lower percentage of vehicles then in the opposite direction 1. The opposite can be observed for punctual passage, here the number of vehicles passing a stop in direction 2 is higher for all time intervals. During the evening in direction 1 there were the most late passages, followed by stops passed during the night.

5.2.3.1.2 Punctuality during the rush-hours

There is no clear difference between the rush-hours, and the stops that were passed outside the rush-hours.

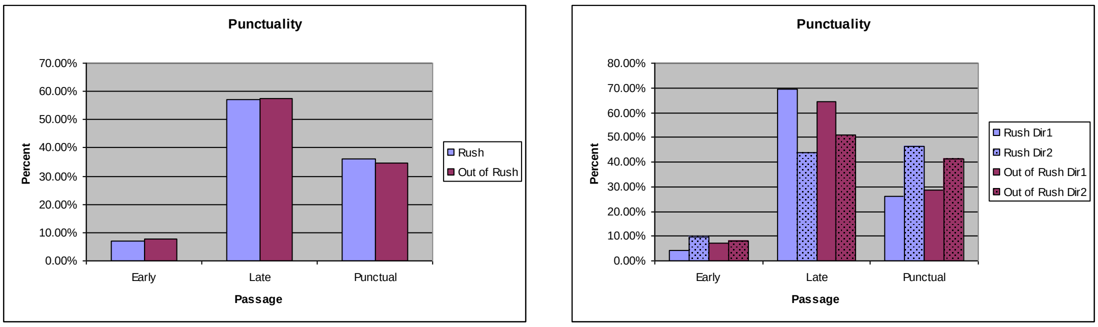


Figure 5.26: Categorized punctuality of vehicles traveling on bus line 68 during and outside the rush-hours and for different directions, direction 1 travels in a south-west to north-east (left) and direction 2 in a north-east to south-west direction (right)

In direction 1, there are more vehicles passing to late then in direction 2, this is for both defined time periods of rush-hours and out of the rush-hours. More stops in direction 2 were passed punctually on time then in the opposite direction, again this is the case for both the defined time periods of rush-hours and out of the rush-hours.

5.2.3.2 Status

Stop status is analyzed on aggregated vehicles in two driving directions for the different hours of the day and during rush-hours and out of the rush-hours.

5.2.3.2.1 Status during the different hours of the day

The stop status are analyzed for the different time intervals defined morning, afternoon, evening and night, and for the rush-hours and non-rush-hours.

Table 5.1: Status during the different hours of the day

Direction	Time	Enter	Leave	Passed
1	Morning	47.67%	47.55%	4.78%
	Afternoon	48.04%	48.17%	3.79%
	Evening	47.72%	48.02%	4.26%
	Night	45.91%	46.49%	7.60%
		47.69%	47.83%	4.48%
2	Morning	48.47%	48.38%	3.16%
	Afternoon	48.31%	48.30%	3.39%
	Evening	48.06%	47.83%	4.11%
	Night	47.15%	46.62%	6.23%
		48.21%	48.08%	3.70%

Compared to the other periods of the day, during the night hours there is a higher percentage (7.0%) of vehicles that passed a stop without stopping then during the other hours. In the morning 3.9% of the vehicles passed without stopping, in the afternoon 3.6% and 4.2% in the evening.

All stop passages without stopping show a higher percentage of passages in direction 1 then in direction 2. The highest number of stop passages without stopping were during the night where 7.6% of the stops in direction 1 were passed without stopping, and 6.2% in direction 2.

5.2.3.2.2 Status during the rush-hours

During the rush-hours there were less (3.8%) stops passed without stopping then during the out of the rush-hours (4.2%).

Table 5.2: Status during and outside the rush-hours

Direction	Rush-hours	Enter	Leave	Passed
1	rush	47.90%	47.86%	4.24%
	normal	47.64%	47.83%	4.53%
		47.69%	47.83%	4.48%
2	rush	48.34%	48.37%	3.28%
	normal	48.19%	48.03%	3.78%
		48.21%	48.08%	3.70%

From the vehicles traveling in direction 1, 4.5% passed more often a stop without stopping then in direction 2 (3.7%). During the rush-hours a little less vehicles passed a stop without stopping then out of the rush-hours. This counts for both directions. The least stops were passed without stopping during the rush-hours in direction 2 (3.3%).

5.2.4 Temporal analysis on individual vehicles on bus line 68

5.2.4.1 Punctuality

Punctuality is analyzed for the individual vehicles passing a stop on the different hours of the day and during rush-hours and out of the rush-hours in two driving directions.

5.2.4.1.1 Punctuality during the different hours of the day

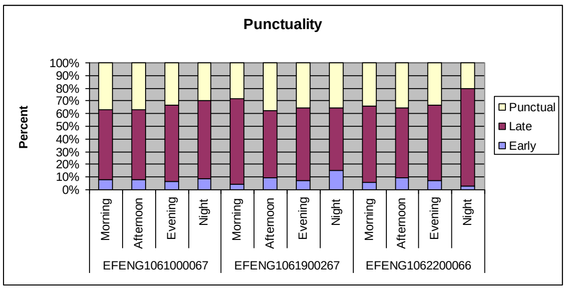


Figure 5.27: Punctuality as a difference in time to the schedule of vehicles traveling on bus line 68 during the different hours of the day.

It can be observed that all vehicles have more late passages then early or punctual passages. In the morning vehicle EFENG1061900267 passes more often late then the other two vehicles. During night-time vehicle EFENG1062200066 shows to pass more often to late then the other vehicles.

5.2.4.1.2 Punctuality during the rush-hours

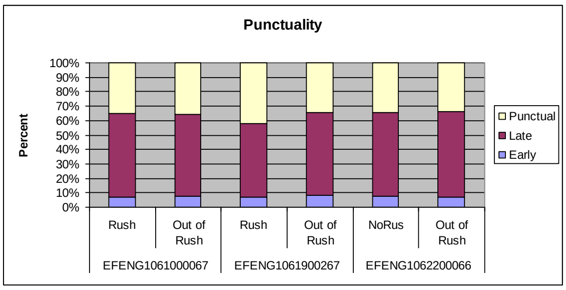


Figure 5.28: Punctuality as a difference in time to the schedule of vehicles traveling on bus line 68 during and outside the rush-hours.

During the rush-hours, vehicle EFENG1061900267 has the least late passages, compared with the other two vehicles. Vehicles EFENG1061000067 and EFENG1062200066 do not show a difference in the stop passage between rush-hours, and the hours outside of the rush-hours.

5.2.4.2 Status

Stop status is analyzed on individual vehicles for the different hours of the day and during rush-hours and out of the rush-hours in both driving directions.

5.2.4.2.1 Status during the different hours of the day

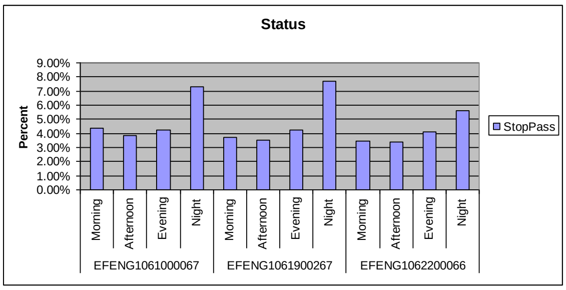


Figure 5.29: Status (passed a stop without stopping) of individual vehicles traveling on bus line 68 during the different hours of the day.

During the night hours all vehicles show that stops are passed without stopping more often then during the other hours of the day. Vehicle EFENG1061000067 and EFENG1061900267 have passed during the night a stop without stopping more often then vehicle

EFENG1062200066. During the afternoon the most stops are made at the stops (the percentage of stops passed without stopping is lowest during the afternoon), this counts for all vehicles. Vehicle EFENG1061000067 has, compared to the other two vehicles, a little more stop passages without a stop being made in the morning.

5.2.4.2.2 Status during the rush-hours

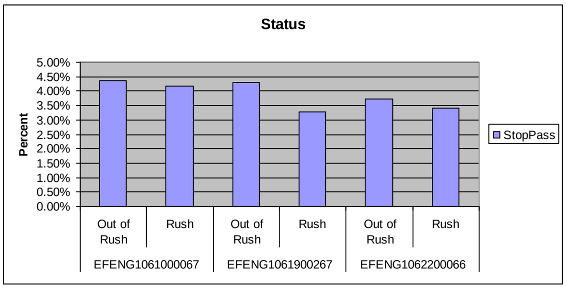


Figure 5.30: Status (passed a stop without stopping) of individual vehicles traveling on bus line 68 during and outside the rush-hours.

Vehicle EFENG1061000067 and EFENG1062200066 show only a small difference between the stop passages without stopping made during rush-hours and the other hours. Vehicle EFENG1061900267 shows a relative larger difference between the stops that are made during the rush-hours and those out of the rush-hours.

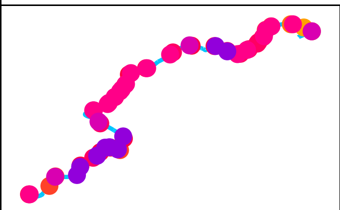
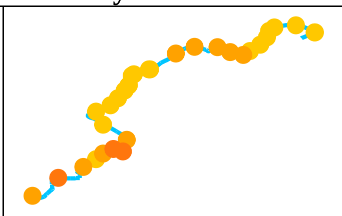
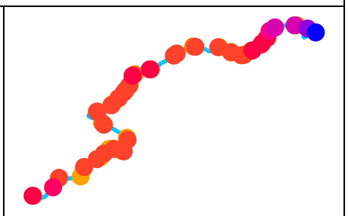
5.2.5 Spatiotemporal analysis on aggregated vehicles on bus line 68

5.2.5.1 Punctuality

Punctuality is analyzed on aggregated vehicles combining the different hours of the day and during rush-hours and out of the rush-hours, together with the location of the stops, and the driving direction of the vehicles.

5.2.5.1.1 Punctuality during the different hours of the day

The same analysis are done splitting the day in morning (6:00 - 11:59), afternoon (12:00-17:59), evening (18:00 – 23:59) and night (0:00 – 5:59) passages. Bus line 68 has trajectories in all four parts of the day. In the morning there were 149,298 (28.4%) stops recorded. In the afternoon 179,969 (34.3%), in the evening 161,766 (30.8%) and during night 34,324 (6.5%) stops were registered

Morning			
	Late + Early + Punctual = 100%		
0%  **100 %**			
	Late	**Early**	**Punctual**

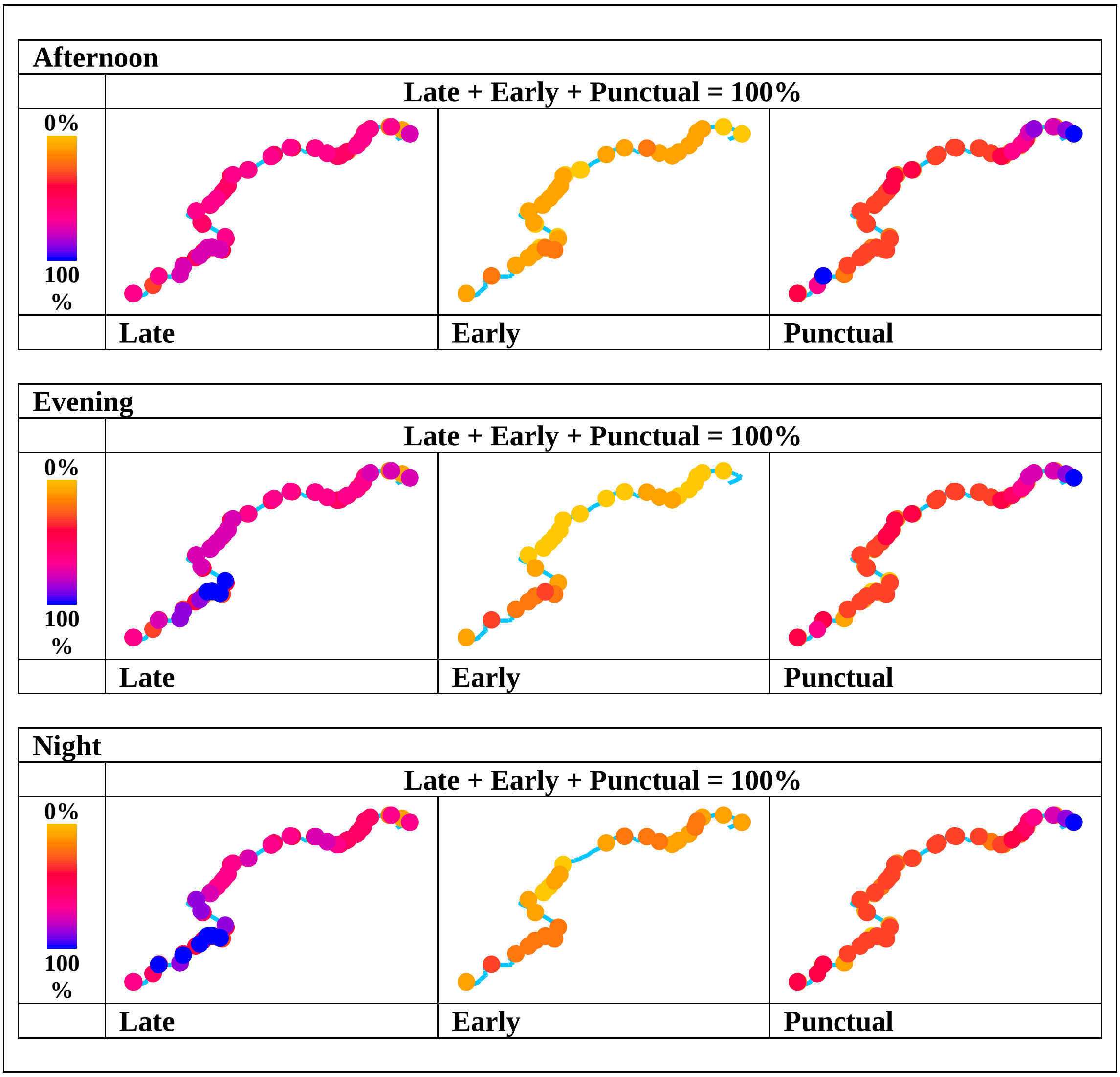
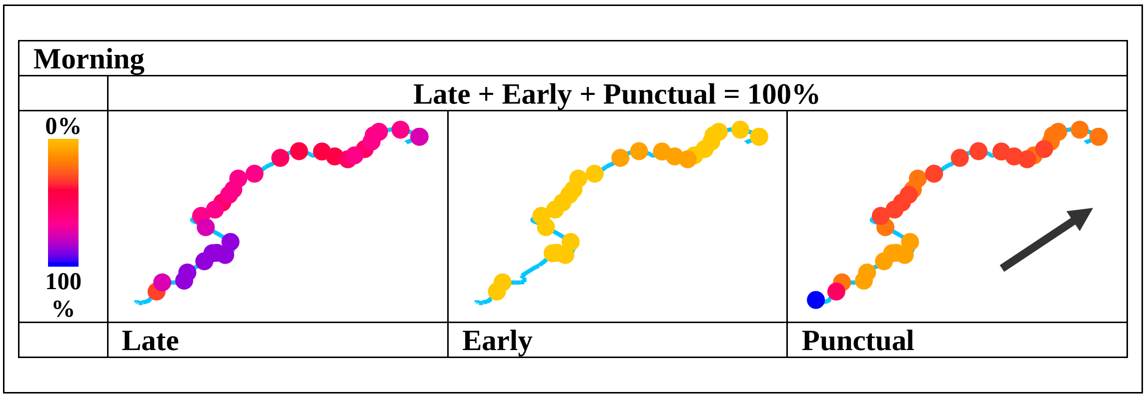


Figure 5.31.: Categorized punctuality (percentages) of vehicles traveling on bus line 68 during the different hours of the day.

No clear difference in spatial composition of the stop punctuality can be observed for the different hours of the day. Only during the afternoon, it can be stated that the percentage of late passage is lower then during the other periods of the day. Especially in the south-western part of the line the percentage of passing late are lower.



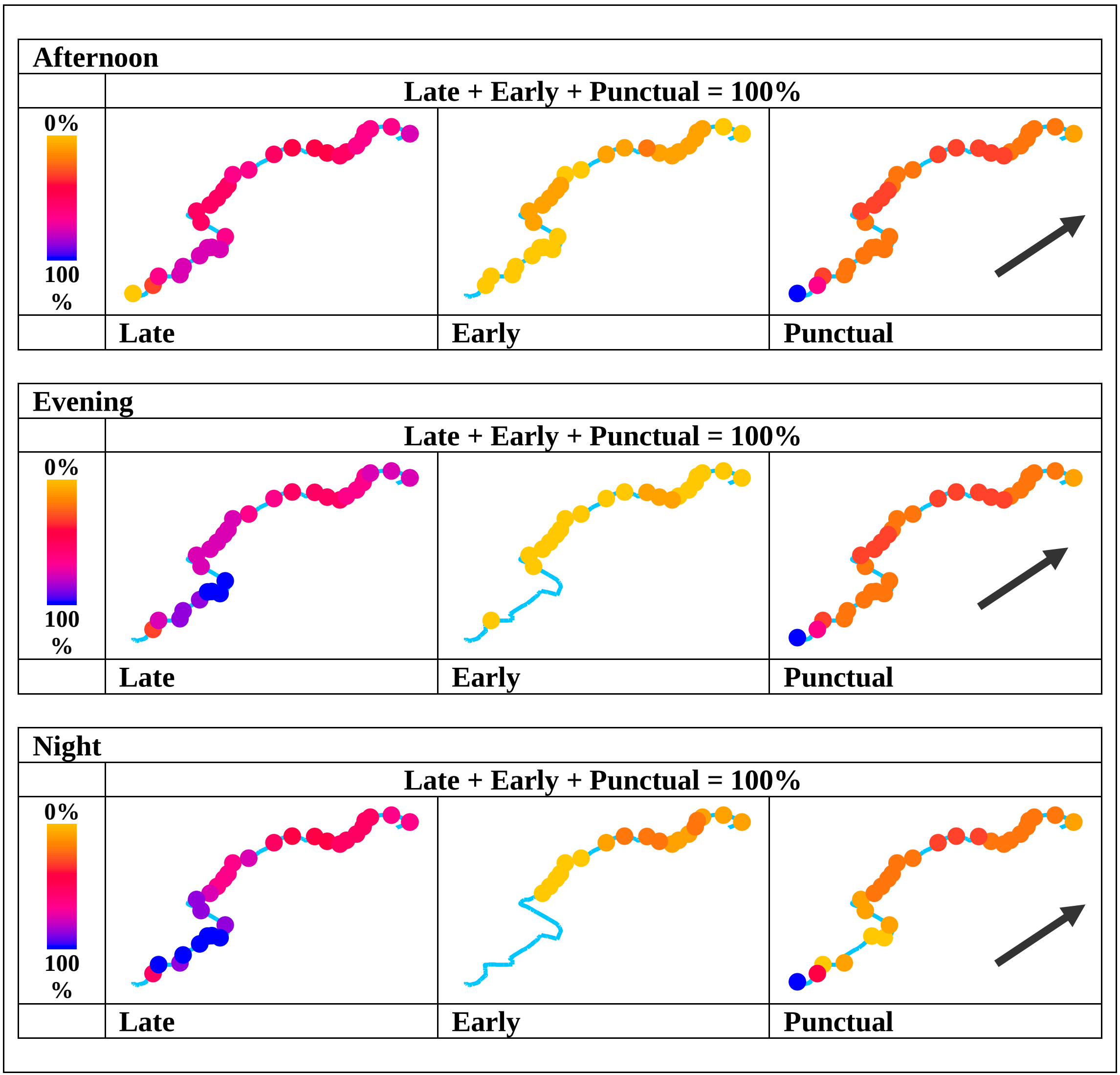


Figure 5.32a: Categorized punctuality (percentages) of vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1) during the different hours of the day.

As can be noticed in temporal analysis of the stop passages, there is a difference between the vehicles passing the line in a south-west to north-east direction and those that pass in a north-east to south-west direction. For this reason also the spatiotemporal analysis are done for both driving directions.

It can be observed that the number of vehicles passing a stop to early, increase along the line, with higher occurrences in the second half of the line (the north-eastern part). During the afternoon, the early passage starts sooner then during the other hours. In the evening and the night the early passage starts more towards the end of the line compared to the other hours. The first stop (the most south-western stop) is passed nearly always punctually on time. During the night, vehicles start more often late with their travel then the during other periods of the day. In the evening, the locations at one third of the line shows a larger concentration of late passage then the other parts of the line. This only occurs in the evening hours. During the night there are less stops passed punctually on time then during the other hours, during the same hours (the night), the punctuality is increasing along with the distance travelled along the line. This also seems to occur during the morning, but not during the afternoon and evening, where the punctual passage is nearly equal along the whole line.

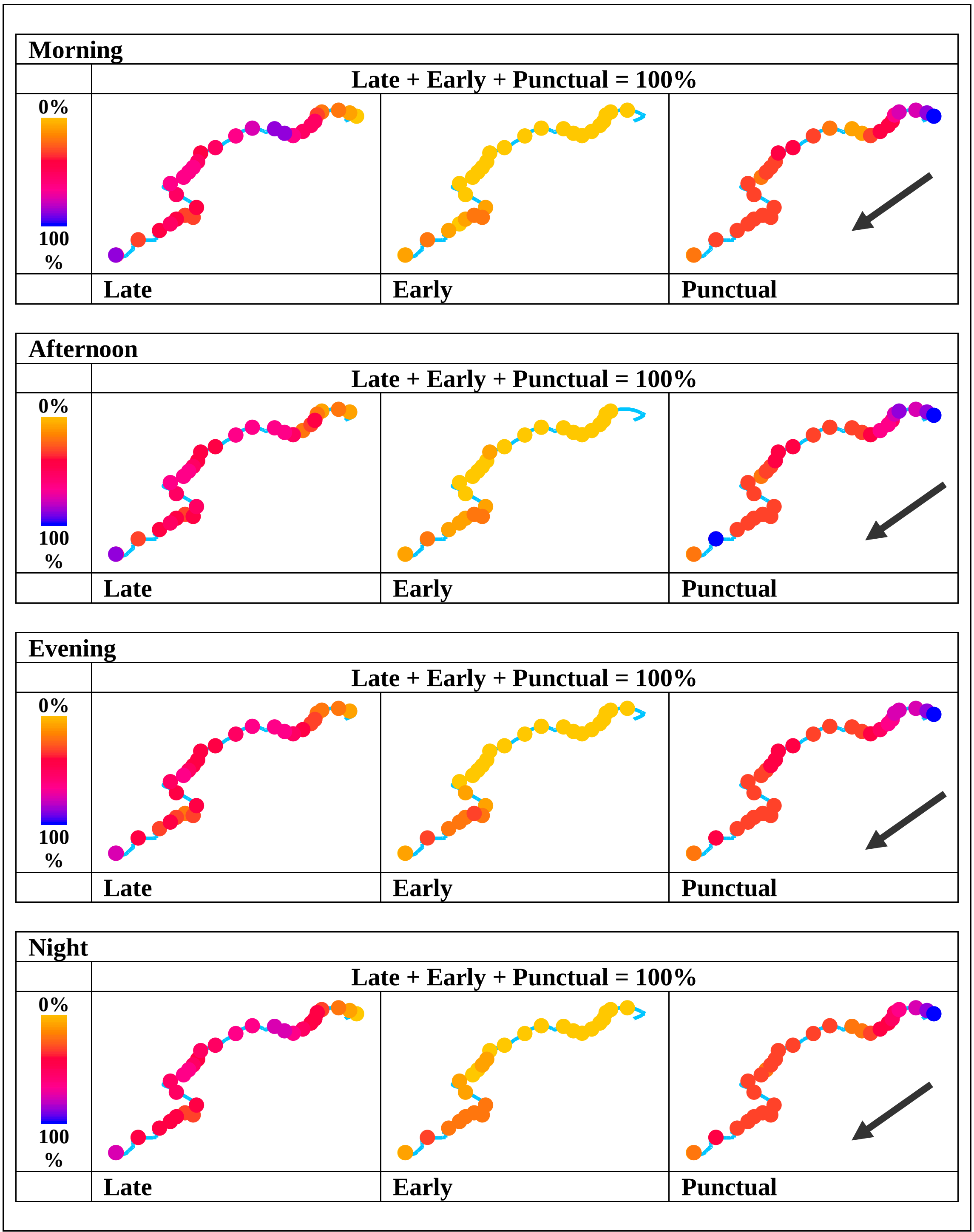


Figure 5.32b: Categorized punctuality (percentages) of vehicles traveling on bus line 68 in a north-east to south-west (direction 2) during the different hours of the day.

As said for early passages in direction 1, it can be observed that for the direction 2, travelled from north-east to south-west, that early passage occurs more often in the second half of the line. There is no clear spatiotemporal difference observed for early passages. In the morning vehicles show a low percentage of late passage at the start of their line (north-east), but suddenly after one-fifth of the line, the late passage increases, and then decreases again further onwards their travel. During the afternoon one stop at the end of the line shows an extreme high percentage of punctual passage. During all periods of the day all vehicles start their route punctually on time, but after a few stops the punctuality decreases.

5.2.5.1.2 Punctuality during the rush-hours

Next the stops are analyzed if the is a difference between rush-hours (8:00-9:30 and 17:00-18:30) and stops that were passed out of the rush-hours.

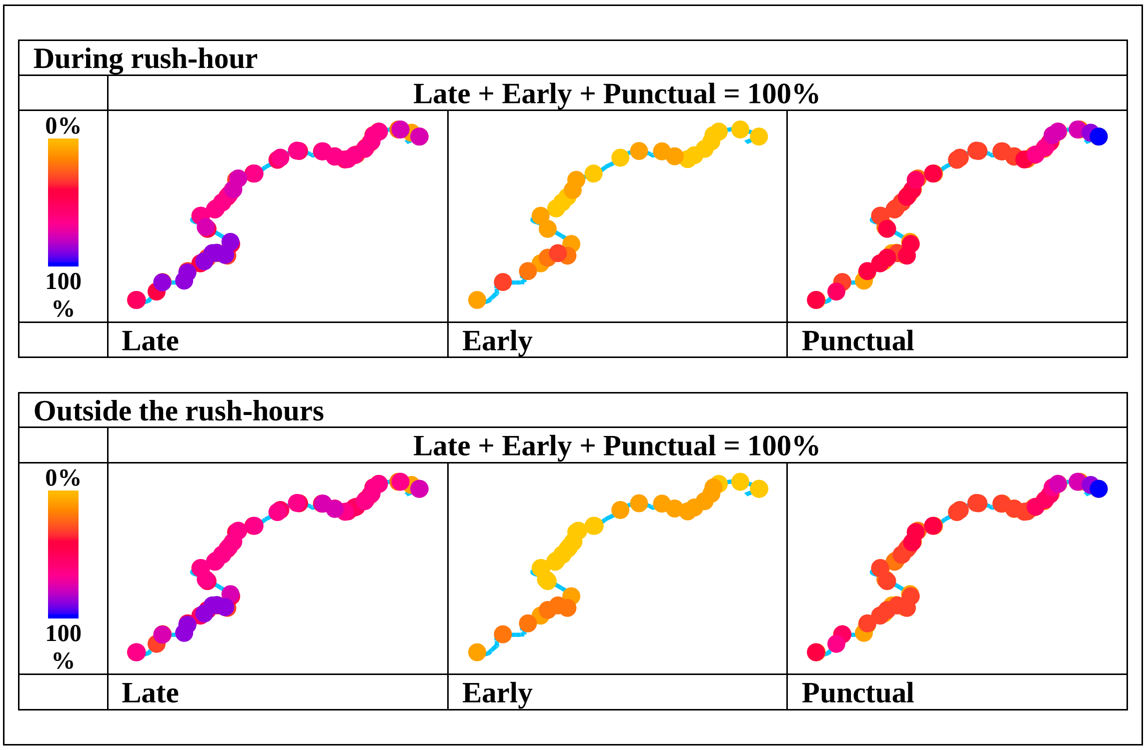
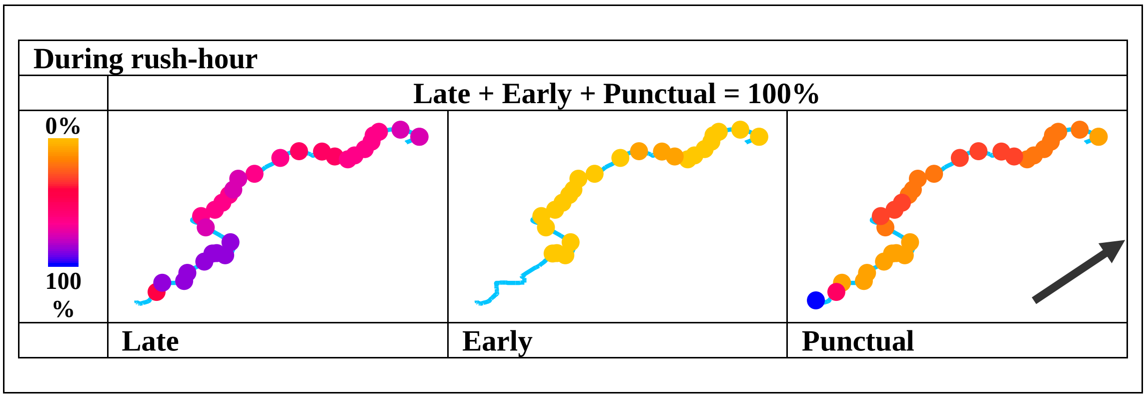


Figure 5.33: Categorized punctuality (percentages) of vehicles traveling on bus line 68 during and outside the rush-hours.

From all recorded stops 87,788 (16,7%) were registered within the rush-hour the other 437,569 (83.3%) were registered out of the rush-hours. No clear differences can be observed between the stops that are passed during the rush-hours, and those that are passed out of the rush-hours. Early passage is a bit higher in the south-west of the line during the rush hours.

The same analysis are performed for the two driving directions.



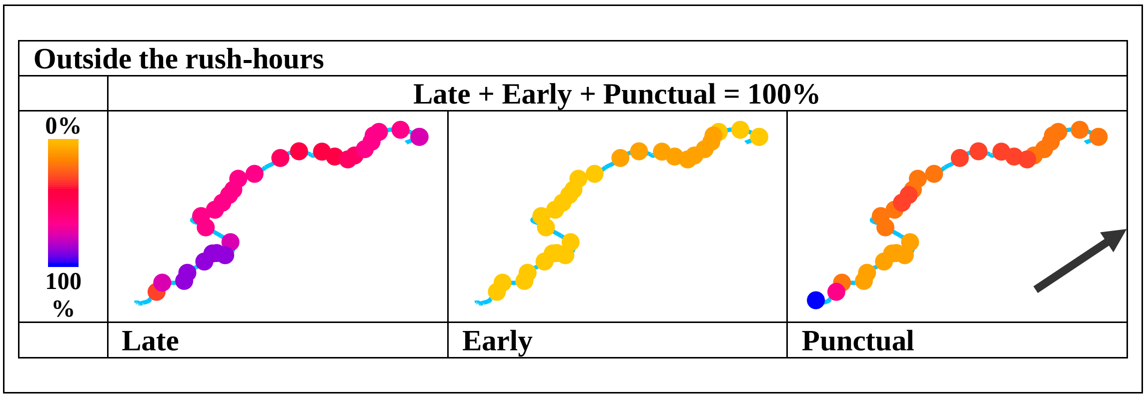


Figure 5.34a: Categorized punctuality (percentages) of vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1) during and outside the rush-hours.

In driving direction 1, from south-west to north-east, during the rush-hours, the early passage occurs later along the line then an early passages out of the rush-hours. During the rush hours there is a small tendency that stops are passed more often to late along the route then out of the rush-hours. No difference can be observed in punctual passage within or out of the rush-hours.

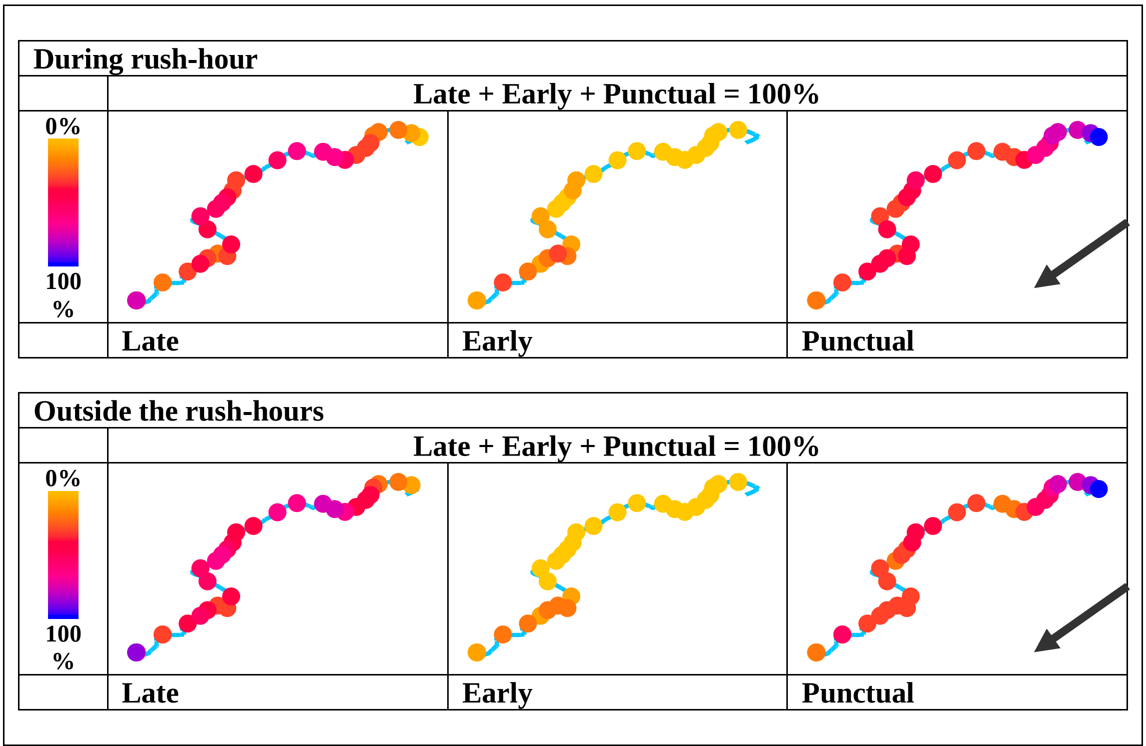


Figure 5.34b: Categorized punctuality (percentages) of vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2) during and outside the rush-hours.

For driving direction 2, from north-east to south-west, both time periods defined (within and out of the rush-hours) have an increasing stop passage along with the line. During the rush hours, the percentage of stops that are passed early is a little higher then those out of the rush hours. The spatial distribution of both periods are the same, with more early stop passages towards the end of the line.

No spatiotemporal difference can be observed for late and punctual stop passage during the defined time periods of rush-hours and outside the rush-hours.

5.2.5.2 Status

Stop status is analyzed on aggregated vehicles combining the different hours of the day and during rush-hours and out of the rush-hours, together with the location of the stops, and the driving direction of the vehicles.

5.2.5.2.1 Status during the different hours of the day

There is no clear difference in the stop status of the vehicles (stop enter, stop leave and stop passed). They are further analyzed on difference in time and location of the passage. Again the time of the day are separated in and morning, afternoon, evening and night and within rush-hours and outside rush-hours.

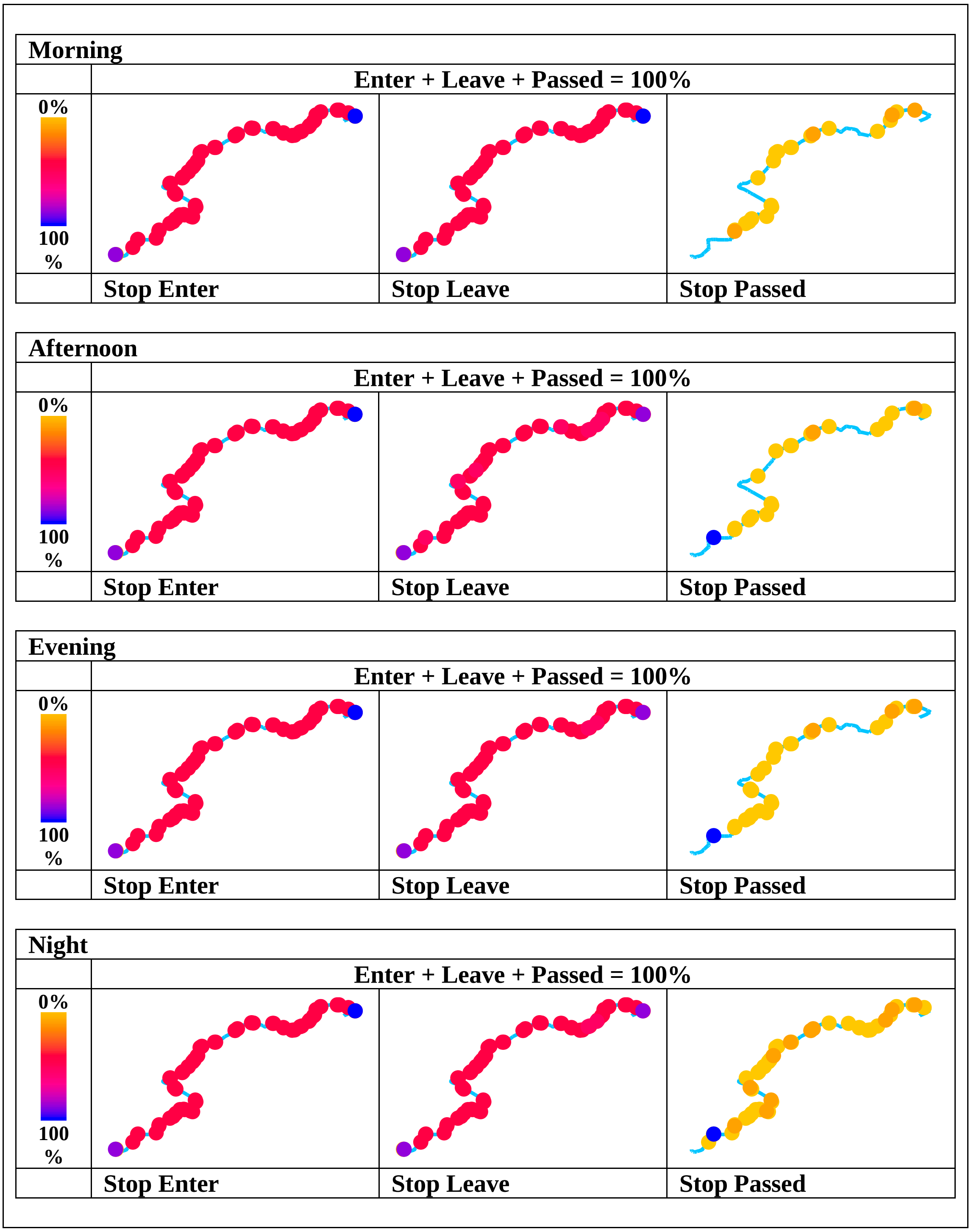


Figure 5.35: Status (percentage) of vehicles traveling on bus line 68 during the different hours of the day.

No distinction can be observed in the stop status when a differentiation is made on the time of the day a vehicle is passing a stop. As the observations are all classified from 0 to 100%, differences in stops that were passed without stopping can not be observed. For this reason, the stop status of passed is reclassified in different categories: *1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100*.

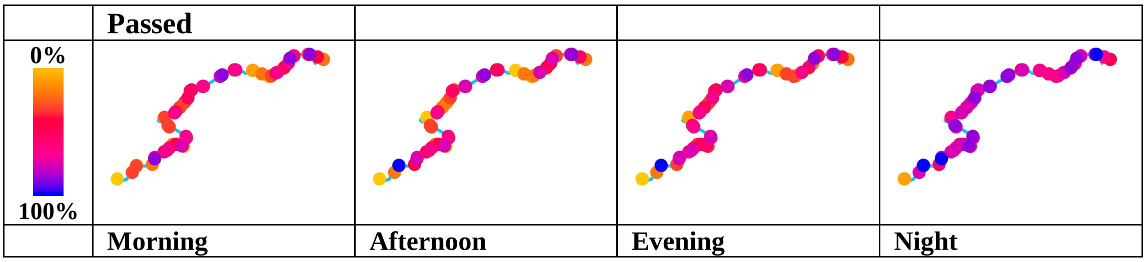


Figure 5.36 Status (passed a stop without stopping) (percentage) of vehicles traveling on bus line 68 during the different hours of the day, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

During night time, there are more vehicles passing a stop without stopping then during the other parts of the day, the distribution of these stops are equally spread along the line. During the morning, afternoon and evening, there is no clear difference in the spatiotemporal distribution of the stops being passed without stopping.

In the next part the status for the different driving directions are analyzed.

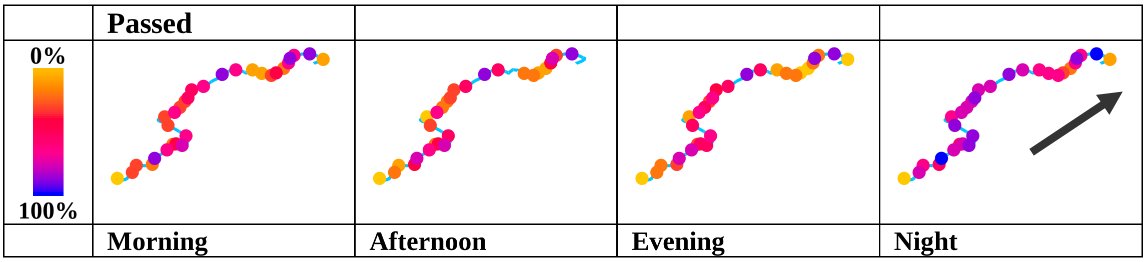


Figure 5.37a Status (passed a stop without stopping) (percentage) of vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1) during the different hours of the day, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

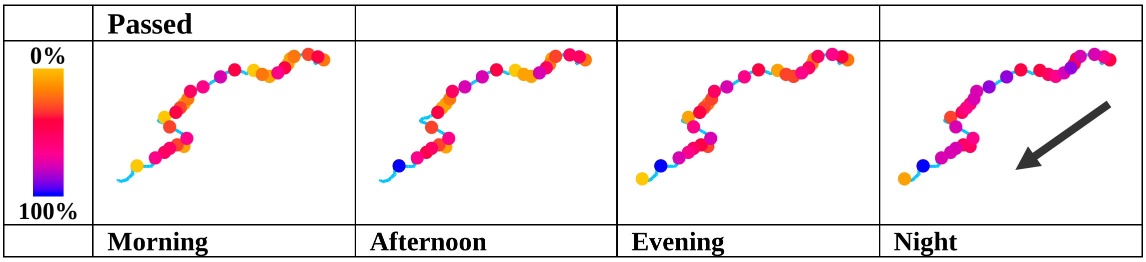


Figure 5.37b Status (passed a stop without stopping) (percentage) of vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2) during the different hours of the day, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

There is no clear spatiotemporal difference between the stops that are passed without stopping in direction 1 or 2. In direction 2, it can be observed that all stops at the south-western end of the line are passed without stopping during the afternoon, evening and night, while during the morning the stop is only passed a few times.

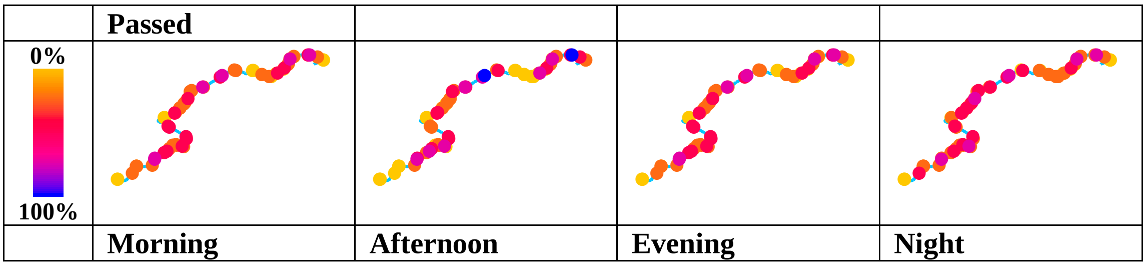


Figure 5.38: Time difference of status (passed a stop without stopping) of vehicles traveling on bus line 68, grouped per time category (sum stops morning = 100%, sum stops afternoon = 100% etc., (color scale 0-5%))

When plotting the stop passages in a different way (here all stops passed in the morning are set to 100%, and divided over all morning stops, e.g. the stops marked in purple/blue are the stops that were passed most often during the morning hours), the stop passage still tend to a random process. There is no relation between a stop being passed and the time of the day the passage occurs.

5.2.5.2.2 Status during the rush-hours

The spatiotemporal analysis is performed on stops passed during rush hours and stops passed out of rush-hours.

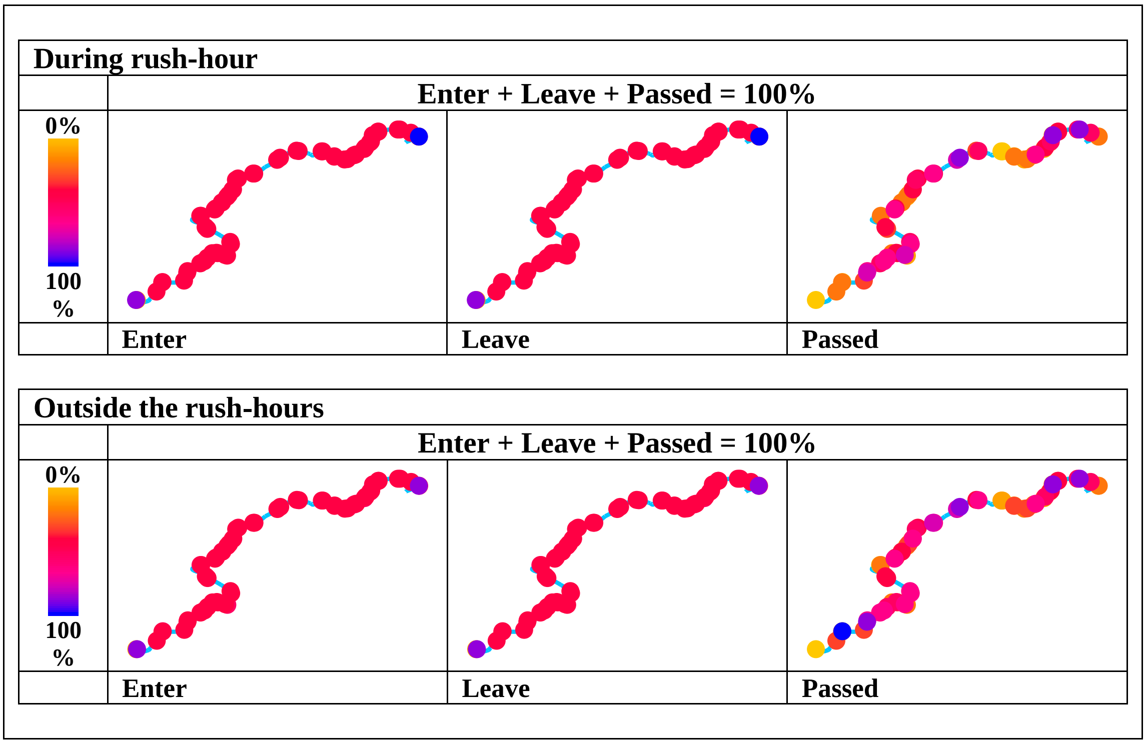


Figure 5.39: Status (percentage) of vehicles traveling on bus line 68 during and outside the rush-hours.

After differentiation in time still no difference can be observed in the stop status (stop enter and stop leave). Therefore further analysis for rush-hours, including the direction the vehicle passed the line, are only performed for stops that are passed without stopping.

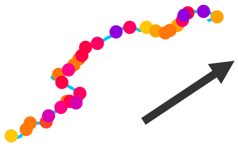
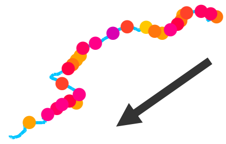
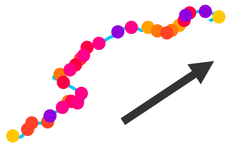
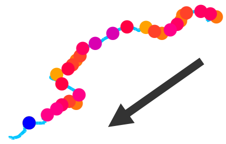
	Passed			
	Rush hours		**Outside the rush-hours**	
0%  100%				
	Direction 1	**Direction 2**	**Direction 1**	**Direction 2**

Figure 5.40 Status (passed a stop without stopping) (percentage) of vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1) and a north-east to south-west direction (direction 2), during and outside the rush-hours, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

No differences between spatiotemporal distribution on the stops being passed without stopping within and out of the rush-hours can be observed. It can only be said that the stop in the south-west of the line is always passed without stopping in direction 2 out of the rush-hours, while during the rush-hours, the stop is passed without stopping less often than the other stops along the line.

5.2.6 Spatiotemporal analysis on individual vehicles on bus line 68

5.2.6.1 Punctuality

The same analysis is performed for individual vehicles.

5.2.6.1.1 Punctuality during the different hours of the day

The analysis are done splitting the day in morning (6:00 - 11:59), afternoon (12:00-17:59), evening (18:00 – 23:59) and night (0:00 – 5:59) passages. All vehicles that were used on line 68 have trajectories in all four parts of the day.

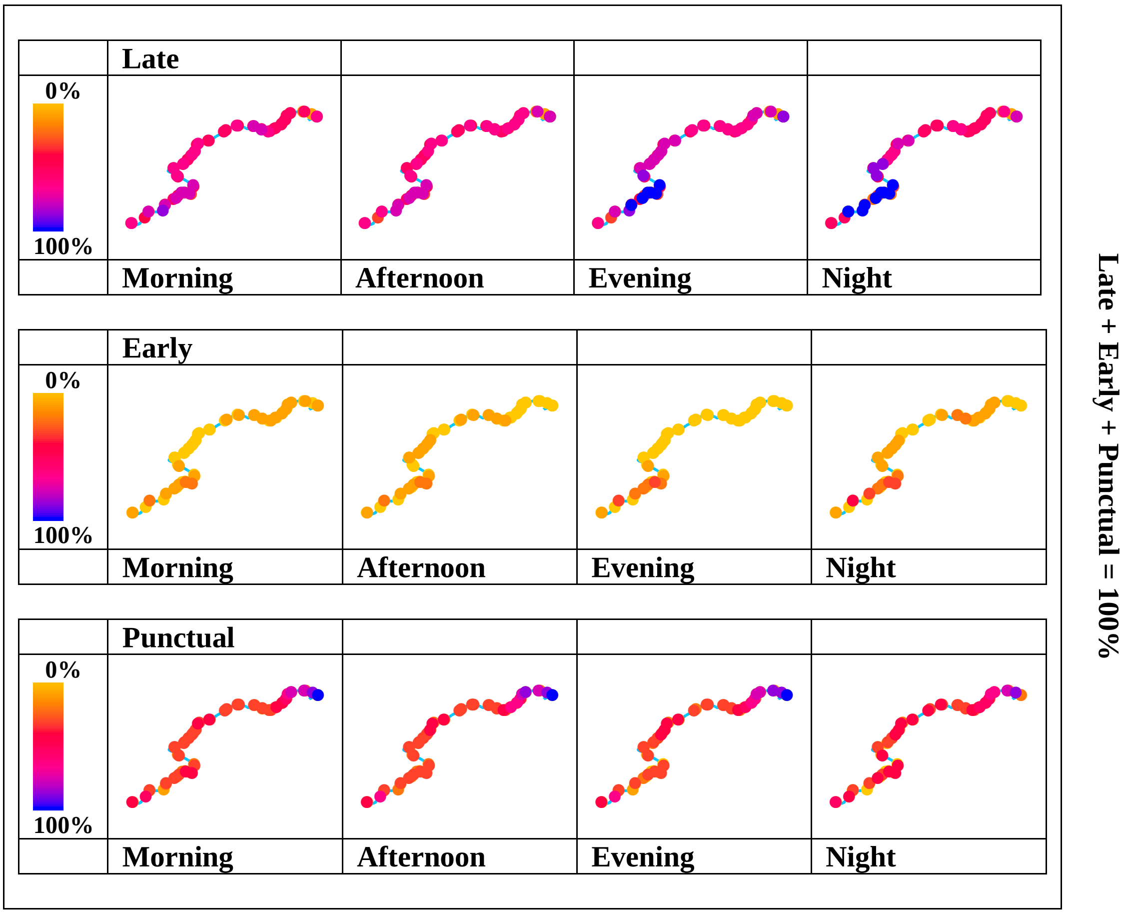


Figure 5.41a: Categorized punctuality (percentages) of individual vehicles (EFENG1061000067) traveling on bus line 68 during the different hours of the day.

During the evening and the night most of the stop in the south-west are passed to late by vehicle EFENG1061000067. During these hours also a higher number of stops that are passed to early can be observed in the south-west. No spatiotemporal difference can be observed between the stops that were passed during the morning and afternoon. No spatiotemporal difference can be observed for punctual passage, stops in the north are passed more often punctual compared to the other stops along the line.

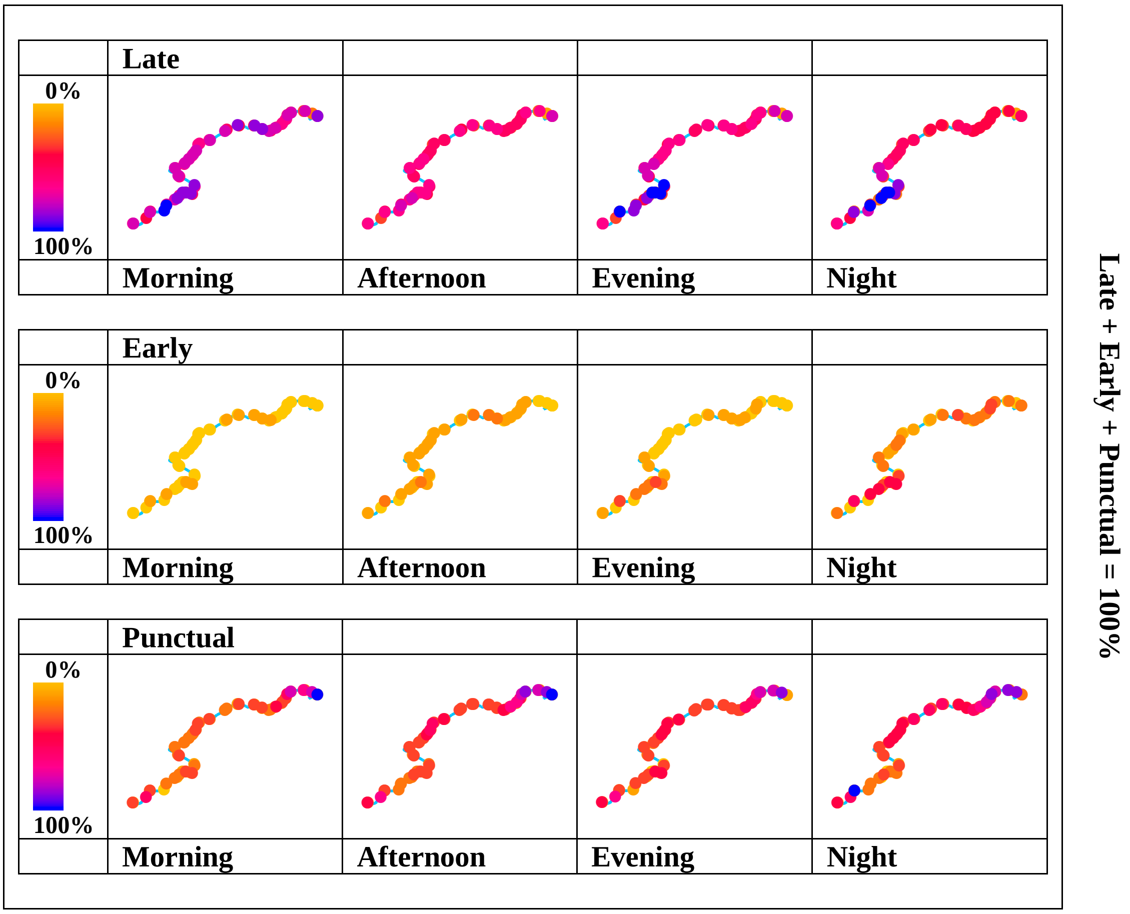


Figure 4.41b: Categorized punctuality (percentages) of individual vehicles (EFENG1061900267) traveling on bus line 68 during the different hours of the day.

Vehicles EFENG1061900267 has a higher number of stops that are passed late in the south-west during the evening and night. during the morning there is a tendency of passing stop later then during the afternoon. During the evening there a higher number of stops are passed earlier in the south-west than in the rest of the line. during the night stops at the start/end of the line are passed more often to early than others. During night there is one stop at the south-east that is always passed punctual. All the other punctually passed stops are comparable for all defined moments of the day.

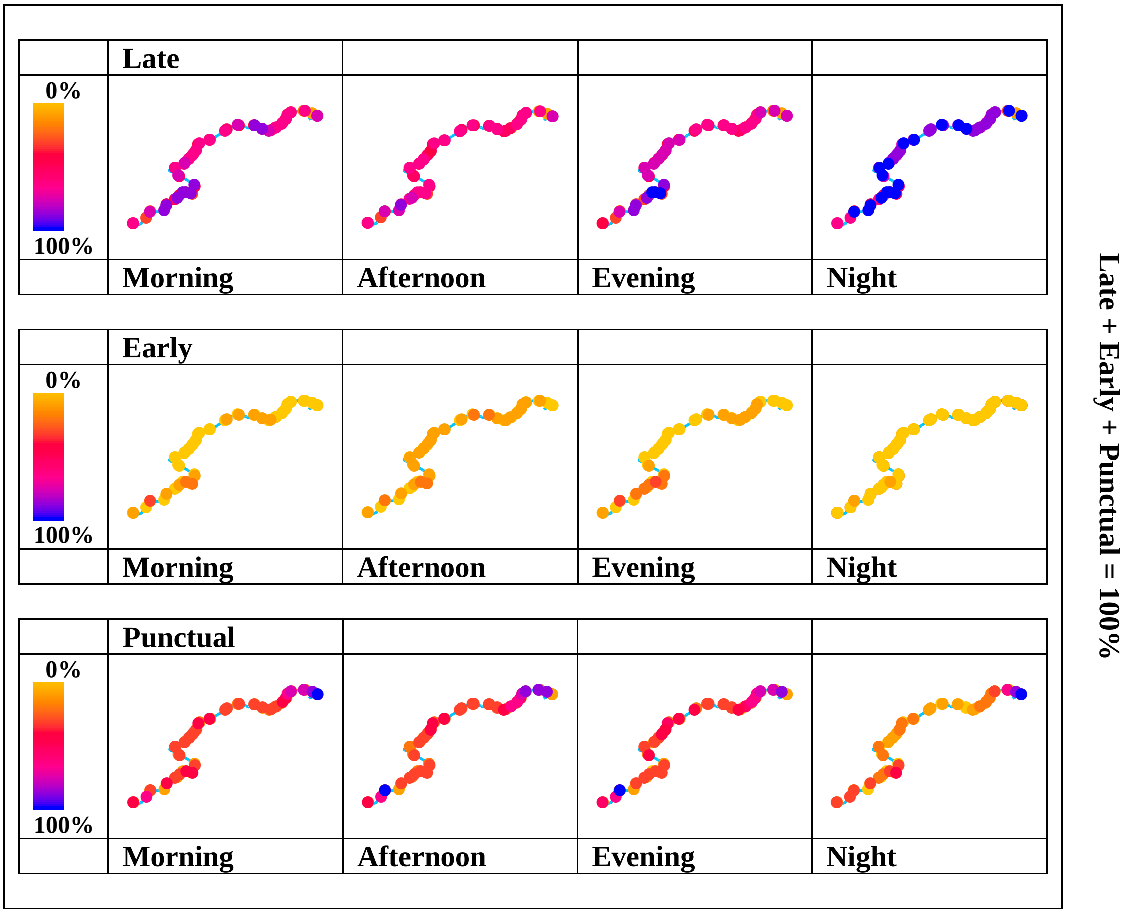


Figure 5.41c: Categorized punctuality (percentages) of individual vehicles (EFENG1062200066) traveling on bus line 68 during the different hours of the day.

Vehicle EFENG1062200066 passed during the night nearly all stops to late. In the evening, late passage can be observed in the south-west of the line. During the evening there are more early passages in the south-west. In the afternoon, the early passages are for all stop comparable. During all moments of the day stops in the north-east are past punctually on time. During the night, the percentage of punctual passages is lower along the compete line then during the other times of the day. During the afternoon and evening there is one stop at the south-west that is always passed on time.

5.2.6.1.1.1 Punctuality during the different hours of the day in direction 1

In the next part the same analysis are performed, taking the different driving directions into account. The first part explores the south-west to north-east direction (direction 1)

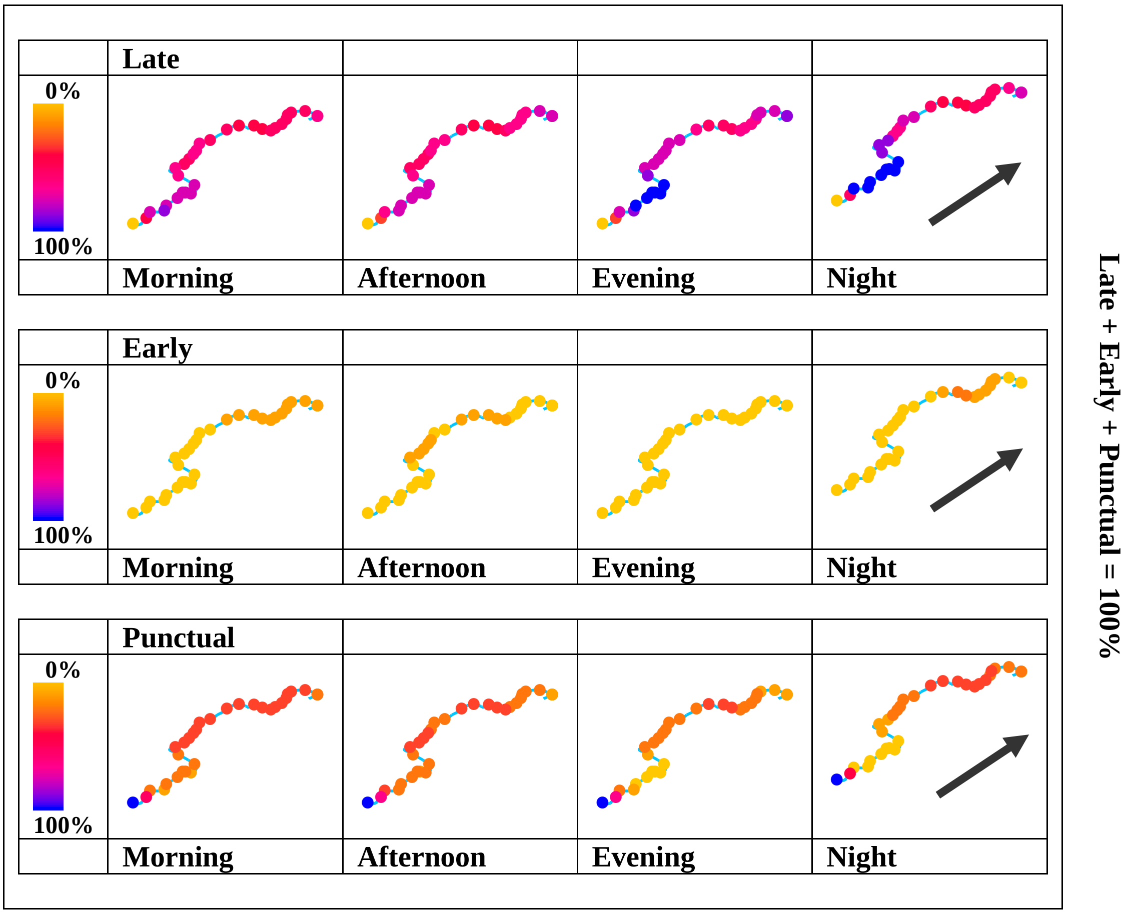


Figure 5.42a: Categorized punctuality (percentages) of individual vehicles (EFENG1061000067) traveling on bus line 68 in a south-west to north-east direction (direction 1) during the different hours of the day.

During all moments of the day vehicle EFENG1061000067 start its route punctually on time. In the evening and night, the delay already starts after a few stops, from the third stop in the south-west until about half way the line, all stops are passed to late. after half of the line, the delay is decreasing, and the percent of punctual passage becomes higher. During the night, even an increase in early passage at the end of the line in the north-east can be observed. During the evening the punctual passage is first decreasing in the beginning of the line, and increases after the half of the line is passed. There is no clear spatiotemporal difference between the morning and afternoon. During the afternoon, the rate of late passage at the end of the line is a little larger then in the morning.

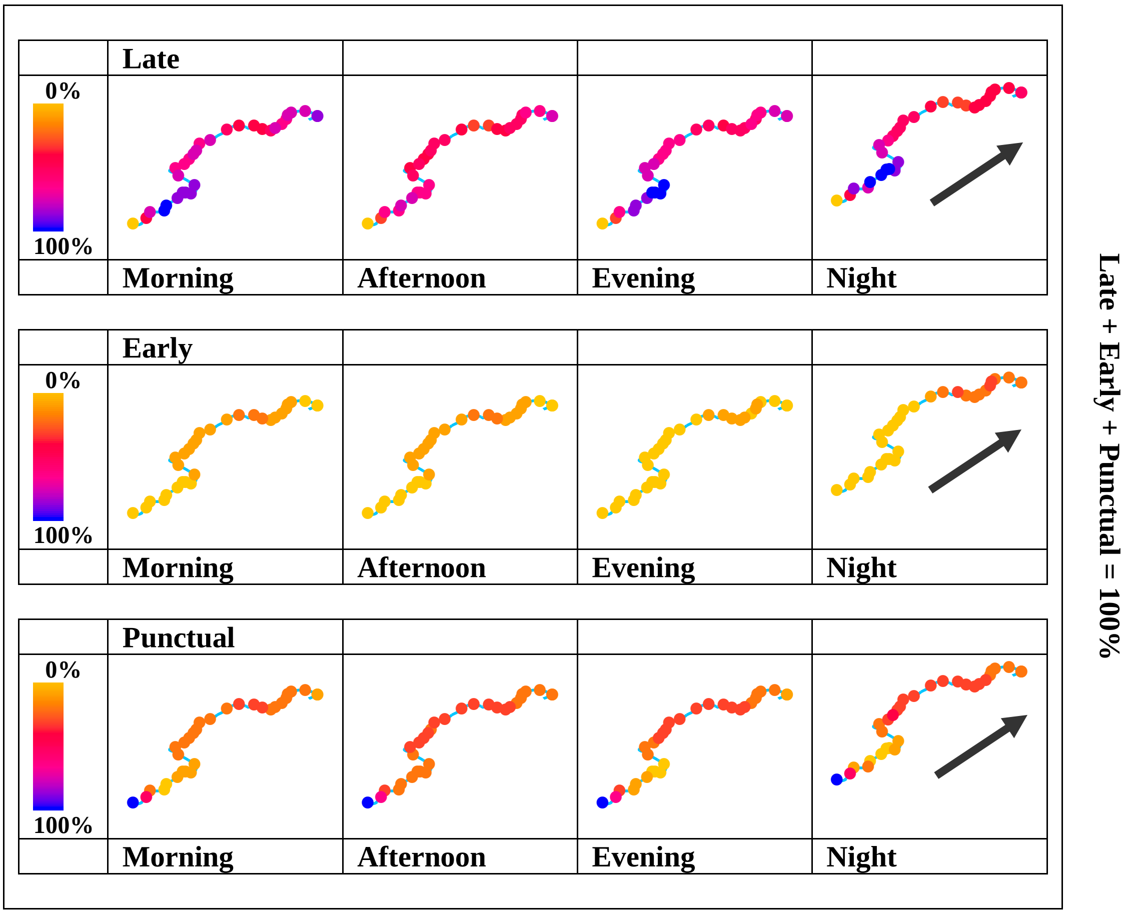


Figure 5.42b: Categorized punctuality (percentages) of individual vehicles (EFENG1061900267) traveling on bus line 68 in a south-west to north-east direction (direction 1) during the different hours of the day.

Vehicle EFENG1061900267 starts all of its travels on time. During the morning, evening and night, the late passage of stops starts already after a few stops. During the afternoon a late passage is compared with the other times of the day lower along the complete route, this can also be observed in the punctual passage. During the night stops at the end of the line (in the north-east) are passed more often to early.

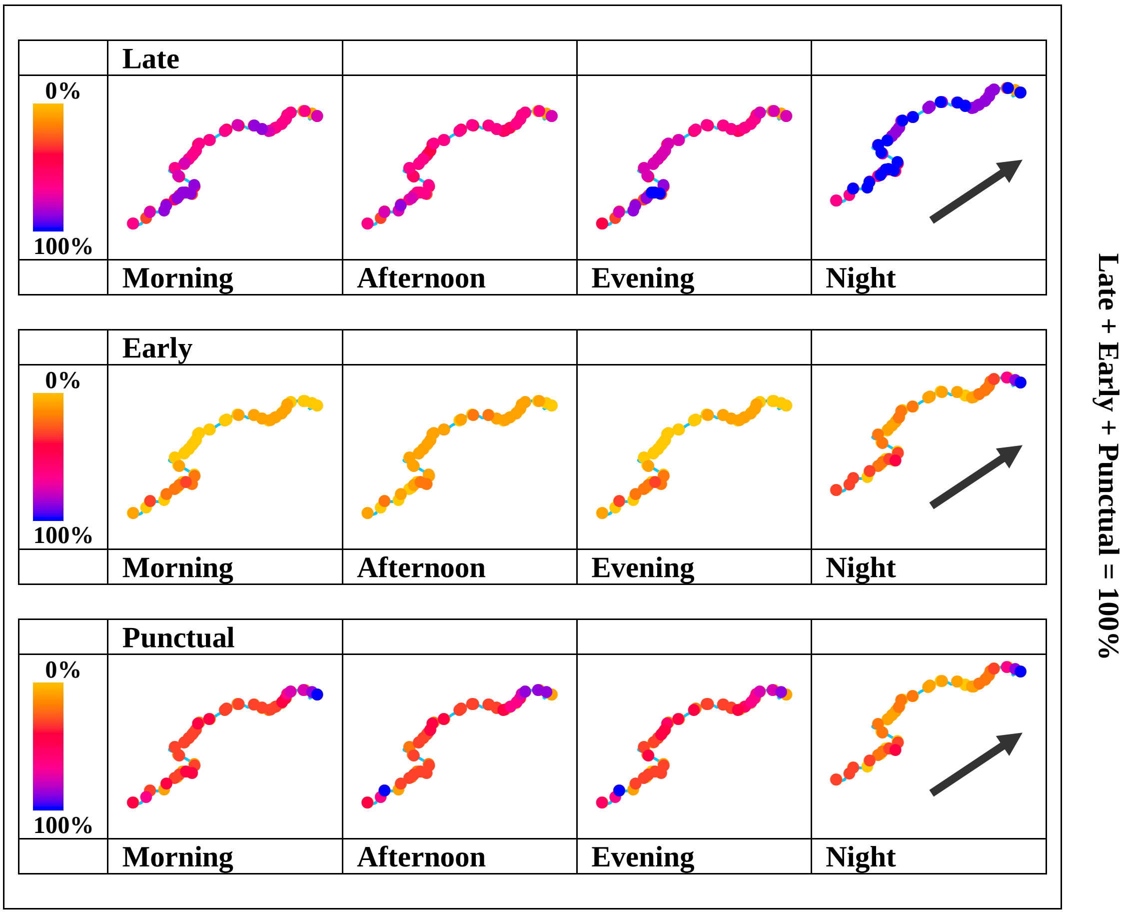


Figure 5.42c: Categorized punctuality (percentages) of individual vehicles (EFENG1062200066) traveling on bus line 68 in a south-west to north-east direction (direction 1) during and the different hours of the day.

During the night nearly all stops traveled by vehicle EFENG1062200066 in a south-east to north-west direction, are passed to late. During the evening, the late passage is the highest at the beginning of the line. In the afternoon, a late passage is about equal along the complete line, a few more stops are passed to late in the beginning of the line. In the morning there is a large spatial variability in the late stop passage. Stops in the beginning of the line are, during all defined time intervals, passed more often to early then further on along the line, only during the night stops at the end of the line are also passed early.

5.2.6.1.1.2 Punctuality during the different hours of the day in direction 2

The second part explores the north-east to south-west direction (direction 2)

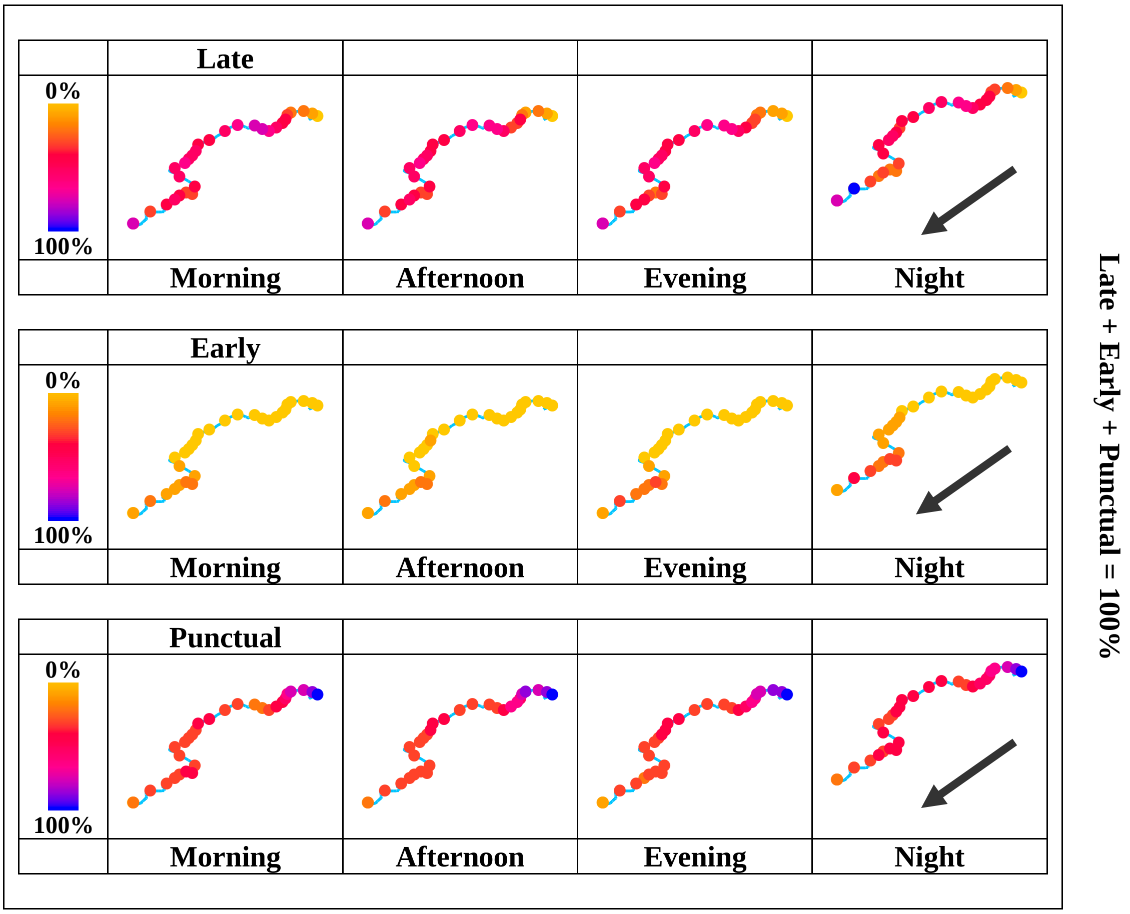


Figure 5.43a: Categorized punctuality (percentages) of individual vehicles (EFENG1061000067) traveling on bus line 68 in a north-east to south-west direction (direction 2) during and the different hours of the day.

The last stops at the end of the line travelled by vehicle EFENG1061000067 during the night are most often past late. During all defined time intervals the stops at the beginning of the line are passed less often late, compared to the stops further along the line. The same can be observed for stops that are passed early; stops at the end of the line are passed more often to early then at the beginning of the line. During the evening and night the percentage of early passage at the end of the line is higher then during the morning end afternoon hours. Stops passed to late are also decreasing a little during the evening and night passage. One stop near the end of the line is passed always late during the night.

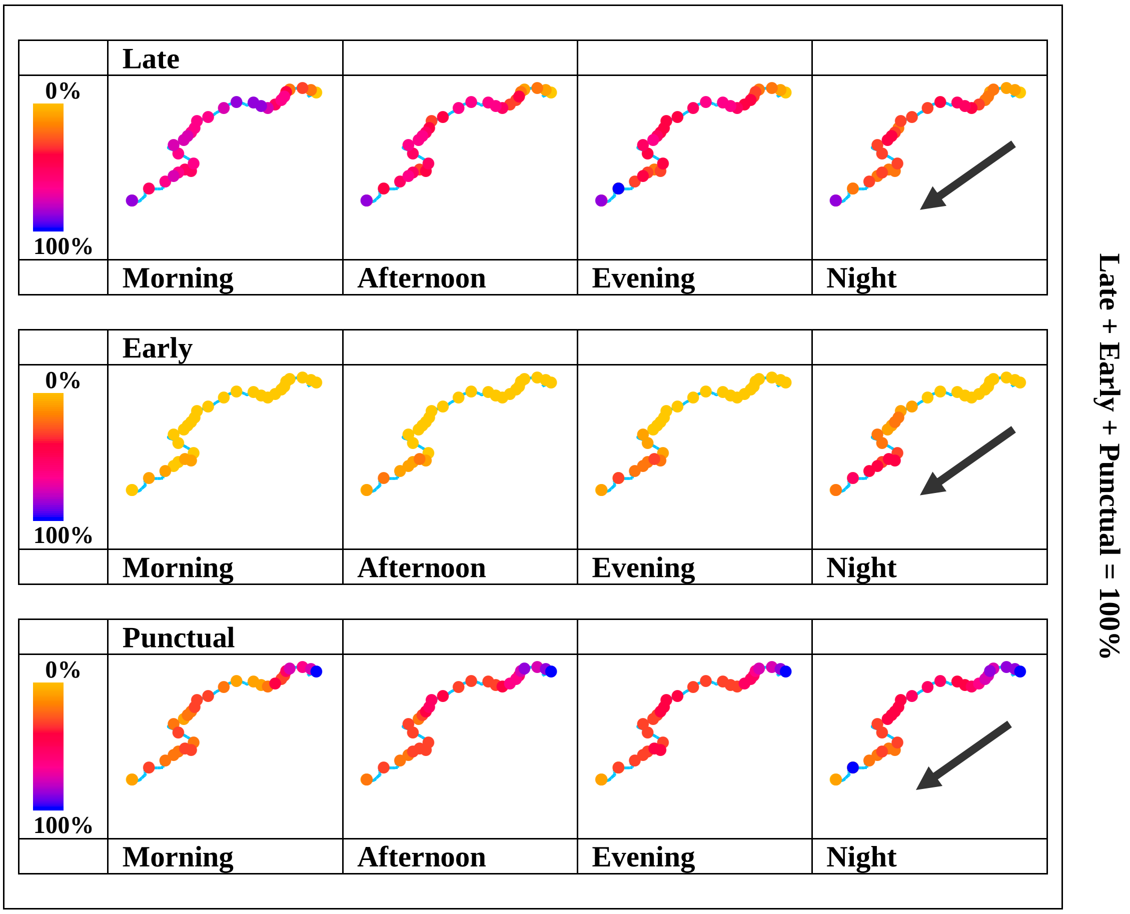


Figure 5.43b: Categorized punctuality (percentages) of individual vehicles (EFENG1061900267) traveling on bus line 68 in a north-east to south-west direction (direction 2) during and the different hours of the day.

During the morning vehicle EFENG1061900267 has a high spatial variability in it late passage, at the beginning of the line, the vehicle starts with punctual passage, but after a few stops, the stops are passed late. and keeps on fluctuating around between 50% and 70% of a stop being passed to late. During the night the overall late passage is lower then during the other hours. At the end of the line, the percentage of early passage is higher during the evening and night. During night the early passage at the end of the line is higher then during the evening. One stop at the end of the line is always passed punctually on time during the night. During the evening the end of the line has a higher number of punctual passages then during the other hours of the day.

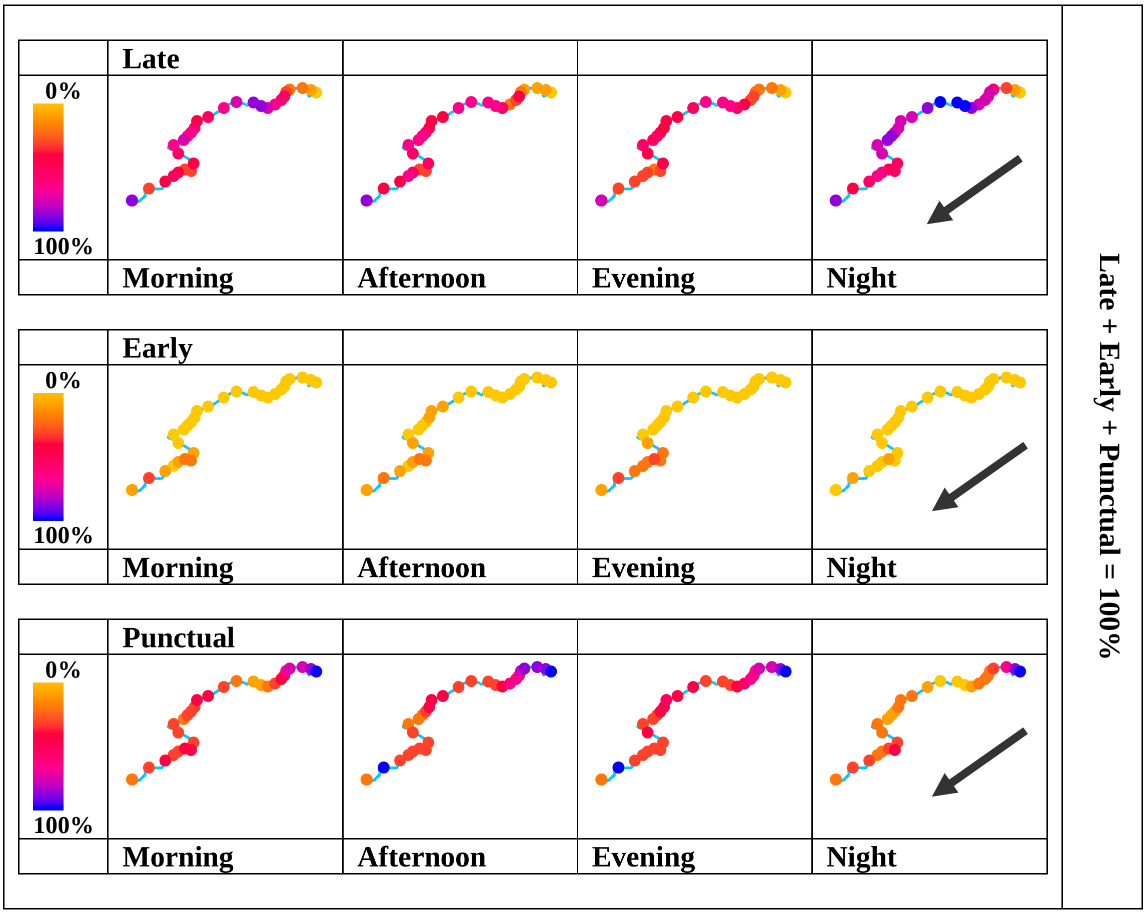
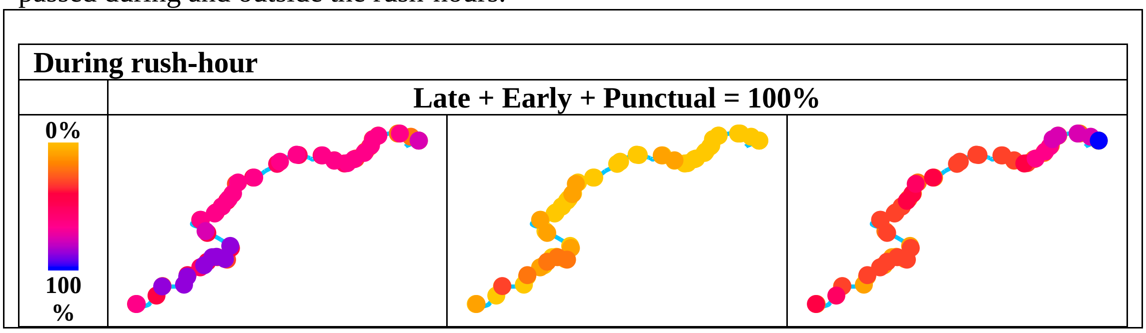


Figure 5.43c: Categorized punctuality (percentages) of individual vehicles (EFENG1062200066) traveling on bus line 68 in a north-east to south-west direction (direction 2) during and the different hours of the day.

Vehicle EFENG1062200066 has during the night more often a late passage then during the other hours of the day, these are located a few stops after the start of the line, increasing to 90-100% of late passage, and next decreasing percentages along the line. During the evening, at the end of the line, more stops are passed to early, this can also be observed during the morning and afternoon, although less then in the evening. During the night, there is no spatial difference in early passage along the line. Punctual passage during the afternoon and the evening start with high percentages at the beginning of the line, and decrease along the route. In the morning the decrease is later along the line then during the afternoon and evening. During the night the punctual passage drops after a few stops to around 10% of the passages, and increases again further along the line.

5.2.6.1.2 Punctuality during the rush-hours

The same exploration as made for the different hours of the day is performed for the stops passed during and outside the rush-hours.



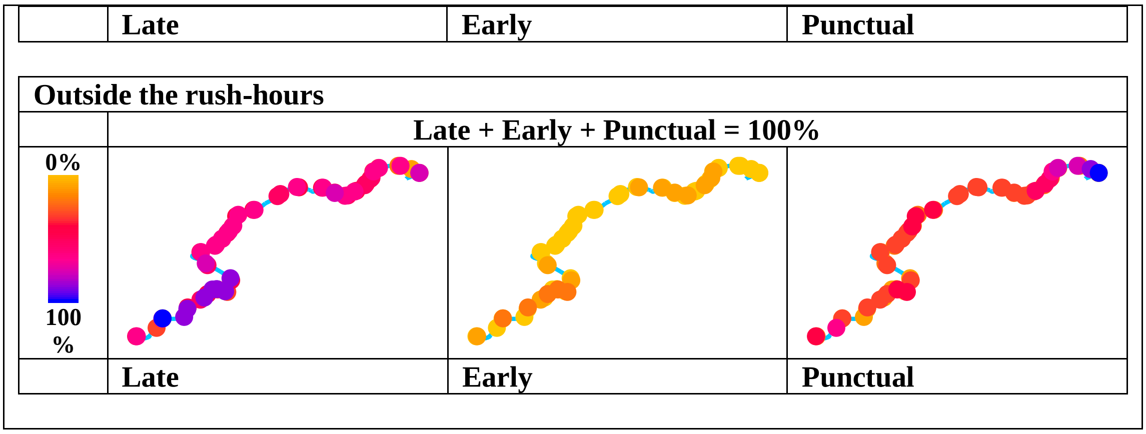


Figure 5.44a: Categorized punctuality (percentages) of individual vehicles (EFENG1061000067) traveling on bus line 68 during and outside the rush-hours.

No differences can be observed between the stops passed by vehicle EFENG1061000067 during and outside the rush-hours.

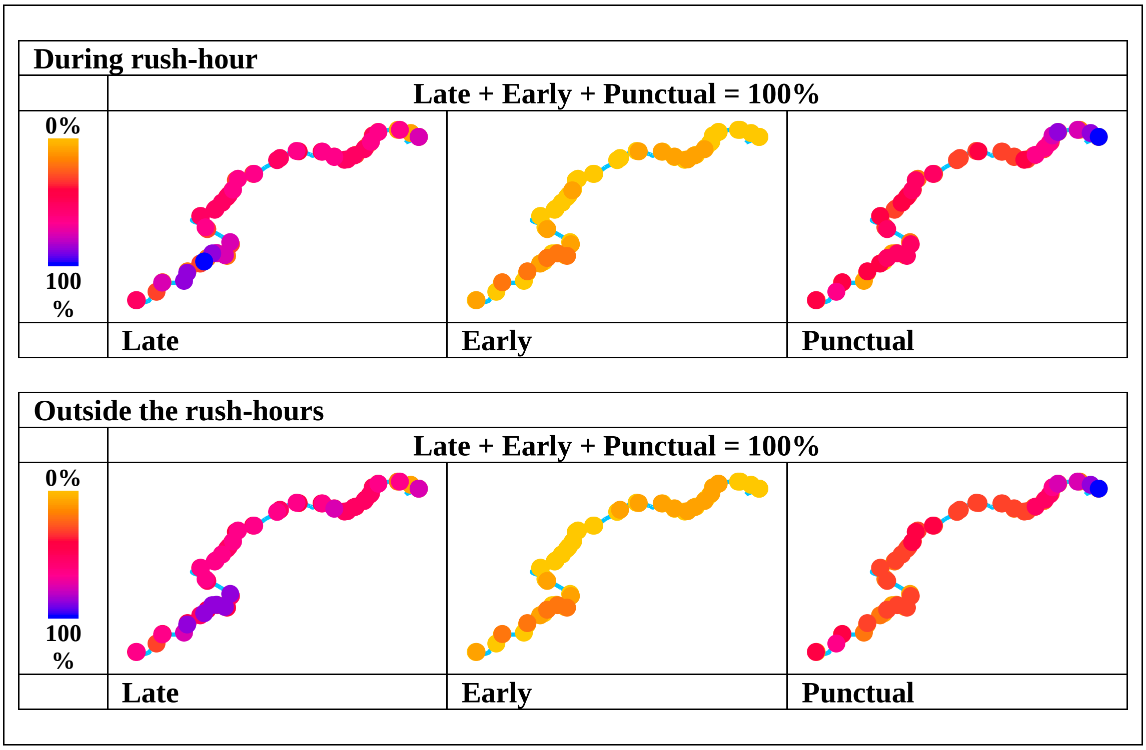


Figure 5.44b: Categorized punctuality (percentages) of individual vehicles (EFENG1061900267) traveling on bus line 68 during and outside the rush-hours.

Also for vehicle EFENG1061900267 no differences can be observed between stops passed during or outside the rush-hours.

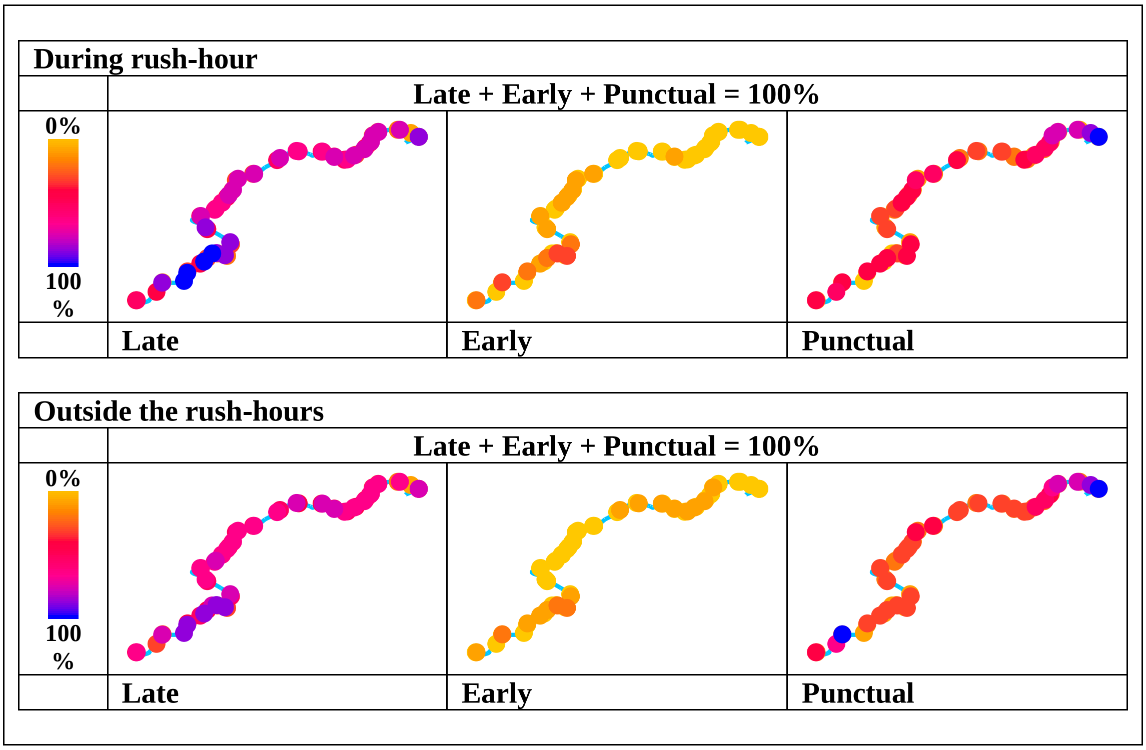


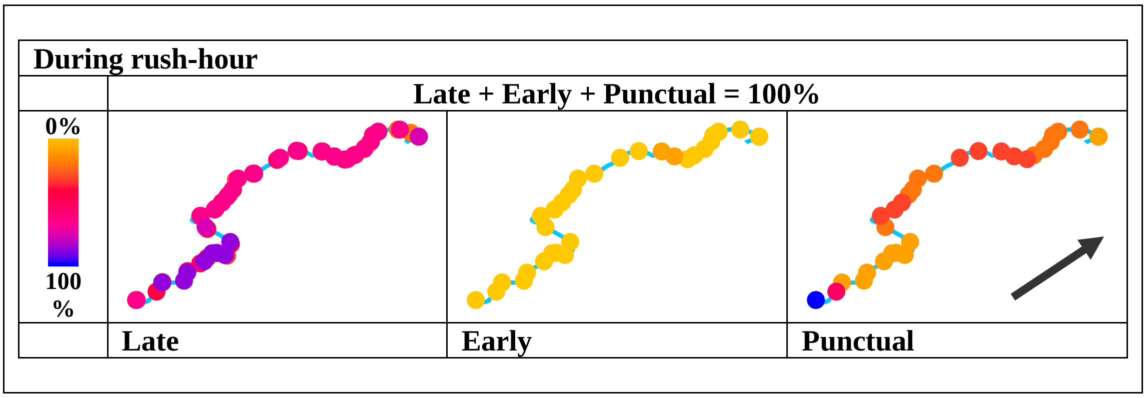
Figure 5.44c: Categorized punctuality (percentages) of individual vehicles (EFENG1062200066) traveling on bus line 68 during and outside the rush-hours.

Vehicle EFENG1062200066 has more stops passed late at the south-east of the line, there is a small difference between the stops passed during the rush-hours (at the south-west of the site reaching nearly 100% of the passages to be late) and those passed out of the rush-hours.

5.2.6.1.2.1 Punctuality during the rush-hours in direction 1

Again the analysis is split in the two driving directions, the first part describes the exploration of vehicles driving from south-west to north-east

.



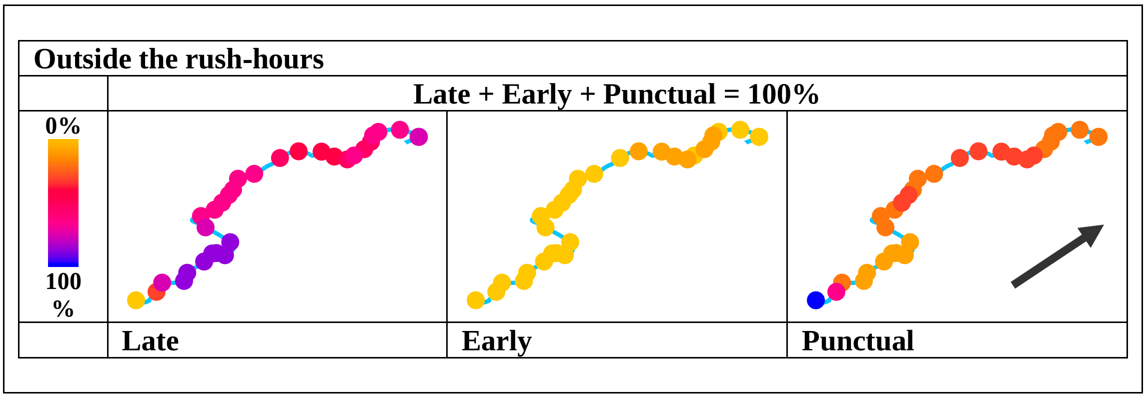


Figure 5.45a: Categorized punctuality (percentages) of individual vehicles (EFENG1061000067) traveling on bus line 68 in a south-west to north-east direction (direction 1) during and outside the rush-hours.

No clear difference can be observed for stops passed by vehicle EFENG1061000067 during the rush-hours, and those that are passed out of the rush-hours.

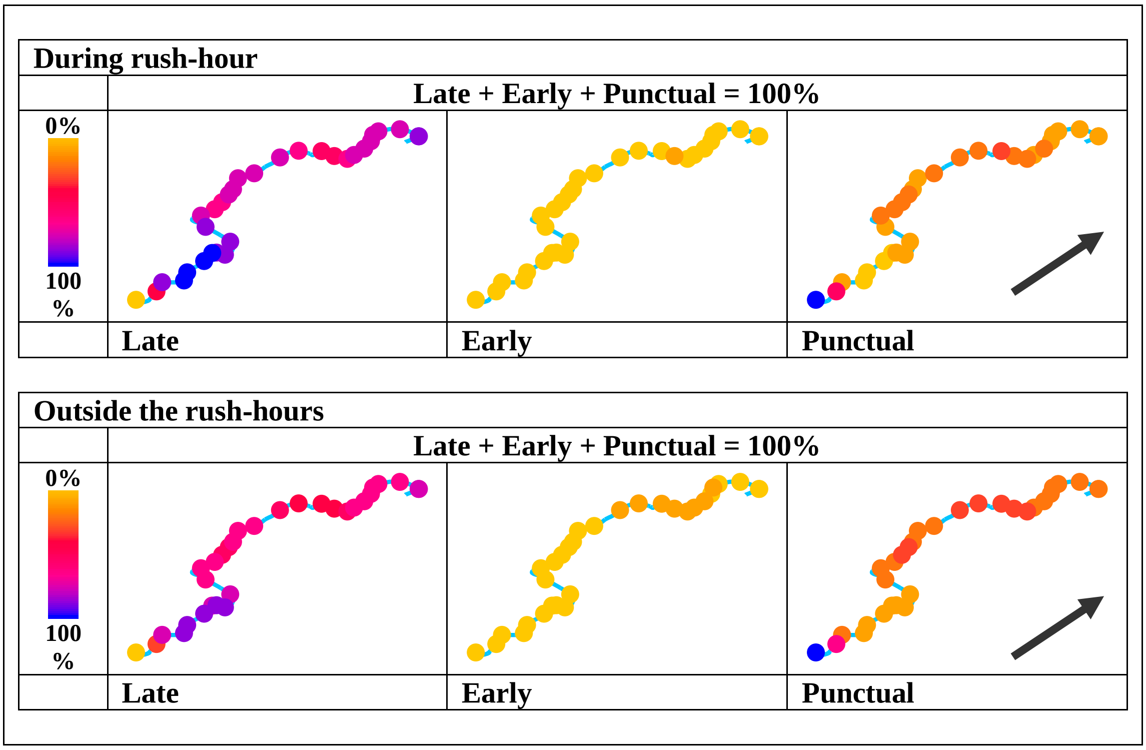


Figure 5.45b: Categorized punctuality (percentages) of individual vehicles (EFENG1061900267) traveling on bus line 68 in a south-west to north-east direction (direction 1) during and outside the rush-hours.

Stops passed by vehicle EFENG1061900267 are more punctual outside the rush-hours, then during the rush-hours. After a punctual start, the number of stops that are passed punctual decreases rapidly towards 10%, along the rest of the line, the number of stops passed punctually is increasing. This increase goes faster out of the rush-hours, then during the rush-hours. The number of stops passed early is a little higher at the end of the line outside the rush-hours then during the rush-hours. Late passages is along the whole line a little higher during the rush-hours then out of the rush-hours.

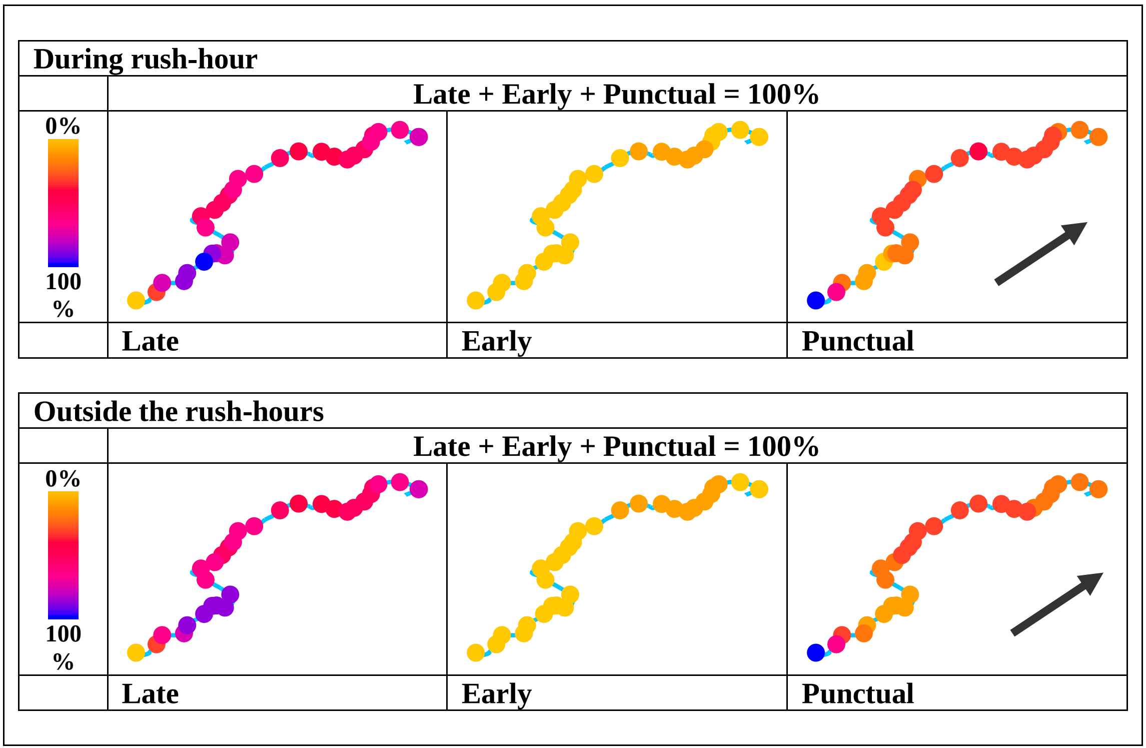
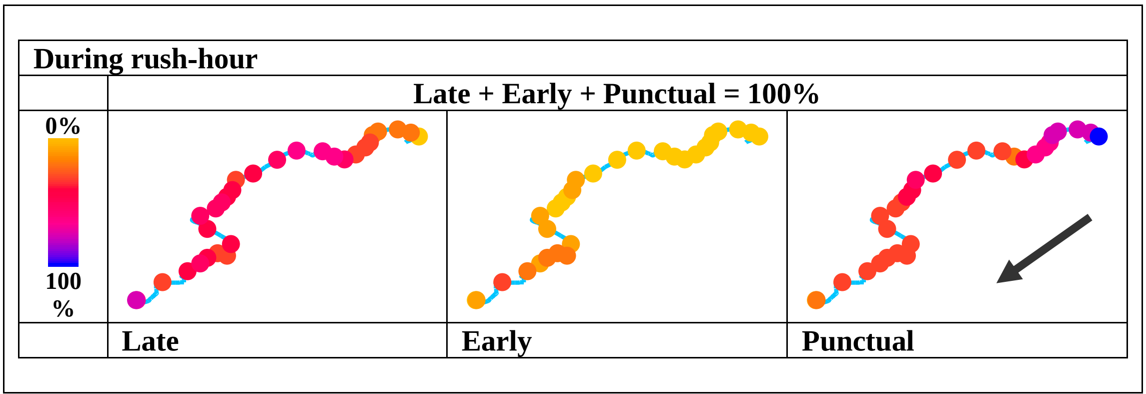


Figure 5.45c: Categorized punctuality (percentages) of individual vehicles (EFENG1062200066) traveling on bus line 68 in a south-west to north-east direction (direction 1) during and outside the rush-hours.

Vehicle EFENG1062200066 shows a small spatial difference between late passage during the rush-hours and outside the rush-hours at the beginning of the line.

5.2.6.1.2.2 Punctuality during the rush-hours in direction 2

The second part describes the exploration for vehicles driving form north-east to south-west.



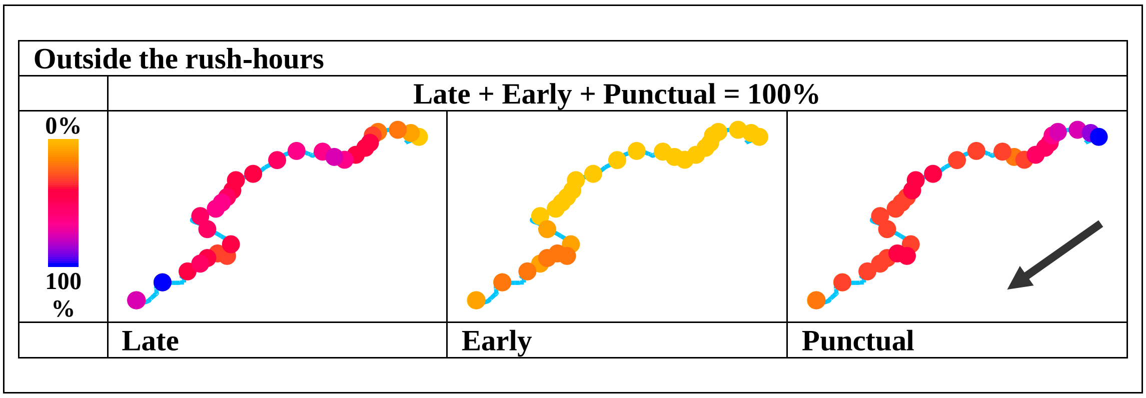


Figure 5.46a: Categorized punctuality (percentages) of individual vehicles (EFENG1061000067) traveling on bus line 68 in a north-east to south-west direction (direction 2) during and outside the rush-hours.

The increase of early passage of vehicle EFENG1061000067 starts a little later out of the rush-hours (after two third of the line) then during the rush-hours (halfway of the line).

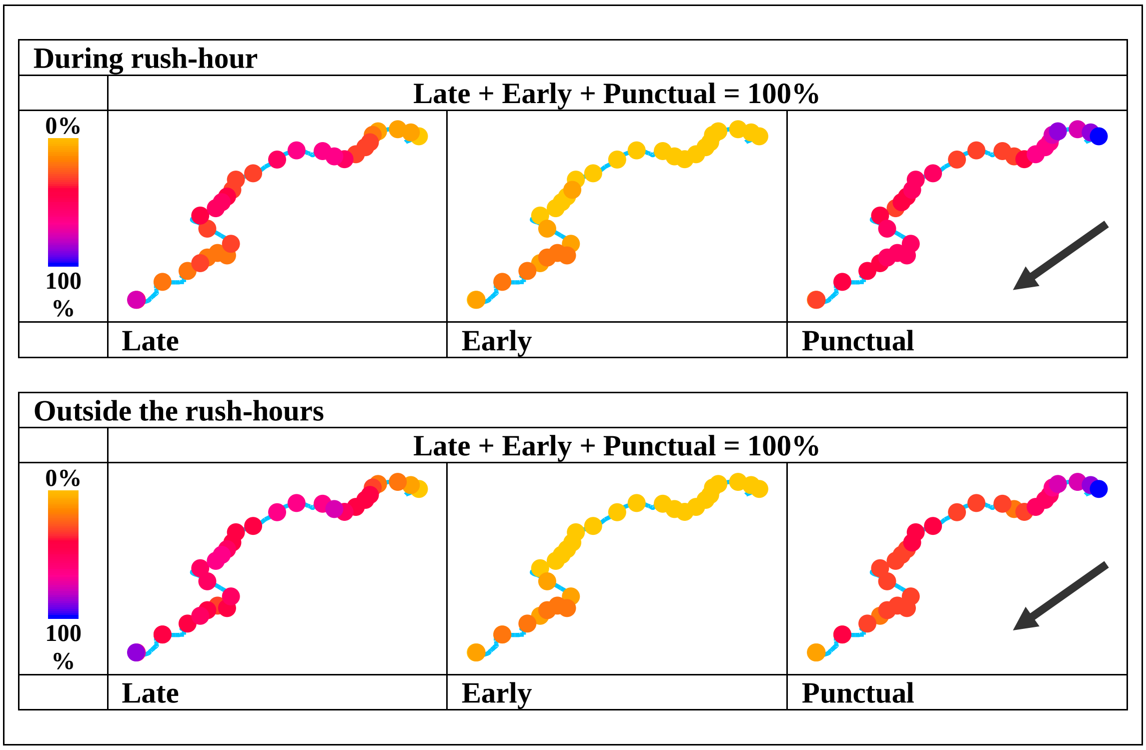


Figure 5.46b: Categorized punctuality (percentages) of individual vehicles (EFENG1061900267) traveling on bus line 68 in a north-east to south-west direction (direction 2) during and outside the rush-hours.

Along the whole line, during the rush-hours the percentage of late passage is a little lower during the rush-hours, then out of the rush-hours. Punctual passage is a little higher on locations after a few stops from the start of the line during the rush-hours.

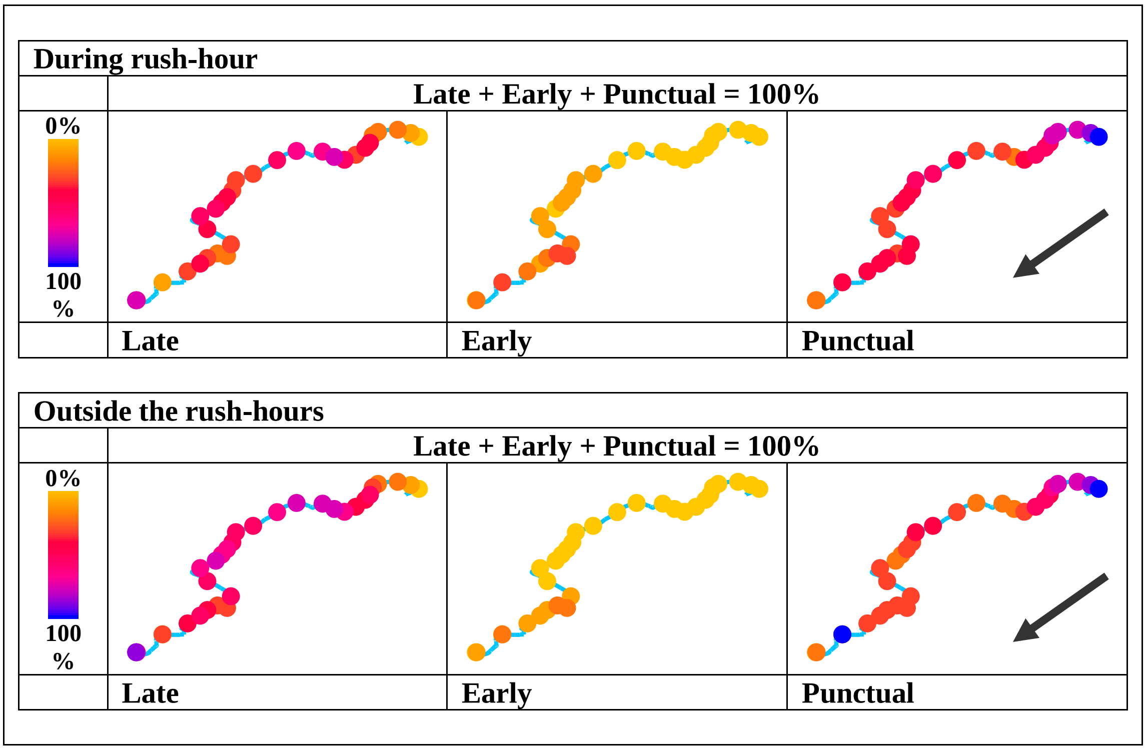


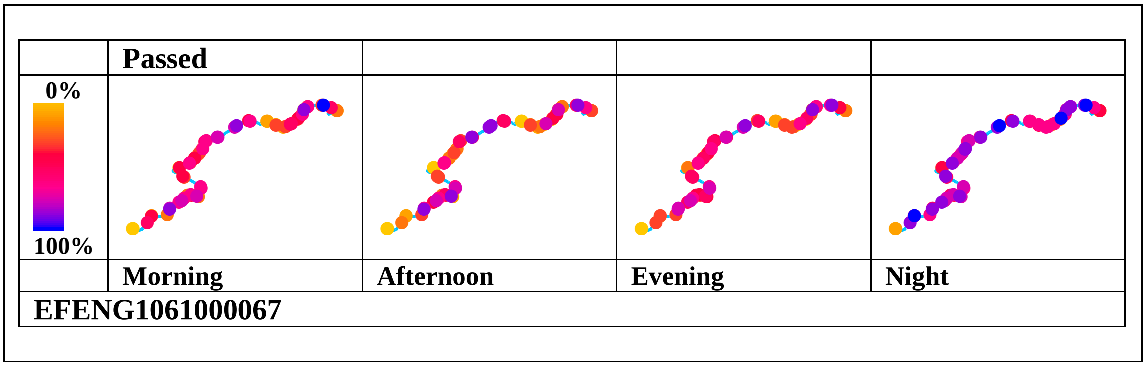
Figure 5.46c: Categorized punctuality (percentages) of individual vehicles (EFENG1062200066) traveling on bus line 68 in a north-east to south-west direction (direction 2) during and outside the rush-hours.

The increase of early passage is sooner along the line (starting halfway the line) during the rush than during passages out of the rush-hours (after two third of the line). Late passage is a little lower during the rush-hours, for stops made after the first ten stops of the line.

5.2.6.2 Status

5.2.6.2.1 Status during the different hours of the day

These analysis are performed for stops that are passed without stopping, as the other two stop status stop enter and stop leave cover both around 48% of the observed possible status.



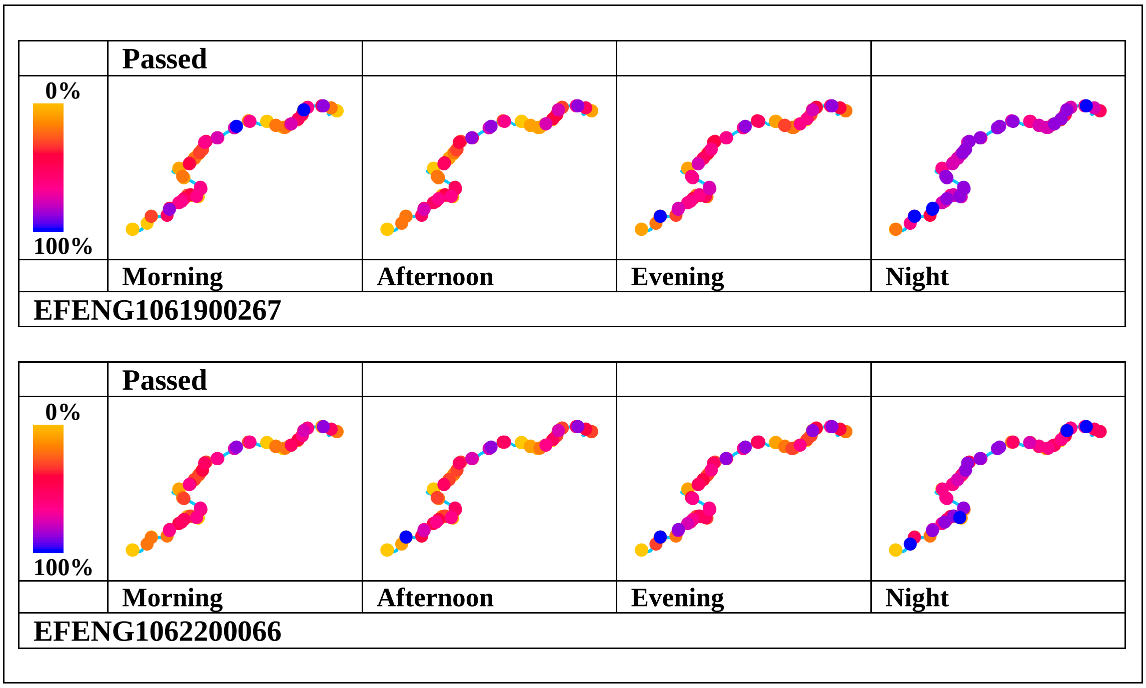
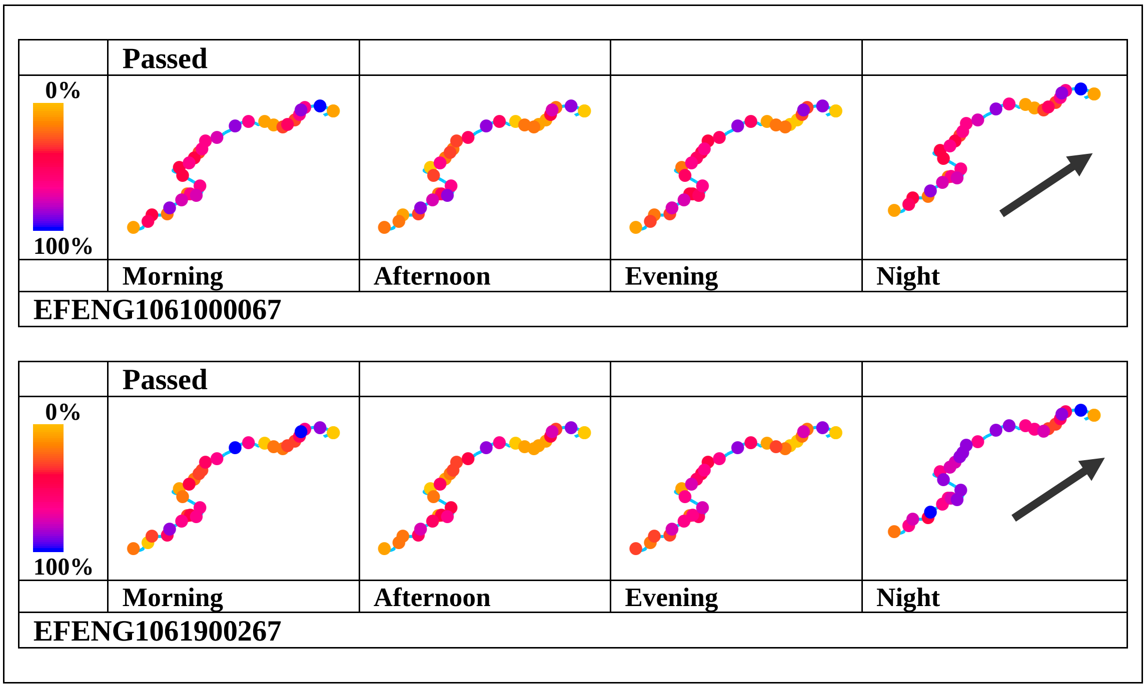


Figure 5.47: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 during the different hours of the day, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

Stops that are passed without stopping seem to be randomly distributed along the line. During the night the number of stops that are passed with stopping is higher then the other hours of the day. A few stops tend to be passed without stopping more often then others.



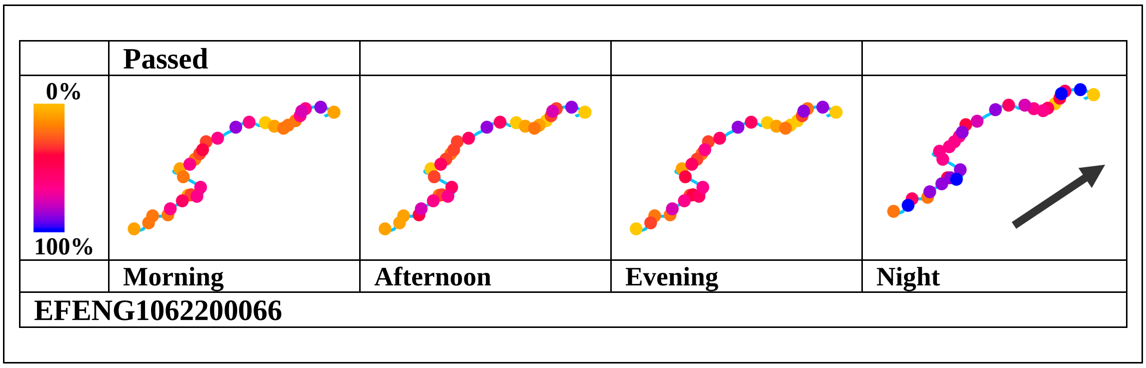


Figure 5.48a: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1), during the different hours of the day, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

Vehicle EFENG1061000067 has a lower stop passage during the night then the other two vehicles. The spatial distribution of the vehicles is comparable, except the one mentioned for the night.

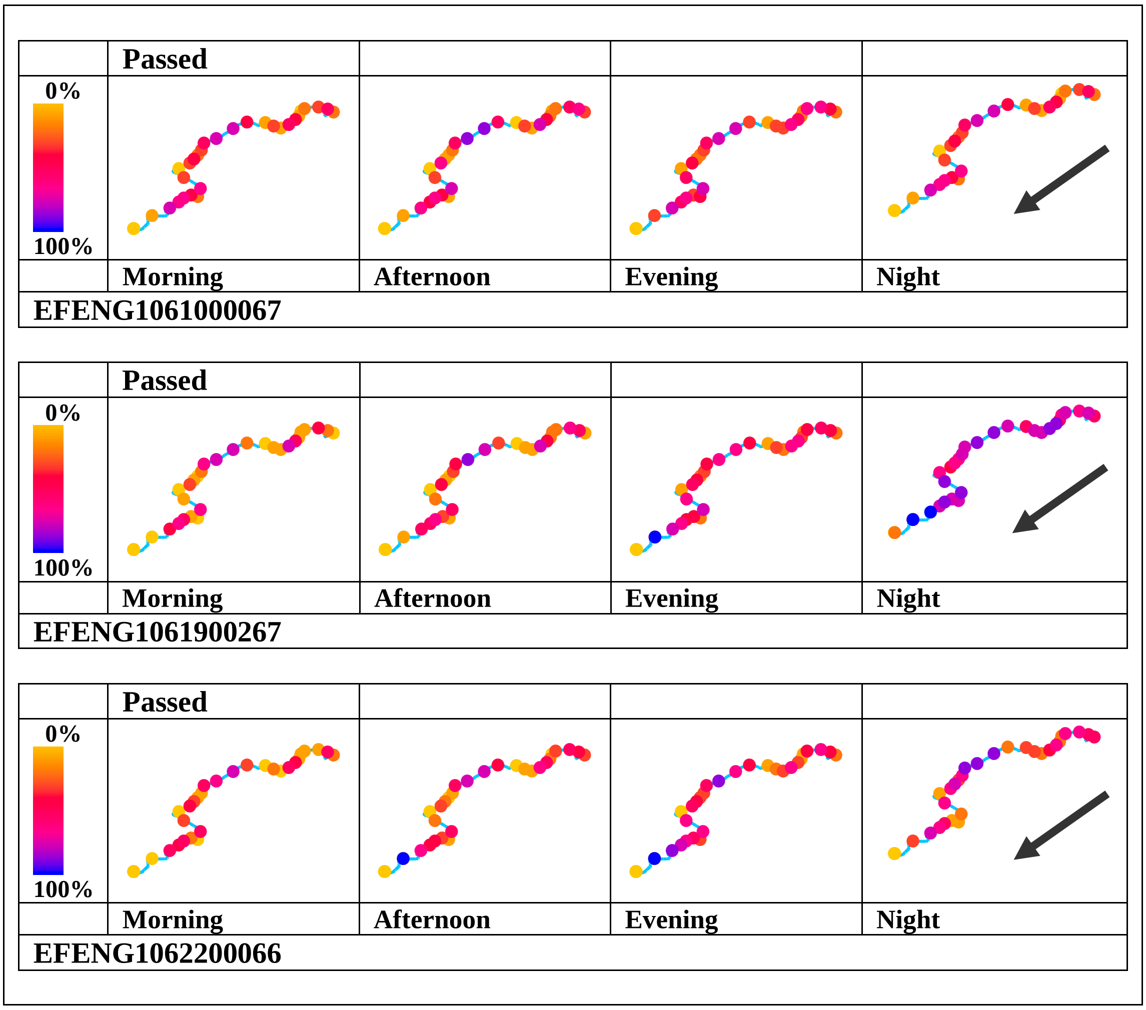


Figure 5.48b: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 in a north-east to south-west direction (direction 2), during the different hours of the day, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

The spatial distribution of stops passed during the night are different for the three vehicles. During the other hours of the day, the spatial distribution is comparable for the three vehicles used on line 68.

5.2.6.2.2 Status during the rush hours

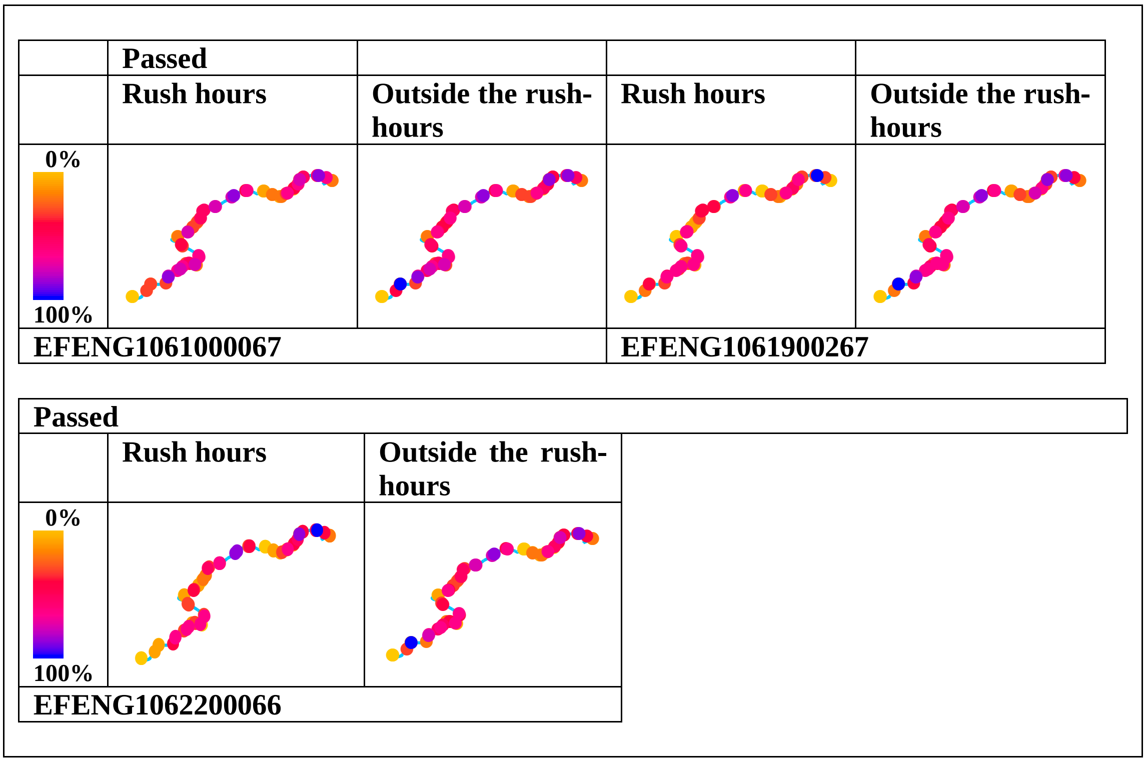
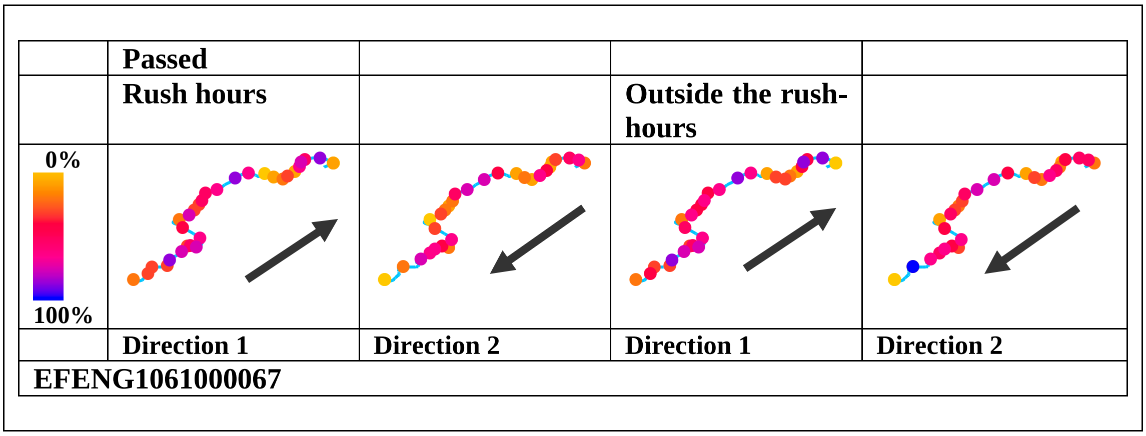


Figure 5.49: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 during and outside the rush-hours, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

The spatial distribution of stops being passed without stopping is comparable for all vehicles. One stop at the north-east end of the line is nearly always passed by all vehicles, except by vehicle EFENG1061900267 during the rush-hours.



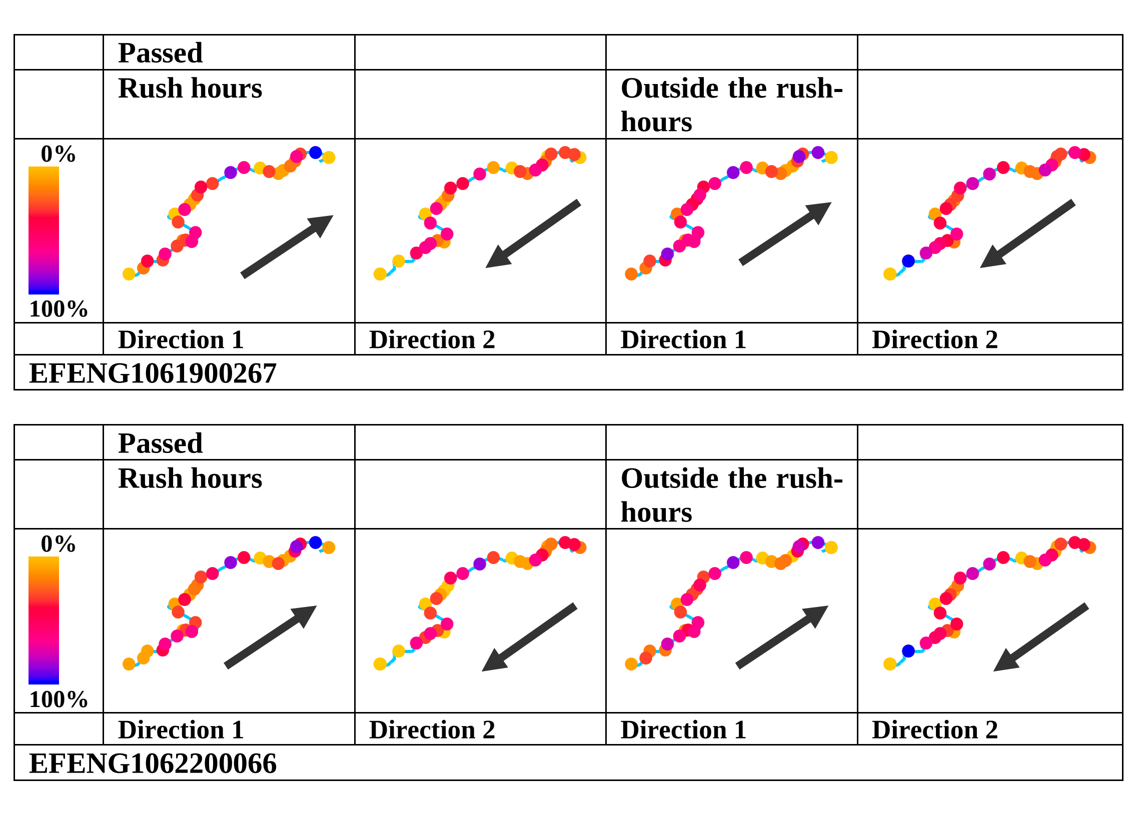


Figure 5.50: Status (passed a stop without stopping) (percentage) of individual vehicles traveling on bus line 68 in a south-west to north-east direction (direction 1) and a north-east to south-west direction (direction 2), during and outside the rush-hours, with class-breaks at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 100.

The mention stop that is not according to the overall spatial distribution of all vehicles can also be found in the stops being passed in direction 2 during the rush-hours. During the rush-hours of vehicle EFENG1061900267, it also does not appear.

Overall the stops that are passed without stopping seem randomly located, although some patterns occur for all vehicles during the different hours defined.

5.3 Discussion

5.3.1 Stop passage tram on line 1

5.3.1.1 Punctuality

In the first half of 2009, on average the tram stops on line 1 are reached behind schedule (mean delay of 222.7 seconds, and a median delay of 14 seconds. When looking to the categories of stop passage as a percentage of all stop passages, 30.8% of the vehicles passed late, 17.6% passed to early and 51.6% passed punctually on time. Driving direction plays a role in the punctuality. In a north-south direction 54.2% of the vehicles passed punctually on time, while in a south-north driving direction 49.2% had punctual top passage. At the start of the line most vehicles start punctually on time. When traveling towards the city center, the number of passage that are passed with a delay start later during the route then traveling in the opposite direction from south to north, away from the city center (see figures 5.4a and 5.4b).

A high number of different vehicles were used on tram line 1 during the first half of 2009, twenty-three different vehicles in a south to north direction, and eighteen in a north to south direction. In both directions individual vehicles overall follow the same pattern as the aggregated vehicles. There are only a few vehicles where a different pattern is observed. These are the vehicles that were only used ones or twice on the line during the first half of 2009, where a low number of stops were registered.

The punctuality does not clearly differ during the different hours of the day (morning/afternoon and during/outside the rush-hours). A punctual passage during the afternoon and out of the rush-hours in a north to south driving direction is a little higher then in the other direction, during the different hours of the day. The individual vehicles do clearly vary in punctuality over time. The leakage in temporal differences, most possible occurs, due to the fact that line 1 is only used during from 9:00 until 15:00.

5.3.1.2 Status

Stop passage without stopping doesn't seem to be a promising event detector, as nearly all stops are passed making a stop, to leave and enter passengers at the tram stops. The stop passages where a vehicle did not stop are not influenced by the driving direction, they are in both direction randomly spread along the line (see figure 5.6a and 5.6b). The stop passage without stopping is a random process, none of the stops show a spatial-temporal regularity to be passed more frequent then other stops.

5.3.2 Stop passage on bus line 68

5.3.2.1 Punctuality

During the first half of 2009 35.1% of the vehicles passed a stop punctually on time, 57.5% passed to late, and 7.5% of the stops was passed to early. Driving direction plays a role. All vehicles driving in a north-east to south-west direction, which is towards the city centre start there route punctually on time, and during the route the punctual passage is decreasing. In the opposite direction, the delay already begins already direct after the start of the line. At all stop the percentage of vehicles passing a stop punctually on time is higher in the direction toward the center then in the other direction. The same counts for late passage, in the direction towards the city center, the percentage of late passage is lower then in the direction away from the center. There are no spatial difference determined for the individual vehicles. The punctuality of vehicles traveling during night in a south-east to north-west direction, is lower then during the other hours of the day.

5.3.2.2 Status

As for the stop passage on tram line 1, also for bus line 68, there is no spatial-temporal regularity determined in the stop status. Also for the bus vehicles, the process is randomly spread. During the night all vehicles had a higher number of stop passage without stopping then during the other hours of the day.

5.4 Conclusions

The high level event of punctuality is explained on bases of two low level events: stop status and punctuality of stop passage. Both events can easily be detected on a real time basis.

5.4.1 Stop passage on tram line 1

For tram line 1 there is a large difference in the punctual stop passages of the different vehicles, the individual vehicles can in this sense not be used as an event detector for punctuality. As there is a clear influence by driving direction, the location of the vehicle together with its location explains largely the possible punctuality of vehicles on line 1, both can be used in explaining the high level event of punctuality. Stop status is clearly a process of registering a vehicle at the stop. In 99% of the cases a stop is made at a tram stop. The stop status can not be used as a parameter to explain punctuality. Monitoring the tram stop passage explains the punctuality of the vehicles. Stop status does not add any value.

5.4.2 Stop passage on bus line 68

A directional difference exists for the punctuality. For both punctuality and status, a temporal difference exists between the night and the other hours of the day. Both event parameters (punctuality of passage, and the moment of the day) can be used to determine the high level event of punctuality. Monitoring the stop passage on a bus line clearly explains the punctuality of a vehicle. Stop status does not add large value.

6 High level Event: Route problems

Differences were found in the punctuality of stop passage on bus line 68, these difference could be a cause of possible route problems on the route. The route problems are further studied on two aspects. The first includes traffic light requests which are studied for bus line 68. The second focuses on possible stop (low speed) locations studied for tram line 1. Low speed is determined on basis of the calculated speed on a segment.

6.1 Traffic light priority

6.1.1 Spatial analysis on aggregated vehicles on bus line 68

During the first half of 2009 29002 times a traffic light priority request was registered. From those 16479 were registered as type 0, which describes the start of the request. The request was 12523 times registered as being closed.

	
Type 0: Start request	**Type 1: Closed request**

Figure 6.1: Locations of the start and closing priority requests.

As can be noted from the figures, the traffic start of a light requests most often start at the south-west start/end of the line.

Table 6.1: Number of priority requests per junction

	Type		
Junction	0	1	Total
161_131		4150	4150
161_132	4014		4014
161_999	4155		4155
162_165		4246	4246
162_166	4147		4147
162_167		4127	4127
162_168	4163		4163
Total	16479	12523	29002

During the fist half of 2009, there were seven junctions with traffic lights where traffic light requests were sent to. A junction belongs either to a start or closing requests.

Junctions

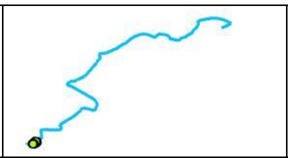
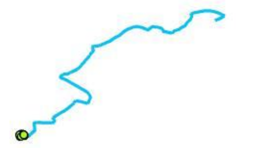
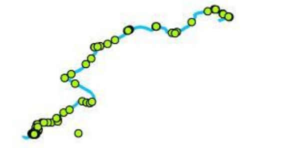
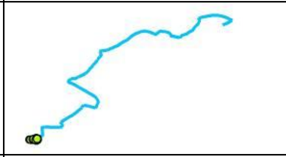
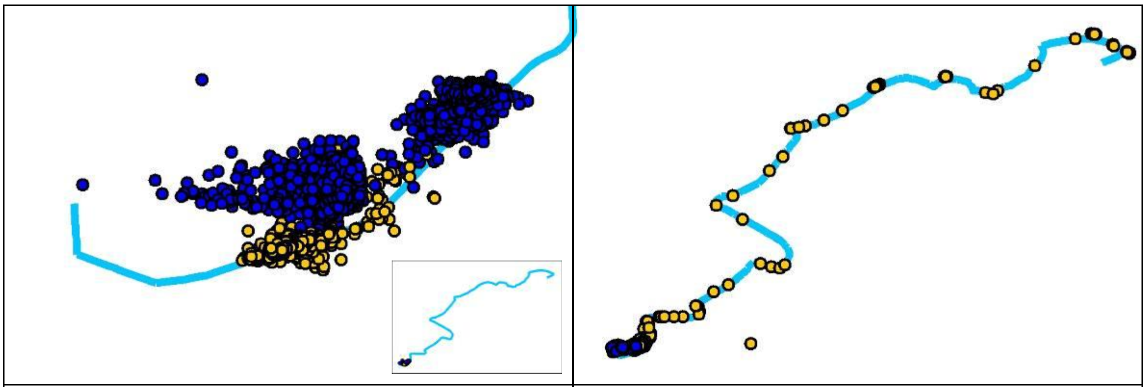
			
Junction 161_132	**Junction 161_999**	**Junction 162_166**	**Junction 162_168**
			
Junction 161_131	**Junction 162_165**	**Junction 162_167**	

Figure 6.2: Locations of the junctions with a start (top row) or closing (bottom row) priority requests.

The most junctions can clearly be observed as clustered recorded traffic light priority requests, which are mostly located in the south-east of the line. Only junction 162_165, which is a closing request, is spread along the complete line. When all recorded traffic light priority requests are taken into account, the central features of all seven junctions are located in the south-eastern part of the line.



Type 0: Start request	**Type 1: Closed request**

Figure 6.3: Locations of the start and closing priority request together with the driving direction (yellow/orange is direction 2, from north-east to south-west and dark blue is direction 1, from south-west to north east).

It can be observed that traffic light priority request of type 0 not only are requests in one direction, but were made on both driving directions of bus line 68. All request in driving direction 1 are made in the beginning of the line.

Table 6.2: Number of priority requests per junction for the different driving directions.

	Direction 1		Direction 2	
Junction	Type 0	Type 1	Type 0	Type 1
161_131				4150
161_132			4014	
161_999			4155	
162_165		4246		
162_166	4147			
162_167				4127
162_168			4163	

It can be noted that all the traffic light priority requests for junction 162_165 and 162_166 were made in direction 1, traveling away from the city centre in a south-west to the north-east direction. The other requests on the five other junctions were made in direction 2, traveling towards the city centre in a north-east to south-west direction. All recordings of a certain type are made in the same direction.

As all junctions only belong to one type and one direction, it does not make sense to differentiate the analysis into these categories. The same counts for the spatial variability, as only seven junctions are present in the recordings, from which the central features are all in the most south-western part of the line.

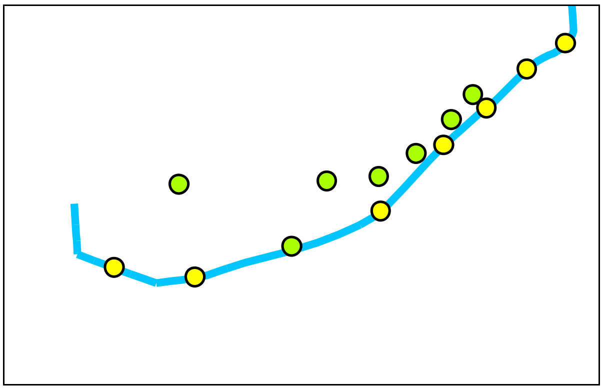


Figure 6.4: OpenStreetMap traffic lights and central features calculated from the recorded traffic light priority requests.

As no variation can be observed for the individual junctions, the rest of the analysis is done on basis of the individual observations. This decision is mainly based on de large spatial variability of the observations on junction 162_165.

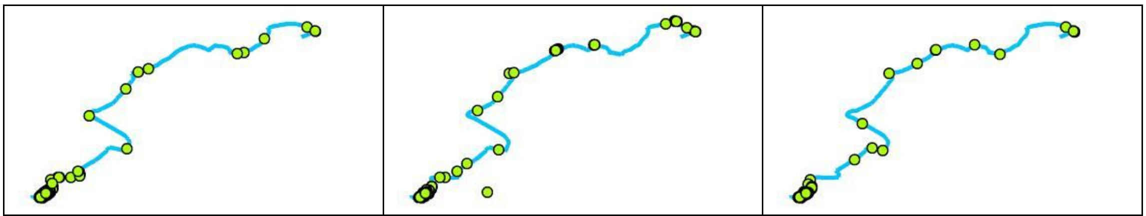
6.1.2 Spatial analysis on individual vehicles on bus line 68

During the first half of 2009 three vehicles were used on bus line 68. All three vehicles were used in both driving directions of the line, and all of them they have send traffic light priority requests.

Table 6.3: Number of priority requests of the individual vehicles in different driving directions.

Vehicle	**Traffic light requests**	**Traffic light requests (direction 1)**	**Traffic light requests (direction 2)**
EFENG1061000067 **EFENG1061900267** **EFENG1062200066**	**11878 (41.0%)** **8518 (39.3%)** **8606 (29.7%)**	**3419 (40.7%)** **2560 (30.5%)** **2414 (28.8%)**	**8459 (41.0%)** **5958 (28.9%)** **6192 (30%)**
	29002	**8393**	**20609**

Vehicle EFENG1061000067 has the most priority requests during the first half of 2009. Most of these requests were made in the direction towards the city centre (traveling from north-east to south-west).



EFENG1061000067	**EFENG1061900267**	**EFENG1062200066**

Figure 6.5: All traffic light priorities given to the individual vehicles.

Most of the requests are made in the south-west of the line, around the centre of Helsinki. All vehicles have a few other requests along the ongoing of the line. Vehicle EFENG1062200066 has most of its requests concentrated around at the star/end of the line located in the centre of Helsinki (south-east).

6.1.3 Temporal analysis on aggregated vehicles on bus line 68

Splitting the day in morning (6:00 - 11:59), afternoon (12:00-17:59), evening (18:00 – 23:59) and night (0:00 – 5:59), respectively 8493 (29.2%), 9732 (33.5), 8910 (30.7%) and 1867 (6.4%) traffic light priority requests were send.

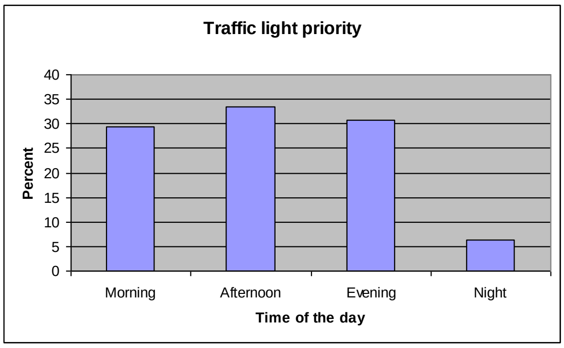


Figure 6.6: Traffic light priority requests during the different hours of the day.

In comparison with the other times of the day, in the night, there are clearly less traffic light priority requests being made.

Only 4779 (16.5%) of the traffic light priority requests were send during the rush hours (8:00-9:30 and 17:00-18:30).

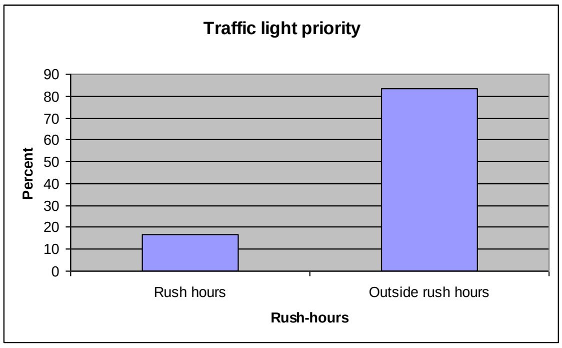


Figure 6.7: Traffic light priority requests during and outside the rush-hours.

During the rush-hours, less requests are made then during the other hours of the day.

6.1.4 Temporal analysis on individual vehicles on bus line 68

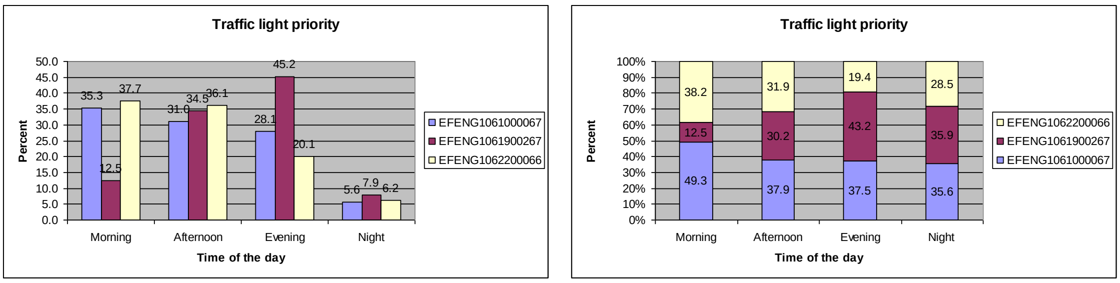


Figure 6.8: All traffic light priorities given during the different hours of the day, per vehicle: morning + afternoon + evening + night = 100% (left), per part of the day: vehicle EFENG1061000067 + EFENG1061900267 + EFENG1062200066 = 100% (right).

Vehicles EFENG1061000067 and EFENG1062200066 have the most of their requests during the morning hours and afternoon. Vehicle EFENG1061900267 has most of its request in the evening. All of the vehicles have les requests during the night.

It can be observed that vehicle EFENG1061900267 has compared to the other two vehicles less requests during the morning. Vehicle EFENG1062200066 has compared with the other vehicles the least requests in the evening.

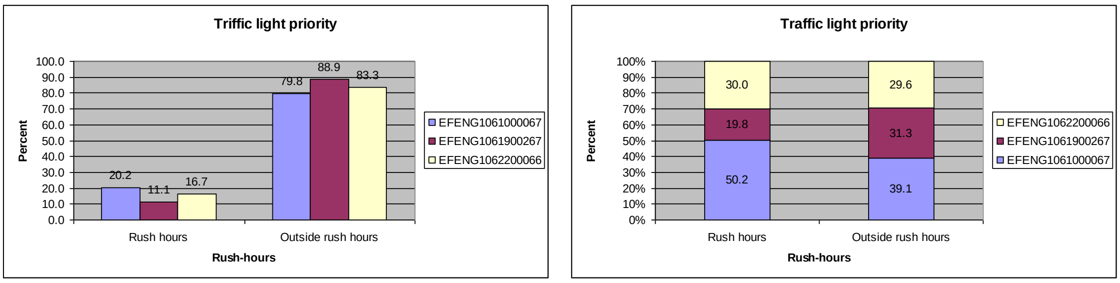


Figure 6.9: All traffic light priorities given during and outside the rush-hours, per vehicle: rush-hours + outside rush-hours = 100% (left), per part of the day: vehicle EFENG1061000067 + EFENG1061900267 + EFENG1062200066 = 100% (right).

All vehicles send more requests outside the rush-hours. Vehicle EFENG1061000067 has compared to the other vehicles a little more requests during the rush-hours.

Vehicle EFENG1061900267 has the least requests during the rush-hours. Out of the rush-hours vehicle EFENG1062200066 makes the least requests.

6.1.5 Spatiotemporal analysis of aggregated vehicles on one line

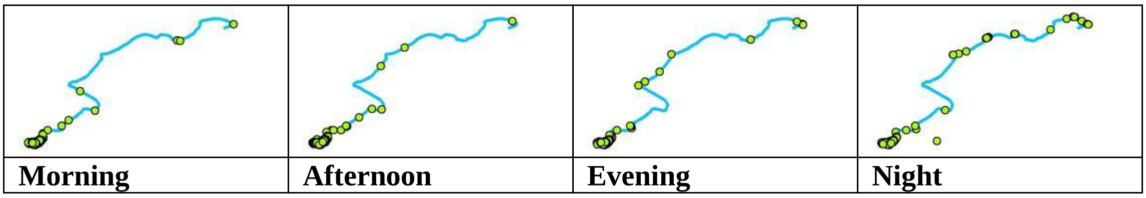


Figure 6.10: All traffic light priorities given at four different periods of the day.

The requests that were made during the night are spread more along the complete line. During the morning and the afternoon, requests were made mainly in the south-west part of the line, which is in the center of Helsinki.

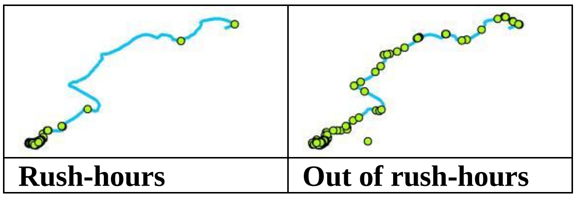
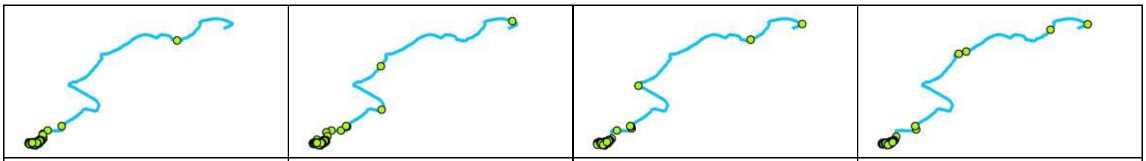


Figure 6.11: All traffic light priorities given during and outside the rush-hours.

The requests that were made during the rush-hours were mainly in the center of Helsinki, at the south-west of the line.

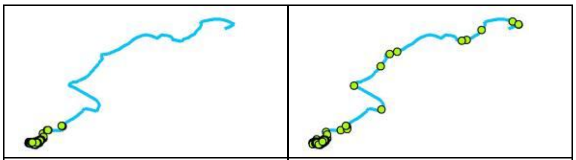
6.1.6 Spatiotemporal analysis individual vehicles on one line



Morning	Afternoon	Evening	Night

Figure 6.12a: All traffic light priorities given to vehicle EFENG1061000067 at four different periods of the day.

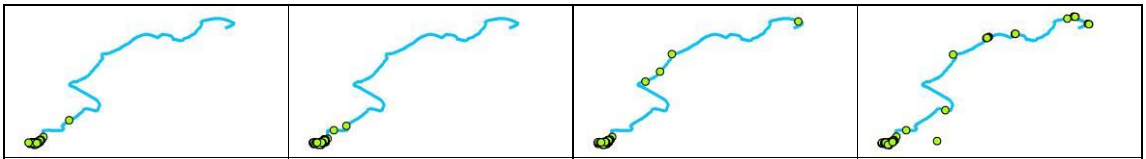
Vehicle EFENG1061000067 had most of its most requests around the centre of Helsinki, at the south-west of the line.



Rush-hours	Out of rush-hours

Figure 6.12b: All traffic light priorities given to vehicle EFENG1061000067 during and outside the rush-hours.

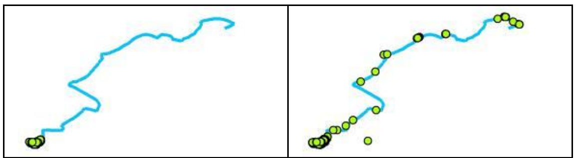
During the rush-hours, the most requests of vehicle EFENG1061000067 were made in the centre of Helsinki, out of the rush-hours, there are also request occurring out of the other parts of the line.



Morning	Afternoon	Evening	Night

Figure 6.13a: All traffic light priorities given to vehicle EFENG1061900267 at four different periods of the day.

Vehicle EFENG1061900267 had most of requests around the centre of Helsinki, in the south-east of the line. During night, there were also requests made further along the line.



Rush-hours	Out of rush-hours

Figure 6.13b: All traffic light priorities given to vehicle EFENG1061900267 during and outside the rush-hours.

During the rush-hours, all requests of vehicle EFENG1061900267 were made in the south-east of the line. Out of the rush-hours, there were also requests made along the rest of the line.

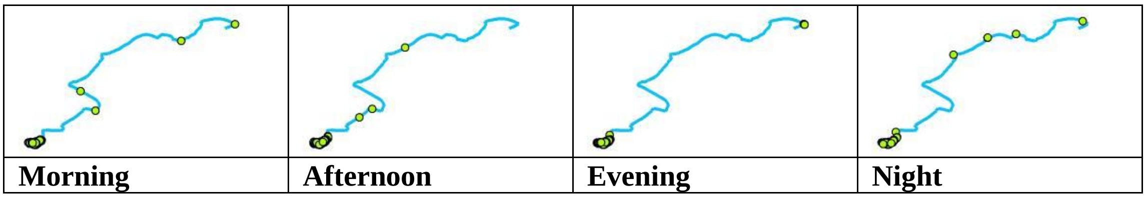


Figure 6.14a: All traffic light priorities given to vehicle EFENG1062200066 at four different periods of the day.

Most request of vehicle EFENG1062200066 were made around the centre of Helsinki, during night a few requests were made in the north-eastern part of the line.

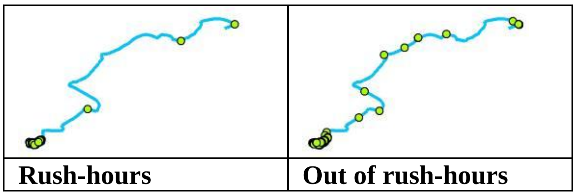


Figure 6.14b: All traffic light priorities given to vehicle EFENG1062200066 during and outside the rush-hours.

During the rush-hours, vehicle EFENG1062200066 made most of its requests in the centre of Helsinki. Out of the rush-hours the some of the requests are also made along the rest of the line.

6.2 Possible stop locations

Three types of possible stops are determined in the OpenStreetMap source data set: road crossings, traffic lights, and tram stops. Of all the segments available in the recorded trajectories, 21.7% are classified as standing still (limiting a low speed as being smaller then 0.1 m/s) and fall within a 30 meter zone around the tram line.

6.2.1 Spatial analysis on aggregated vehicles on tram line 1

6.2.1.1 Tram road crossings

Tram Line 1 has 29 road crossings defined in the OSM source data. The crossings are of two different types: uncontrolled road intersections and those that are controlled by traffic lights. Around the 29 individual crossings, 30 meters zones were created. These zones were used to count the number of low speed passage.

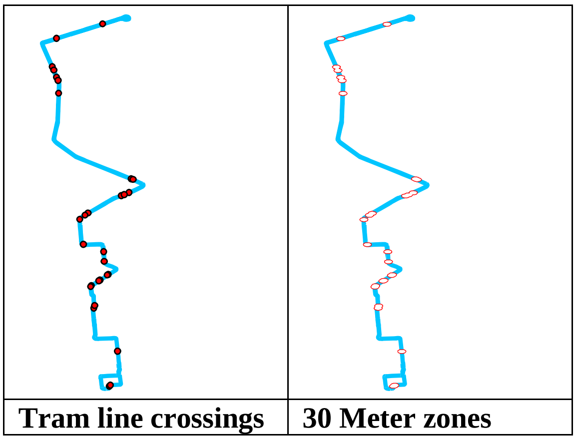
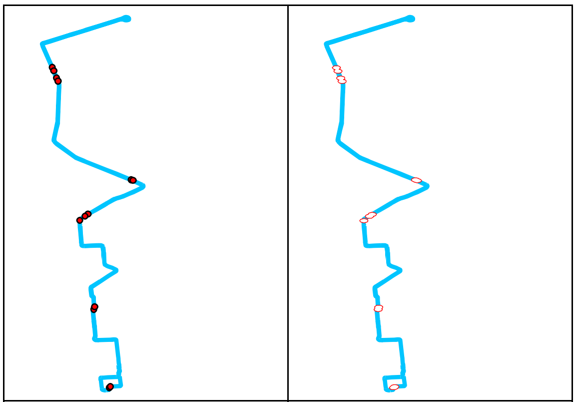


Figure 6.15: location of road crossings in the OpenStreetMap source dataset.

From all the segments that were passed with a lower speed then 0.1 m/s on tram line 1, 17.2% were located near a road crossing.

6.2.1.2 Tram Traffic lights

13 Traffic lights are located along tram line 1. All these traffic lights are also included as road crossings in the OpenStreetMap source data set. Around the traffic lights a zone of 30 meter is created, which is used to count the number of slow passages in these areas.



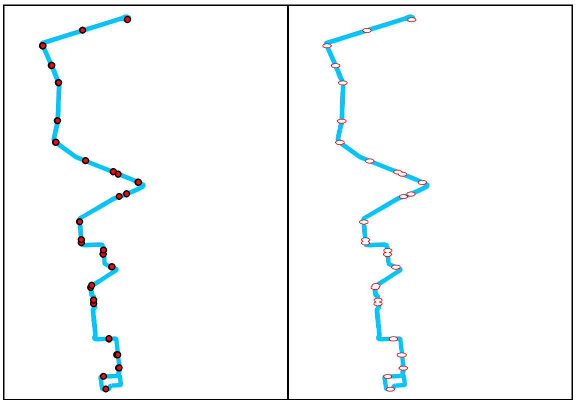
Tram line traffic lights	**30 Meter zones**

Figure 6.16: location of traffic lights in the OpenStreetMap source dataset.

From all the segments that were passed with a lower speed then 0.1 m/s on tram line 1, 13.8% were located near a traffic lights.

6.2.1.3 Tram Stops

There are 41 tram stops along tram line 1. They are located in two directions along the line. Around the known tram stops zones are created in a distance of 30 meter.



Tram stops	**30 Meter zones**

Figure 6.17: location of tram stops in the OpenStreetMap source dataset.

From all the segments that were passed with a lower speed then 0.1 m/s on tram line 1, 78.2% were located near a tram stops.

6.2.1.4 Aggregated stop locations (Crossings, traffic lights and stops)

There are 83 locations of road crossings, traffic lights and stops on tram line 1. All these locations are expected to have possible low speeds.

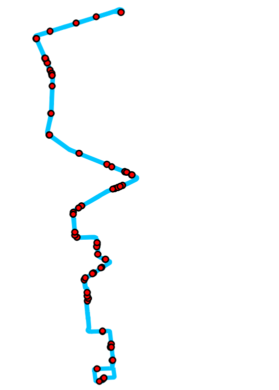
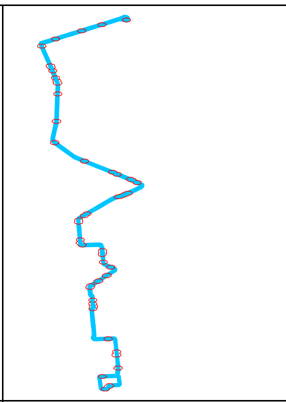
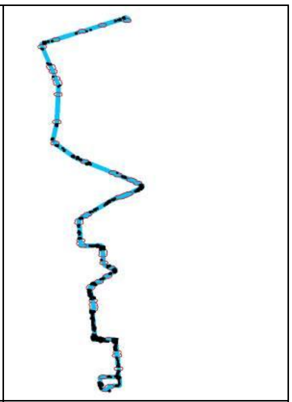
		
a) Tram line crossings	**b) 30 Meter intersection zones**	**c) Outside 30 meter intersection zone**

Figure 6.18: location of aggregated road intersections in the OpenStreetMap source dataset.

In an aggregated analysis, from all the segments that were passed with a lower speed then 0.1 m/s on tram line 1, The majority (85.9%) are located near a road crossing, traffic light or tram stops. Which means the other low speed locations (14.1%) are located elsewhere along the line but outside the 30 meter intersection zones of the determined stop locations (see figure 6.18c).

6.2.2 Spatial analysis on individual vehicles on tram line 1

The same analysis is done on individual vehicles.

6.2.2.1 Road crossings

The percentage of the individual vehicles that passed a road crossing with a speed lower then 0.1 m/s on tram line 1 ranges from 12.6% to 40.0%. It can be observed that most of the vehicles had to stop 20% at a road crossing. Vehicle CEENG1074300240 stopped 40% of its road cross passages, and vehicles CEENG1074300172 more then 30%.

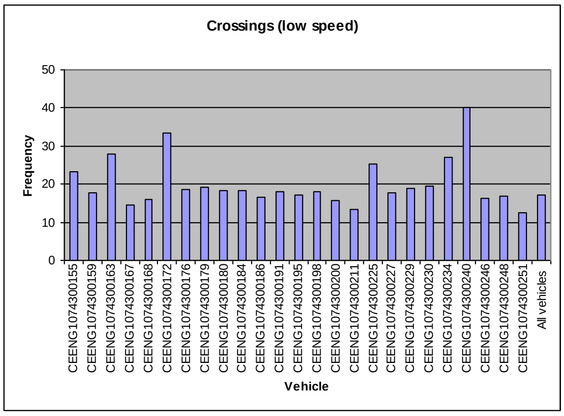


Figure 6.19: Stop made by individual vehicles at road crossings.

6.2.2.2 Traffic lights

The percentage of the individual vehicles that passed a road crossing with a speed lower then 0.1 m/s on tram line 1 ranges from 7.3% to 30.0%. Vehicle CEENG1074300240 had to stop 30% of it's traffic light passage.

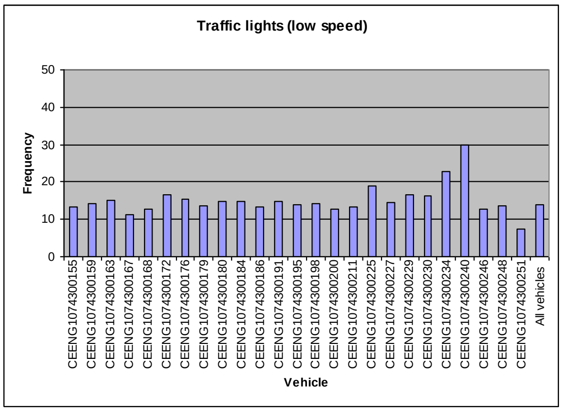


Figure 6.20: Stop made by individual vehicles at traffic lights.

6.2.2.3 Stops

The percentage of the individual vehicles that passed a road crossing with a speed lower then 0.1 m/s on tram line 1 ranges from 46.3% to 91.7%

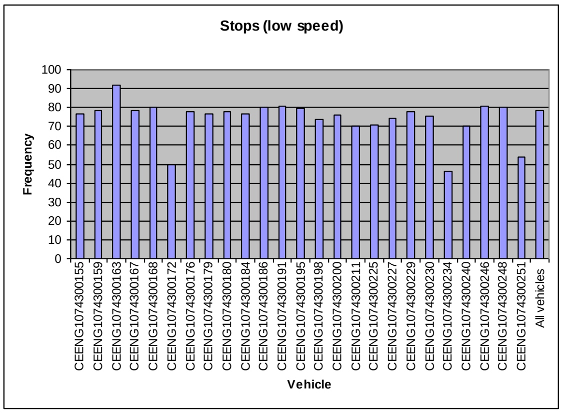


Figure 6.21: Stop made by individual vehicles at tram stops.

6.2.2.4 Aggregated stop locations (Crossings, traffic lights and stops)

The percentage of the individual vehicles that passed a road crossing with a speed lower then 0.1 m/s on tram line 1 ranges from 61.0% to 91.1%. Vehicle CEENG1074300251 only stopped 60% of its passages, vehicles CEENG1073400172 and CEENG1074300234 stopped a little more then 60% of the passages.

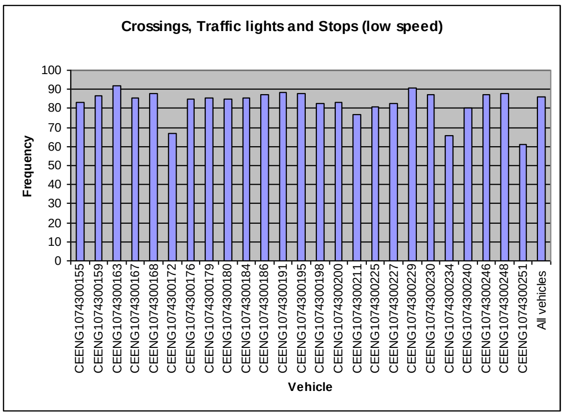


Figure 6.22: Stop made by individual vehicles at aggregated road intersections.

6.2.3 Temporal analysis on aggregated vehicles on tram line 1

6.2.3.1 Time of the day

The next analysis takes the time of the day when a low speed passage took place into account.

***Table 6.4: Stop made at road different road intersections during the different hours of the day*.**

		Crossing	Traffic lights	Stops	Aggregated
Movements in the selected zones	**Morning**	**55.1%**	**55.4%**	**57.8%**	**57.5%**
	Afternoon	**44.9%**	**44.6%**	**42.2%**	**42.5%**
		100%	**100%**	**100%**	**100%**

57.5% of all the movements that were located within a 30 meter distance from tram line 1 that had a lower speed then 0.1 m/s took place during the morning hours. The other 42.5% took place during the afternoon.

The crossings (and its 30 meter zone) that were passed with a low speed were passed 55.1% of the cases during the morning, and 44.9% during the afternoon.

The traffic lights (and the surrounding 30 meter zone) were passed with a low speed in 55.4% of the cases during the morning, during the afternoon 44.% of the passages took place.

In 57.8 of the cases a tram stop (and its 30 meter influence zone) was passed with a low speed during the morning. In 42.2 of the cases they were passed during the afternoon.

6.2.3.2 Rush-hours

The same analysis is done for stops at possible low speed areas during the rush-hours, and during the other hours of the day.

***Table 6.5: Stop made at road different road intersections during and outside the rush hours*.**

		Crossing	Traffic lights	Stops	Aggregated
Movements in the selected zones	**Rush**	**10.8%**	**10.8%**	**15.1%**	**14.7%**
	Out of Rush	**89.2%**	**89.2%**	**84.8%**	**85.3%**
		100%	**100%**	**100%**	**100%**

89.2% of the low speed passages in the road crossing zones were made out of the rush-hours. The other 10.8% took place within the rush-hours. From all the low speed passages that were recorded along tram line 1, 12.6% were registered during the rush-hours, and 18.0% in the hours outside the rush-hours

6.2.4 Temporal analysis on individual vehicles on tram line 1

6.2.4.2 Time of the day

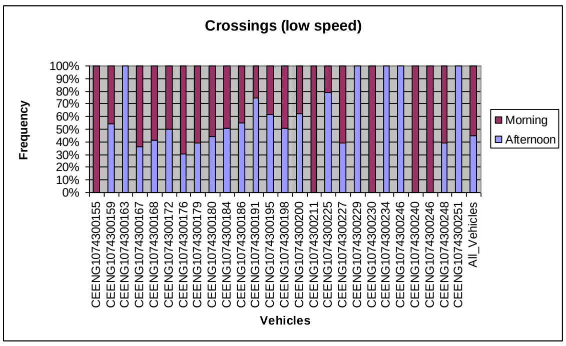


Figure 6.23: Stop made by individual vehicles at road crossings during the different hours of the day.

Some vehicles had all of their stops at road crossing either during the morning (5 vehicles) or during the afternoon (5 vehicles). The other vehicles are fluctuating in their morning afternoon crossing.

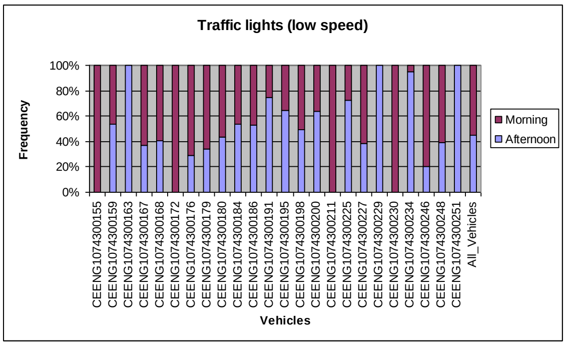


Figure 6.24: Stop made by individual vehicles at traffic lights during the different hours of the day.

Some of the vehicles had either stopped during the morning (4 times) or during the afternoon (3 times) a traffic light. They are the same vehicles that had only morning or afternoon stops at road crossings (as all traffic lights are located at a road crossing).

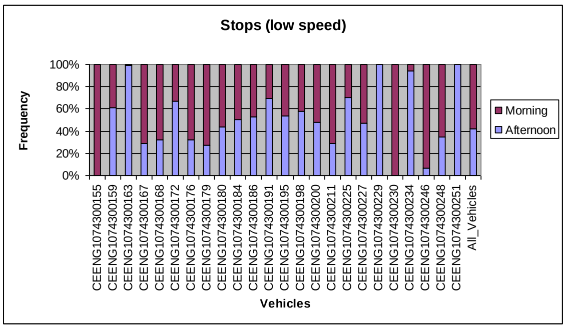


Figure 6.25: Stop made by individual vehicles at tram stops during the different hours of the day.

Some vehicles only pass either during the morning (2 times) or the afternoon (3 times) a tram stop. Some vehicles (CEENG1073400163 and CEENG1073400234) had most of their stops during the afternoon. Some others tend more towards the morning hours.

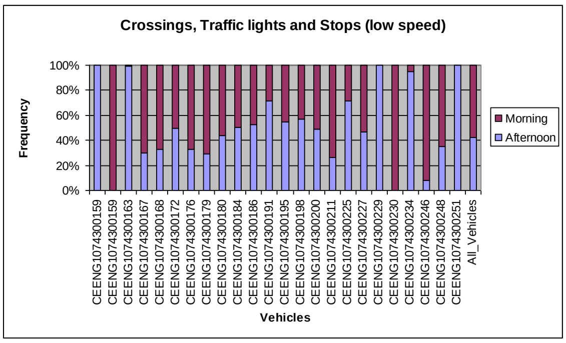


Figure 6.26: Stop made by individual vehicles at aggregated road intersections during the different hours of the day.

When all the possible stop locations are aggregated together, two vehicles only had stops during the morning, and four only during the afternoon. The other vehicles are fluctuating, some had more stops during the morning, and some more during the afternoon.

6.2.4.2 Rush hours

The same analysis can be performed splitting the day in driving the line during the rush-hours and out of the rush-hours.

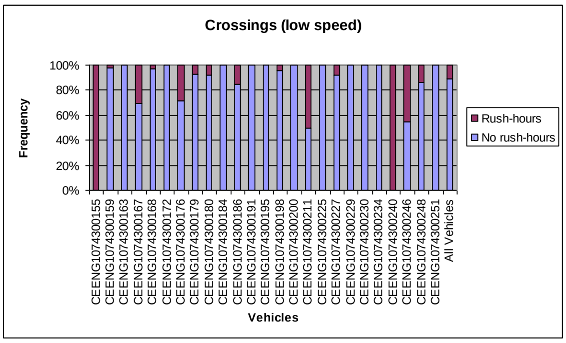


Figure 6.27: Stop made by individual vehicles at road crossings during and outside the rush hours.

It can be observed that most of the stops at road crossings were made out of the rush-hours. Only two vehicles had all of their stops during the morning (vehicle CEENG1073400155 and CEENG1073400240).

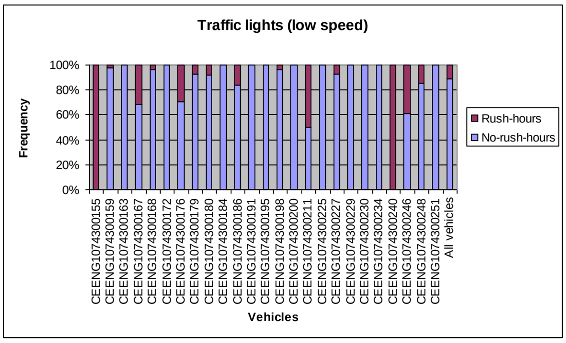


Figure 6.28: Stop made by individual vehicles at traffic lights during and outside the rush hours.

The same can be observed for stops made at traffic lights, the same two vehicles had only stops at traffic lights during the rush-hours. Most of the others only stopped out of the rush-hours.

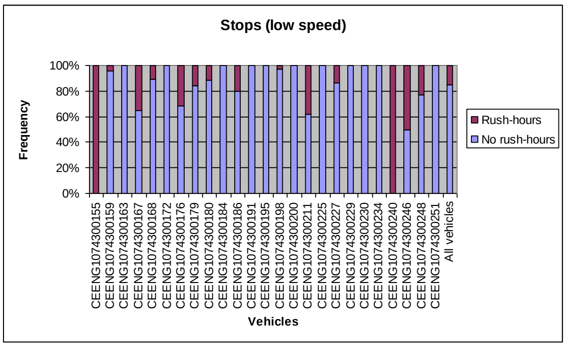


Figure 6.29: Stop made by individual vehicles at tram stops during and outside the rush hours

The same can be said for vehicles stopping at tram stops, the same two vehicles that had all of their stops at road crossings and traffic lights during the rush-hours, had all of their stops at tram stops during the rush-hours. The other vehicles had most of their stops out-of the rush-hours.

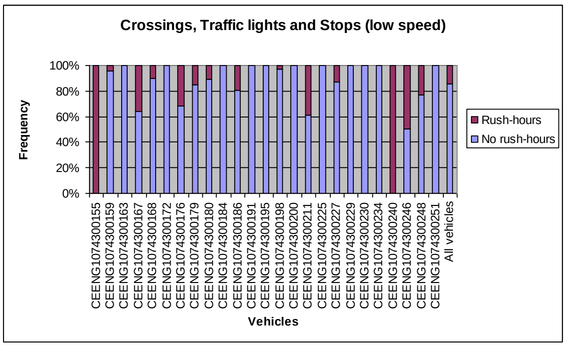
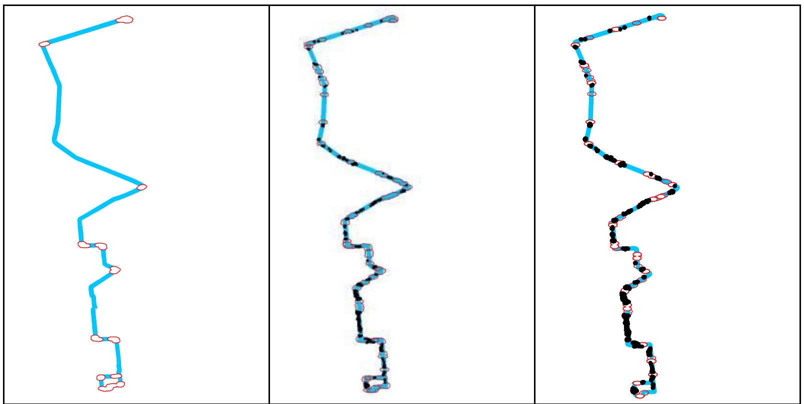


Figure 6.30: Stop made by individual vehicles aggregated road intersections during and outside the rush hours

The aggregated figure of all possible stops that could be determined show the same results. Only two vehicles (CEENG1073400155 and CEENG1073400240) had all of their stops during the rush-hours, the other vehicles had most of their stops out of the rush-hours. Vehicle CEENG1073400246 had around 50% of its stops during the rush-hours, and the other 50% out- of the rush-hours.

6.3 Unexpected stops

When also the segments that fall in the 30 meter zone around line parts that have a shape turn are removed as possible stop locations, only 5.0 % of the no movement (speed smaller 0.1 m/s) segments are left (see fig 6.31). As these stops are at locations where no regular stops are expected, they can be used to determine the unexpected stops locations.



Sharp turn locations	**Outside 30 meter intersection and sharp turn zones**	**Unexpected stop locations**

Figure 6.31: Locations of unexpected stops

The locations that are left as unexpected stops are explored visually in more detail, to simplify the visualization, the line is split into four parts.

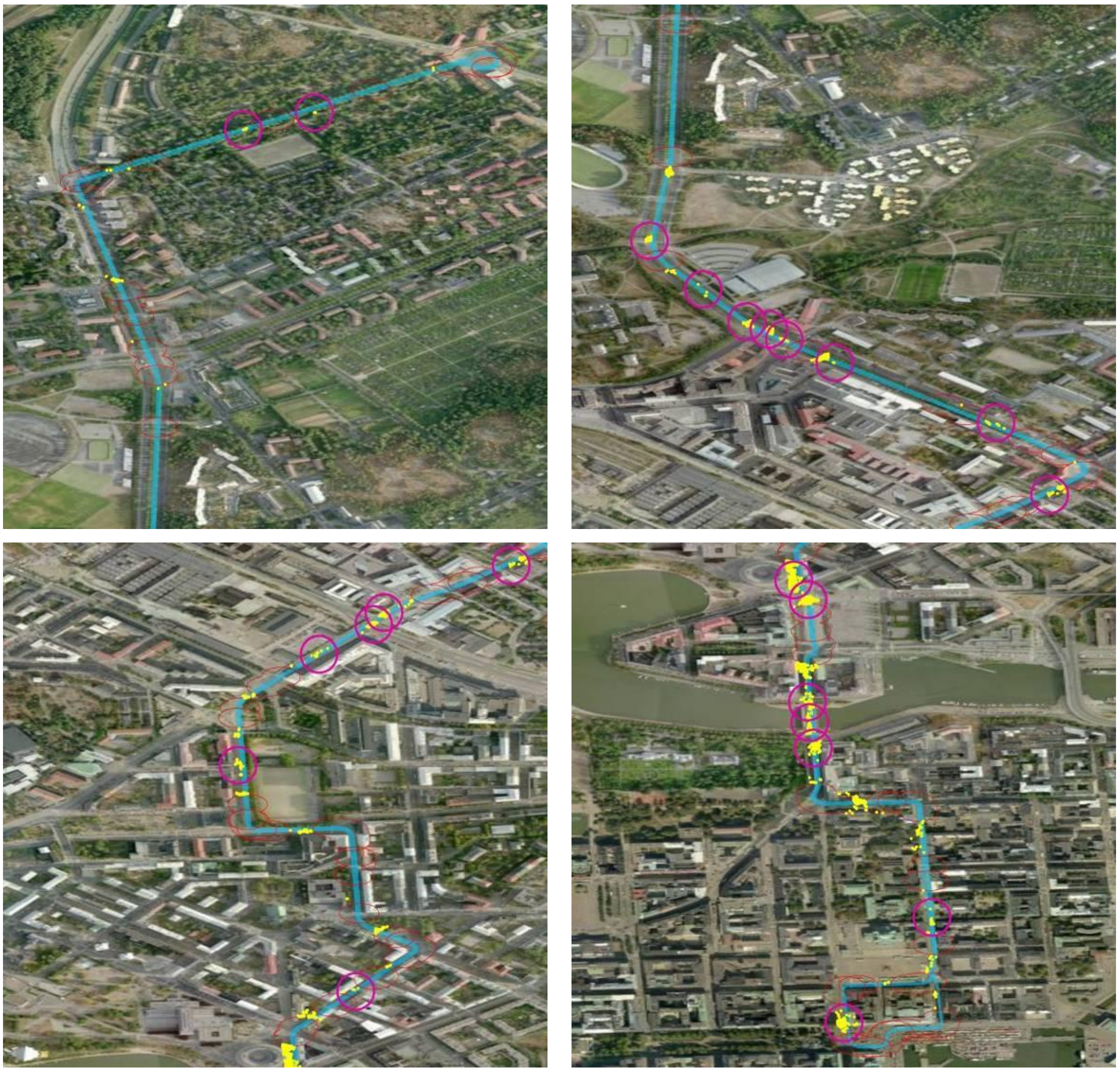


Figure 6.32: Locations of unexpected stops along tram line 1, the line is split in four parts starting from the north (part 1- upperleft) going southward (part 2- upperright) continuing to the south (part 3- lowerleft) and ending at the southern start/end of the line (part 4- lowerright) that will be explored in more detail (marked in lilac)

Some of the unexpected stop clearly should belong to on of the expected stop categories: road crossings, traffic lights, tram stops or sharp turn. They are located around the sides of the defined zones, but just fall outside of the influence distance of 30 meters. These cases are left of the exploration.

Figure 6.33: Unexpected stops in part 1 (respectively a and b)

In part a two unexpected stop locations are determined. Both locations (a) and (b) can not clearly be explained as the passage is covered by trees. The number of observations is rather low; only three observations for the first unexpected stop location, seven for the second.

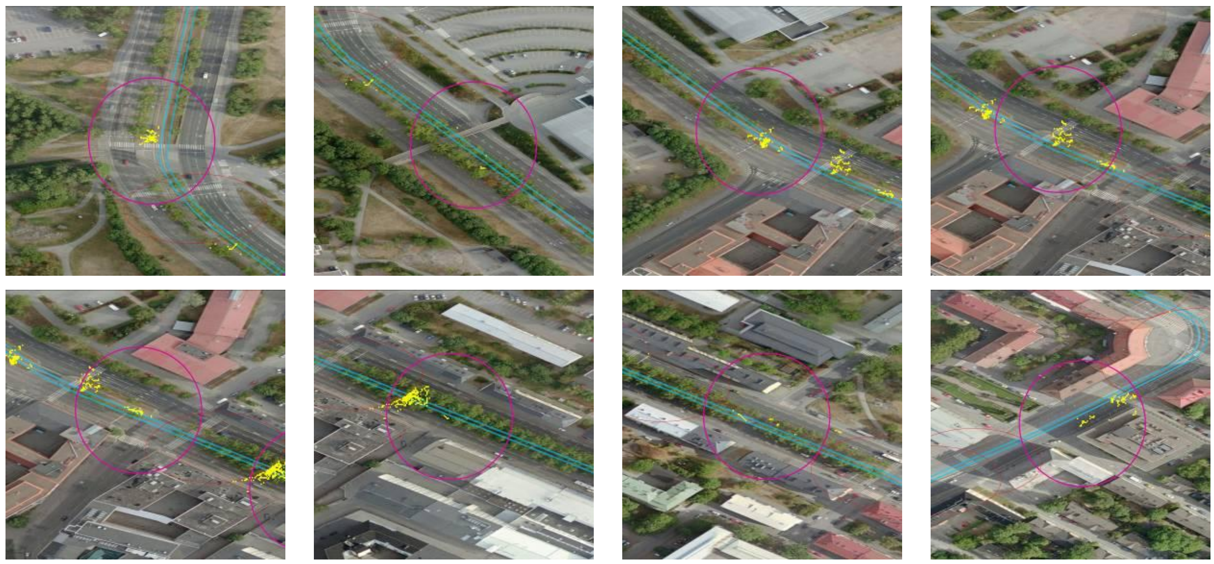


Figure 6.34: Unexpected stops in part 2 (respectively a to h; starting upperleft and viewing clockwise)

In the second part eight unexpected stops are determined. The first location (a) stops are made most likely due to the pedestrian crossing. At location (b) there are only a six observations, can not be explained by crossings etc. Location (c) (d) and (e) are located near a road and pedestrian crossing. Location (f) are the four observations in the centre of the image, they are determined as unexpected stops. Location (g) and (h) are located near a road/pedestrian crossing.

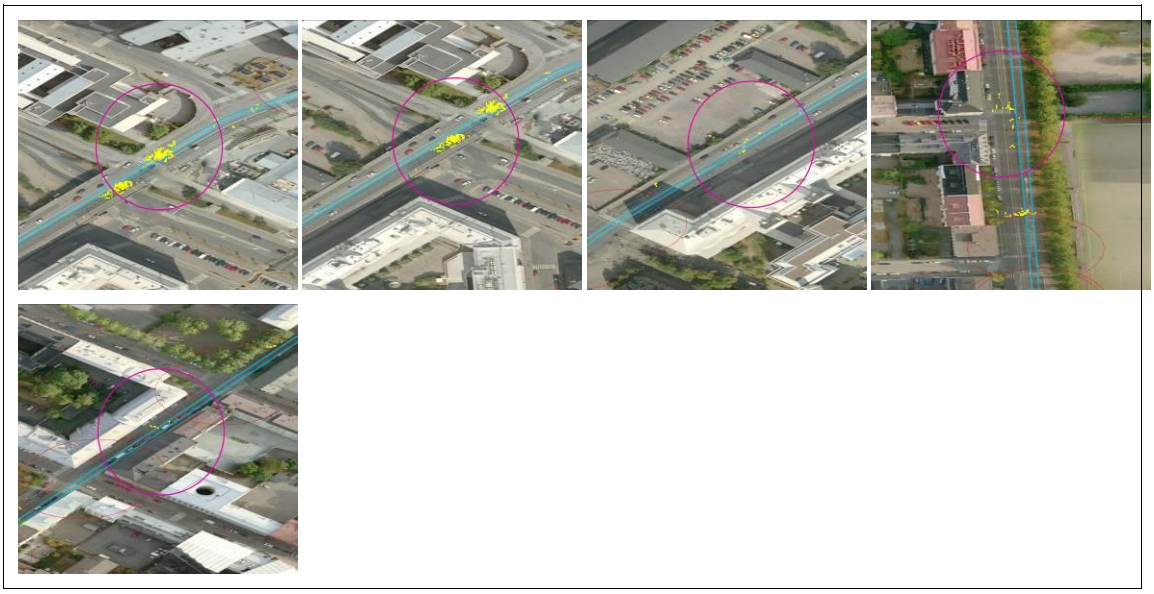


Figure 6.35: Unexpected stops in part 3 (respectively a to e; starting upperleft and viewing clockwise)

In part 3 of the line, there are 5 locations that are explored in more detail. Location (a) and (b) are clearly near road intersections. Location (c) consists of a few spread observations. This part of the line is located in a large road, where cars could influence the driving of the vehicle. Location (d) is around a pedestrian crossing. Location (e) is located between two predefined possible stop locations, but the observations do not seem to belong to one of these.

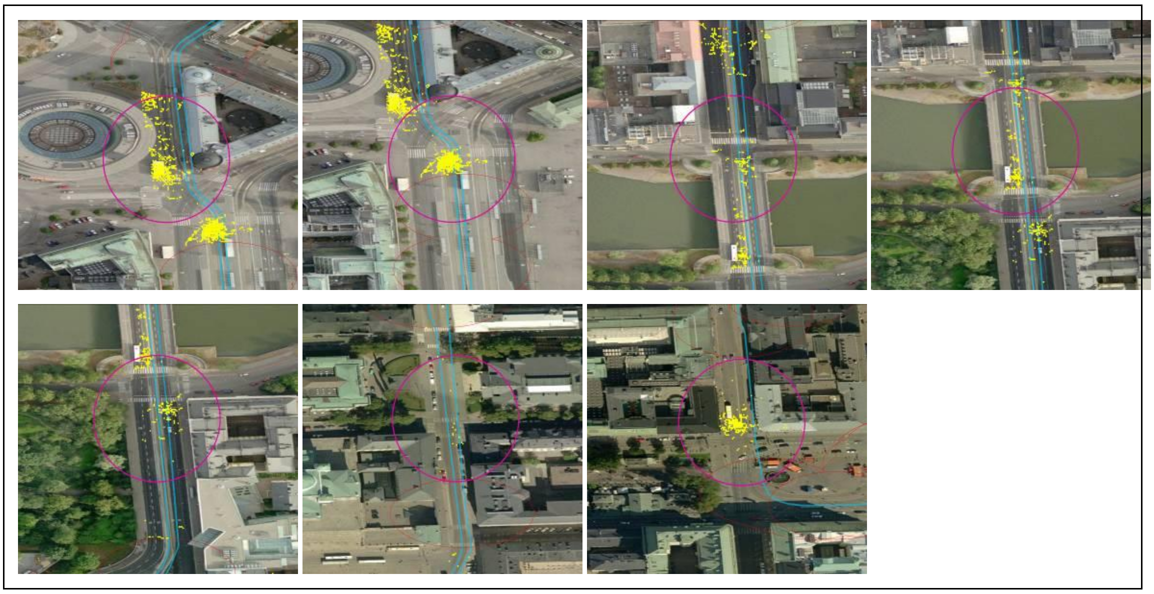


Figure 6.36: Unexpected stops in part 4 (respectively a to g; starting upperleft and viewing clockwise)

In the fourth part of the line seven unexpected stops are explored in more detail. Situation (a) and (b) are clearly due to road crossings. Locations (c) and (d) are situated on a bridge, with at the both ends there are pedestrian crossings. Situation (e) is located just before/after the bridge near a pedestrian crossing. Location (f) is near a pedestrian crossing. Location (g) is at the start/end of the line, where trams could be waiting for their next travel.

Along the complete line there are only six locations where stops could not be explained: part 1 (a) and (b), part 2 (b) and (f) and part 3 (c) and (e).

6.4 Discussion

Traffic light priority is given as two different status, the fist opens the request, the second closing it. The requests are bound to junctions. A junction belongs only to one of the driving directions. There are more requests made in the direction towards the city center. Less requests are made during the night hours, and during the rush-hours. The number of requests differ per vehicle. The locations of 6 of the seven junctions are all located near the south-western start/end of the line. One junction does not have a fixed location, but is spread along the line. No spatial difference can be determined between the vehicles. Temporal differences do exist for the different vehicles.

It can be noticed from the low speed analysis that the majority of low speed movements are within a distance of 30 meters from road intersections, traffic lights and stops. Only 5% of the made stops are located out of these possible stop locations. From these 5 percent, most of the stops should actually be included in one of the predefined possible stop locations. After studying these locations in more detail, only six locations were left that could not be explained by one of the defined possibilities. Based on the visual interpretation, there are no spatiotemporal regularities determined in the stops.

6.5 Conclusions

Traffic light priority request are made all along the line, they are bound to junctions, but these junctions have no clear locations. The is a temporal difference in the requests of the different vehicles. The low level event of a traffic light request can be used with temporal parameters to explain the high level event of punctuality. The registration a traffic light on a junctions should be bound to exact locations, in this way zones on traffic light can be used to determine the punctuality of a vehicle.

The high level event of route problems are explained by possible stop locations.
Defining zones around possible stop locations can exclude 95% of the expected stops. So the locations of know stops can be used to determine the high level event of route problems. Expected stop locations that could not be determined, were mostly due to a the fact that the locations were not all included in the OpenStreetMap source data. For example several pedestrian crossings are not present in the source dataset, for this reason these stop locations are included as unexpected stop.

7 High level Event: Driving behavior and Passenger comfort

Possible stops on a route can clearly be determined, at locations out of the determined possible stop zones, route problems can occur. Driving behavior and passenger comfort does most likely have a relation with the stops/breaks a vehicle needs to make during the ongoing of their route. One of the possible route problem locations sharp turns are studied in more detail. The analysis of the high level evens driving behavior and passenger comfort are performed for tram line 1. Sharp turns are determined from the line as using the OpenStreetMap. Visually seven sharp turns (turns with an angle smaller then 135°) can be determined. A generic study to determine sharp turns is performed, splitting the line into segments of different lengths. At the end, the line is segmented in 5, 10, 25, 50 and 100 meter segments.

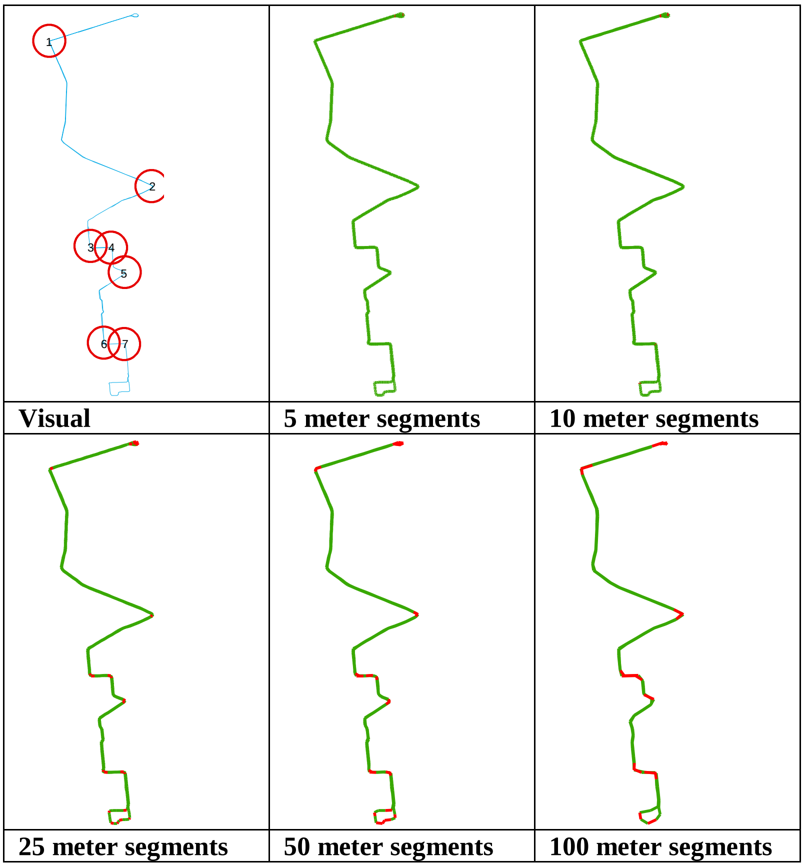


Figure 7.1: determined sharp turns using different segmentation lengths

From the figures it can be observed that the shorter segmentations do hardly determine any sharp turns (3 at 5 meter segments, and 5 at 10 meter segments) during the track. At 5 meter segments, all 3 are located at the start and the end of the line, at a 10 meter segmentation, only 1 is located at the track, the other 4 are at the start/end of the line which should be excluded as they do not influence the high level events: driving behavior and passenger comfort). From 25 meters and onwards, turns are detected. For 25 meter segments, 26 sharp turns are traced (12 are within the track, 14 are at the start and end turns of the line). At 50 meter segments, 27 turns are traced, of which 14 are within the track and 13 are located at the start/end of the line. For the 100 meter segments 19 turns are found (13 are within the track and 6 at the start/end of the line), some turns are grouped into one turn (the turn at the center of the line).

To find the extremes in the speed and acceleration/deceleration, a 30 meters distance around the turns traced in the 25 meter segments are used. The sharp turns at the start and end of the line are excluded.

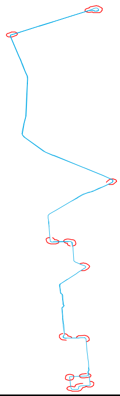
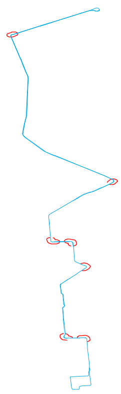
		
30 meter distance from all determined stops at 25 meter segmentation	**30 meter distance from the determined stops at 25 meter segmentation, excluding the stops at the start and end of the line**	

Fig 7.2 locations of sharp turns along line 1

When all accelerations and speeds at sharp turns are analyzed, the distribution of the Acceleration at the sharp turns are normal distributed (see fig 7.3).

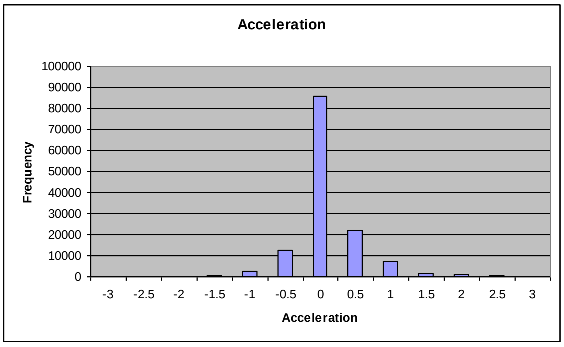


Fig 7.3: Distribution of acceleration at sharp turns, μ= -0.04252 , σ= 0.471419.

The value of 2σ (-0.98536) is used as a limit to define strong decelerations.
Speed is not normal distributed, as there are a lot of zero speed occurrences.

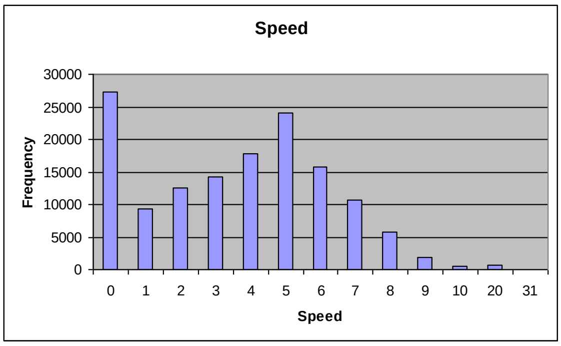


Fig 7.4: Distribution of speed at sharp turns, μ= 3.234894, σ= 2.500114.

The value of 2σ (8.235122) is used as a limit to define high speed.

7.1 Spatial analysis of aggregated vehicles on one line

During the first half of 2009, 29651 times a deceleration higher then 0.985 was registered. From these 29651 observations, 3354 (11.3%) are within a distance of 30 meters from a sharp turn. The following decelerations were determined at the sharp turns as numbered in table 7.1.

Table 7.1: Strong decelerations at sharp turns

Sharp-turn number	Number of observations	Average deceleration
1	**247**	**1.44**
2	**100**	**1.27**
3	**575**	**1.31**
4	**374**	**1.24**
5	**528**	**1.24**
6	**493**	**1.32**
7	**1037**	**1.40**
Total	***3354***	***1.33***

During the first half of 2009, 2591 times a vehicle passed a sharp turn (including its surrounding in a distance of 30 meter) with a speed that was higher then 8.235 m/s. The following division were found over the stops (see table 7.2).

Table 7.2: High speed passage of sharp turns

Sharp-turn number	Number of observations	Average speed
1	**403**	**9.23**
2	**135**	**8.99**
3	**545**	**9.22**
4	**232**	**9.76**
5	**465**	**9.20**
6	**182**	**10.27**
7	**629**	**9,85**
Total	***2591***	***9.48***

7.2 Spatial analysis individual vehicles on one line

The analysis done for the aggregated vehicles is next focused on the individual vehicles, that had a strong deceleration at the sharp turns.

Table 7.3: Strong deceleration (average per vehicle) at sharp turns for individual vehicles (in bold the measured decelerations that were stronger then the average strong deceleration)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300155	1.21	1.03	**1.41**	1.13	1.28	1.33	**1.58**	1.33
CEENG1074300159	**1.49**	1.25	1.22	1.20	1.22	**1.36**	**1.40**	1.32
CEENG1074300163					1.26			1.26
CEENG1074300167	**1.73**	**1.56**	**1.41**	1.34	1.34	1.33	1.38	1.40
CEENG1074300168	1.21	1.15	1.29	1.21	1.21	**1.38**	**1.49**	1.32
CEENG1074300172	1.79				**3.41**	1.17		2.12
CEENG1074300176	1.30	1.12	1.29	1.24	1.31	1.21	**1.46**	1.33
CEENG1074300179	1.21		**1.32**	1.25	1.16	1.21	**1.40**	1.26
CEENG1074300180	**1.60**	1.17	**1.31**	1.17	1.15	**1.33**	**1.34**	1.30
CEENG1074300184	**1.29**	1.07	1.24	1.25	1.17	1.21	**1.33**	1.27
CEENG1074300186	**1.57**	1.22	1.24	1.28	1.22	1.31	1.31	1.31
CEENG1074300191	**1.45**	1.01	1.32	1.21	1.21	**1.49**	**1.53**	1.38
CEENG1074300195	1.17	**1.59**	**1.42**	1.24	1.36	1.38	**1.50**	1.41

CEENG1074300198	**1.32**	1.23	**1.30**	1.25	1.21	1.30	1.28	1.28
CEENG1074300200	1.06	1.11	**1.35**	1.23	1.27	1.13	**1.37**	1.27
CEENG1074300211	1.32	**1.56**	1.30					1.37
CEENG1074300225	**1.62**	1.09	1.32	1.05	1.21	1.36	**1.80**	1.46
CEENG1074300227	**1.62**	0.99	1.30	1.21	1.17	**1.47**	**1.54**	1.37
CEENG1074300229			**1.40**	1.32	**1.50**	1.09	1.29	1.32
CEENG1074300230		1.25			1.08		**1.39**	1.31
CEENG1074300234			**1.84**	1.43		1.40		1.54
CEENG1074300240			1.12	**1.44**		1.12		1.20
CEENG1074300246	**1.46**	**1.37**	1.17	1.03	1.22	**1.48**	**1.37**	1.30
CEENG1074300248	**1.46**	1.18	**1.37**	1.29	1.30	1.33	**1.42**	1.35
CEENG1074300251			1.05		**1.27**	1.15		1.16
Total	**1.44**	**1.27**	**1.31**	**1.24**	**1.24**	**1.32**	**1.40**	**1.33**

Twenty-five vehicles were counted to have a strong deceleration at a sharp turn. Sixteen of these vehicles were counted to have at all of the sharp turns a strong declaration. Vehicle CEENG1074300163 only had one strong acceleration at turn 5. Six vehicles had only three strong acceleration occurrences. It can be observed that sharp turn 7, the last turn before the southern end of the line, had most strong deceleration, compared to the other turns.

Some extreme decelerations were made at turn 1 by vehicle CEENG1074300167 (7.10 m/s^2) and vehicle CEENG1074300180 (5.15 m/s^2), at turn 2 by vehicle CEENG1074300195 (3.98 m/s^2), at turn 6 by CEENG1074300168 (4.26 m/s^2), vehicle CEENG1074300180 (4.23 m/s^2) and vehicle CEENG1074300227 (4.25 m/s^2), at turn 7 by vehicle CEENG1074300176 (4.09 m/s^2), vehicle CEENG1074300195 (4.29 m/s^2) and vehicle CEENG1074300248 (4.27 m/s^2)

The same is done for individual vehicles passing the sharp turns with a high speed.

Table 7.4: High speed (average per vehicle) at sharp turns for individual vehicles (in bold the measured decelerations that were stronger then the average strong deceleration)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300155	8.97	8.90	**9.99**		9.04	**11.60**	**9.79**	9.39
CEENG1074300159	**9.63**	9.41	9.39	**10.05**	9.10	9.39	9.39	9.46
CEENG1074300163		**8.67**	8.56	**8.91**	8.48			8.63
CEENG1074300167	9.33	8.74	9.30	9.33	9.17	**9.48**	**10.19**	9.44
CEENG1074300168	9.15	8.92	9.24	9.23	9.03	**9.99**	**9.84**	9.42
CEENG1074300172					8.80	**9.42**		9.18
CEENG1074300176	9.20	9.00	9.01	9.19	**9.45**	**10.92**	**10.08**	9.62
CEENG1074300179	8.77	8.26	8.93	8.95	**9.32**	8.94	**10.30**	9.26
CEENG1074300180	9.29	8.94	8.85	**9.89**	9.30	**9.80**	**9.67**	9.39
CEENG1074300184	9.37	9.12	8.98	**9.57**	8.84	**10.35**	**10.13**	9.41
CEENG1074300186	9.44	8.64	9.11	**10.50**	8.97	**10.68**	**9.91**	9.60
CEENG1074300191	9.66		8.97	**10.50**	9.76	**10.59**	**10.10**	9.82
CEENG1074300195	8.80	9.11	9.54	**9.80**	9.59	**12.57**	9.76	9.78
CEENG1074300198	**9.60**	9.38	9.18	**10.02**	**9.62**	9.37	9.55	9.56
CEENG1074300200	8.72	**9.13**	**9.04**	8.93	8.81	8.96	**9.12**	9.01
CEENG1074300211	**9.58**		8.28					8.93
CEENG1074300225	8.95	8.47	**9.38**	8.98	8.63	9.07	**10.91**	9.37
CEENG1074300227	8.88	8.28	8.92	**9.42**	9.34	**10.89**	**9.81**	9.39
CEENG1074300229		8.26			**8.80**			8.62
CEENG1074300230			**11.20**	**10.10**		8.93	9.15	9.82
Total	**9.23**	**8.99**	**9.22**	**9.76**	**9.20**	**10.27**	**9.85**	**9.48**

Twenty vehicles passed a sharp turn with a high speed ones or more times. Turn 4, 6 and 7 were passed more often with a high speed by nearly all vehicles than the other turn. Turn 5 was passed by most vehicles with a high speed, but the speed values are most of the times lower then the average high speed of a vehicle. Thirteen vehicles passed all of the turns at least ones with a high speed. Two vehicles passed six out of seven turns with a high speed. Vehicle CEENG1074300172 passed only two sharp turns with a high speed (turn 5 and 6). Vehicle CEENG1074300211 passed twice a sharp turn with a high speed (turn 1 and 3). Vehicle CEENG1074300229 passed two sharp turns with a high speed (turn 2 and 5).

7.3 Temporal analysis of aggregated vehicles on one line

Table 7.5: Strong deceleration (average) at sharp turns during the different hours of the day

Turn	**Number of observations**		**Average deceleration**	
	Morning	**Afternoon**	**Morning**	**Afternoon**
1	**140**	**107**	**1.35**	**1.55**
2	**62**	**38**	**1.23**	**1.35**
3	**325**	**250**	**1.31**	**1.32**
4	**213**	**161**	**1.24**	**1.24**
5	**280**	**248**	**1.28**	**1.20**
6	**262**	**231**	**1.29**	**1.36**
7	**553**	**484**	**1.46**	**1.39**
Total	**1853**	**1519**	**1.33**	**1.34**

All sharp turns were passed more often with a strong deceleration during the morning then during the afternoon. The total average deceleration was 1.3 m/s^2 for both the morning and the afternoon. Turn 3 and 4 had comparable average strong decelerations during the morning and afternoon. Turn 1, 2, and were passed with a higher deceleration during the afternoon than in the morning. Turn 5, and 6 had a passage with a stronger deceleration during the morning, compared with the afternoon hours.

Table 7.6: Strong deceleration (average) at sharp turns during the and outside the rush-hours

Turn	**Number of observations**		**Average deceleration**	
	Rush-hours	**Out of rush-hours**	**Rush-hours**	**Out of rush-hours**
1	**51**	**196**	**1.39**	**1.45**
2	**20**	**80**	**1.20**	**1.29**
3	**84**	**491**	**1.34**	**1.31**
4	**68**	**306**	**1.26**	**1.24**
5	**58**	**470**	**1.31**	**1.23**
6	**72**	**421**	**1.33**	**1.32**
7	**112**	**925**	**1.44**	**1.40**
Total	**465**	**2889**	**1.35**	**1.33**

Out of the rush hours far more often a passage of a sharp turn in combination with a strong deceleration was registered. Turn 5 had a higher deceleration when passing during the rush-hours, then when passing out of the rush-hours. Turn 1 and 2 had a higher deceleration outside the rush-hours then during the rush hours. Turn 3, 4, 6 and 7 had comparable strong decelerations during the rush hours and out of the rush hours.

Table 7.7: High speed (average) at sharp turns during the different hours of the day

Turn	**Number of observations**		**Average speed**	
	Morning	Afternoon	Morning	Afternoon
1	228	175	9.25	9.21
2	91	44	9.02	8.92
3	341	204	9.24	9.18
4	125	107	9.95	9.54
5	352	212	9.17	9.23
6	90	92	9.99	10.54
7	328	301	9.65	10.07
Total	**1456**	**1135**	**9.42**	**9.56**

During the morning the first four sharp turns are passed with a higher average speed then in the afternoon. The last turns are passed with a higher speed during the afternoon then during the morning. During the morning all sharp turns except turn 6, were passed with a high speed then during the afternoon.

Table 7.8: High speed (average) at sharp turns during and outside the rush-hours

Turn	**Number of observations**		**Average speed**	
	Rush-hours	Out of rush-hours	Rush-hours	Out of rush-hours
1	102	301	9.37	9.18
2	44	91	8.94	9.01
3	136	409	9.09	9.26
4	24	208	10.20	9.71
5	77	388	9.14	9.21
6	37	145	9.51	10.46
7	102	527	9.67	9.89
Total	**522**	**2069**	**9.33**	**9.52**

All turns have more high speed passages during outside the rush-hours, then during the rush-hours. Turn 1 and 4 were passed with a higher speed during the rush-hours than outside the rush-hours. Turns 2, 3, 5, 6 and 7 were passed with a higher average speed out of the rush-hours then during the rush-hours. At turn 4 the highest average speed was found during the morning (10.20 m/s). In the afternoon, turn 6 was passé with the highest average speed (10.46 m/s).

7.4 Temporal analysis individual vehicles on one line

Table 7.9: Strong deceleration (average per vehicle) at sharp turns for individual vehicles passed during the morning hours (in bold the measured decelerations that were stronger then the average strong deceleration)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300155	1.21	1.03	**1.41**	1.13	1.28	1.33	**1.58**	1.33
CEENG1074300159	1.28	1.21	1.25	1.24	1.28	**1.37**	**1.41**	1.33
CEENG1074300167	**1.79**	1.16	**1.51**	1.36	1.43	1.30	1.39	1.43
CEENG1074300168	1.20	1.22	1.23	1.24	1.23	**1.32**	**1.44**	1.29
CEENG1074300172	1.79							1.79
CEENG1074300176	1.17	1.05	1.30	1.16	1.38	1.21	**1.48**	1.32
CEENG1074300179	1.25		**1.39**	**1.28**	1.15	1.15	**1.30**	1.26
CEENG1074300180	1.20	1.21	1.27	1.18	1.19	**1.36**	**1.35**	1.28
CEENG1074300184	1.23	1.05	**1.29**	1.11	1.18	1.13	**1.39**	1.25
CEENG1074300186	**1.79**	1.24	1.30	**1.36**	1.22	1.31	1.32	1.33
CEENG1074300191		1.01	**1.33**	1.10	1.10	1.14	**1.44**	1.26

CEENG1074300195	1.13	**1.49**	1.40	1.12	**1.51**	1.25	**1.62**	1.44
CEENG1074300198	**1.26**	**1.26**	**1.27**	**1.26**	1.24	**1.26**	1.21	1.25
CEENG1074300200	1.10		**1.31**	1.14	**1.28**	1.12	**1.29**	1.25
CEENG1074300211		**1.56**	1.30					1.38
CEENG1074300225	**1.62**		1.32		1.08	1.28	**1.41**	1.36
CEENG1074300227	1.03	0.99	1.30	1.14	1.17	1.28	**1.70**	1.34
CEENG1074300230		1.25			1.08		**1.39**	1.31
CEENG1074300240			1.12	**1.44**		1.12		1.20
CEENG1074300246	**1.46**	**1.37**	1.17		1.19	1.07	**1.42**	1.28
CEENG1074300248	**1.39**	1.18	1.33	1.33	1.36	1.29	**1.46**	1.37
Total	**1.35**	**1.23**	**1.31**	**1.24**	**1.28**	**1.29**	**1.42**	**1.33**

During the morning, twenty-one vehicles passed at least ones a sharp turn with a strong deceleration. One vehicle passed only ones a sharp turn with a strong deceleration (CEENG1074300172). One vehicle only passed two turns with a strong deceleration (CEENG1074300211). Two vehicles passed three turns with a strong deceleration (CEENG1074300230, CEENG1074300240). Twelve vehicles have passed at least ones all the turns with a strong deceleration. Turn 7 was passed with a high deceleration by all vehicles except three, the strong decelerations at this turn were always except three times higher then the average high deceleration of the individual vehicle.

Table 7.10: Strong deceleration (average per vehicle) at sharp turns for individual vehicles passed during the afternoon hours (in bold the measured decelerations that were stronger then the average strong deceleration)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300159	**1.73**	1.28	1.19	1.16	1.15	**1.36**	**1.39**	1.31
CEENG1074300163					1.26			1.26
CEENG1074300167	1.24	**2.17**	1.21	1.31	1.10	**1.39**	**1.37**	1.34
CEENG1074300168	1.22	1.06	**1.38**	1.15	1.19	**1.47**	**1.54**	1.37
CEENG1074300172					3.41	1.17		2.29
CEENG1074300176	**1.69**	1.23	1.27	**1.44**	1.23	1.21	**1.42**	1.35
CEENG1074300179	1.06		1.26	1.11	1.16	**1.29**	**1.86**	1.27
CEENG1074300180	**1.86**	1.12	**1.36**	1.16	1.10	1.32	1.31	1.32
CEENG1074300184	**1.34**	1.09	1.19	**1.37**	1.17	1.26	**1.31**	1.27
CEENG1074300186	**1.41**	1.03	1.19	1.20	1.22	**1.32**	**1.31**	1.28
CEENG1074300191	**1.45**		1.32	1.25	1.22	**1.84**	**1.56**	1.42
CEENG1074300195	1.17	**1.68**	**1.45**	1.30	1.22	**1.45**	**1.43**	1.40
CEENG1074300198	**1.44**	1.06	**1.33**	1.24	1.14	**1.36**	1.32	1.31
CEENG1074300200	1.00	1.11	**1.38**	1.25	1.26	1.14	**1.42**	1.29
CEENG1074300211	1.32							1.32
CEENG1074300225		1.09	1.33	1.05	1.28	1.43	**1.84**	1.52
CEENG1074300227	**1.88**		1.29	1.37	1.17	**1.62**	1.22	1.40
CEENG1074300229			**1.40**	1.32	**1.50**	1.09	1.29	1.32
CEENG1074300234			**1.84**	1.43		1.40		1.54
CEENG1074300246				1.03	**1.39**	**1.68**	1.23	1.35
CEENG1074300248	**1.70**	1.19	**1.43**	1.19	1.22	**1.39**	**1.35**	1.34
CEENG1074300251			1.05		**1.27**	1.15		1.16
Total	**1.55**	**1.35**	**1.32**	**1.24**	**1.20**	**1.36**	**1.39**	**1.34**

During the afternoon, twenty-two vehicles have passed at least ones a sharp turn in combination with a strong deceleration. Two vehicles only passed one turn with a strong deceleration (CEENG1074300163, CEENG1074300211). One vehicle passed twice a sharp turns with a strong deceleration (CEENG1074300171) Two vehicles passed three of the defined sharp turns with a strong deceleration (CEENG1074300234 and CEENG1074300251). Eleven vehicles passed all of the seven turns with a strong deceleration. Turn 2 was passed the least times with a strong deceleration compared to the other stops. Turn 6 and 7 were passed more often with an higher deceleration of the vehicles average compared to the other turns. Vehicle CEENG1074300172 has made on average the strongest decelerations.

Table 7.11: Strong deceleration (average per vehicle) at sharp turns for individual vehicles passed during the rush-hours (in bold the measured decelerations that were stronger then the average strong deceleration)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300155	1.21	1.03	1.41	1.13	1.28	1.33	**1.58**	1.33
CEENG1074300159	0.99					**1.91**	1.44	1.56
CEENG1074300167	**1.70**	1.19	**1.48**	1.42	1.31	1.33	1.41	1.43
CEENG1074300168	**1.35**	1.06	1.17	**1.36**	1.22	**1.39**	**1.54**	1.34
CEENG1074300176	1.17		1.22	1.13	**1.42**	**1.34**	**1.50**	1.33
CEENG1074300179				1.26				1.26
CEENG1074300180	1.21	1.02	**1.37**	1.18	1.09	**1.38**	1.30	1.27
CEENG1074300186	1.08	1.27	**1.41**	**1.36**	1.24	1.28	**1.43**	1.34
CEENG1074300195			1.06	**1.26**		**1.25**		1.21
CEENG1074300198	**1.29**	**1.20**	1.09	1.06	1.05			1.14
CEENG1074300227	1.05		1.28	1.04	1.14	**1.40**	**2.12**	1.28
CEENG1074300240			1.12	**1.44**		1.12		1.20
CEENG1074300246	**1.46**	**1.37**	1.22		1.24	1.00	**1.40**	1.30
CEENG1074300248	**1.43**	1.09	**1.44**	1.30	**1.53**	1.12	1.36	1.38
Total	**1.39**	**1.20**	**1.34**	**1.26**	**1.31**	**1.33**	**1.44**	**1.35**

During the rush hours, fourteen vehicles passed a sharp turn at least ones with a strong deceleration. Five vehicles passed all their turns with a strong deceleration ones or more. One vehicle passed only one turn with a strong deceleration (CEENG1074300179). Three vehicles passed three sharp turns with a strong deceleration (CEENG1074300159, CEENG1074300195 and CEENG1074300240). Turn 6 and 7 were passed with stronger decelerations then the vehicles average.

Table 7.12: Strong deceleration (average per vehicle) at sharp turns for individual vehicles passed outside the rush-hours (in bold the measured decelerations that were stronger then the average strong deceleration)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300159	**1.53**	1.25	1.22	1.20	1.22	**1.34**	**1.40**	1.32
CEENG1074300163					1.26			1.26
CEENG1074300167	**1.79**	**1.94**	1.35	1.29	1.35	1.32	1.37	1.38
CEENG1074300168	1.16	1.17	1.30	1.20	1.21	**1.38**	**1.49**	1.32
CEENG1074300172	1.79				**3.41**	1.17		2.12
CEENG1074300176	**1.43**	1.12	1.31	1.28	1.28	1.14	**1.45**	1.33
CEENG1074300179	1.21		**1.32**	1.25	1.16	1.21	**1.40**	1.26
CEENG1074300180	**1.62**	1.19	1.30	1.17	1.15	**1.33**	**1.34**	1.31
CEENG1074300184	**1.29**	1.07	1.24	1.25	1.17	1.21	**1.33**	1.27
CEENG1074300186	**1.59**	1.16	1.19	1.25	1.21	**1.33**	1.29	1.30
CEENG1074300191	**1.45**	1.01	1.32	1.21	1.21	**1.49**	**1.53**	1.38
CEENG1074300195	1.17	**1.59**	1.43	1.24	1.36	1.39	**1.50**	1.42
CEENG1074300198	**1.33**	1.24	**1.33**	1.27	1.23	**1.30**	1.28	1.29
CEENG1074300200	1.06	1.11	**1.35**	1.23	1.27	1.13	**1.37**	1.27
CEENG1074300211	1.32	**1.56**	1.30					1.37
CEENG1074300225	**1.62**	1.09	1.32	1.05	1.21	1.36	**1.80**	1.46
CEENG1074300227	**1.69**	0.99	1.30	1.31	1.18	**1.49**	**1.49**	1.38

CEENG1074300229			**1.40**	1.32	**1.50**	1.09	1.29	1.32
CEENG1074300230		1.25			1.08		**1.39**	1.31
CEENG1074300234			**1.84**	1.43		1.40		1.54
CEENG1074300246			1.04	1.03	1.19	**1.57**	**1.34**	1.29
CEENG1074300248	**1.47**	1.19	**1.36**	1.28	1.25	1.34	**1.42**	1.35
CEENG1074300251			1.05		**1.27**	1.15		1.16
Total	**1.45**	**1.29**	**1.31**	**1.24**	**1.23**	**1.32**	**1.40**	**1.33**

Out of the rush hours, twenty-three vehicles passed a sharp turn at least ones with a strong deceleration. Four vehicles passed three of the seven turns with a strong deceleration. One vehicle CEENG1074300163 passed only one turn at least ones with a strong deceleration. Fourteen vehicles passed all of the turns at least ones with a strong deceleration. Turn 7 had most of the strong decelerations larger then the vehicles average. Vehicle CEENG1074300172 has made on average the strongest decelerations.

Table 7.13: High speed (average per vehicle) at sharp turns for individual vehicles passed during the morning hours (in bold the measured decelerations that were stronger then the average high speed)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300155	8.97	8.90	**9.99**		9.04	**11.60**	**9.79**	9.39
CEENG1074300159	8.59	8.90	9.40	**10.31**	9.38	9.28	**9.49**	9.48
CEENG1074300167	**9.25**	8.87	**9.35**	9.04	9.13	8.96	**9.47**	9.24
CEENG1074300168	9.19	8.94	**9.27**	9.22	8.79	9.08	**9.51**	9.23
CEENG1074300176	9.29	9.14	9.02	8.98	9.31	**11.34**	**10.00**	9.59
CEENG1074300179	**8.86**	8.26	**8.91**		8.78	**8.92**	**8.92**	8.81
CEENG1074300180	**9.56**	8.66	8.86	**10.81**	9.27	**10.02**	**9.71**	9.48
CEENG1074300184	**9.71**	**9.42**	9.09	**9.31**	8.69	8.95	**9.25**	9.10
CEENG1074300186	**10.21**	8.64	9.16	**12.33**	9.02	9.77	**10.09**	9.79
CEENG1074300191			8.98	**10.20**	**10.74**		9.31	10.10
CEENG1074300195	8.76	9.35	9.37	**9.88**	**9.83**	**12.80**	9.14	9.68
CEENG1074300198	8.69	**9.66**	9.39	**10.29**	8.66	**10.01**	9.26	9.46
CEENG1074300200		**9.13**			**9.44**		8.93	9.02
CEENG1074300211	**8.68**		8.28					8.41
CEENG1074300225			**9.57**		8.35			8.96
CEENG1074300227	8.93	8.28	8.72	**9.41**	**9.68**	8.84	**9.97**	9.38
CEENG1074300230			**11.20**	**10.10**		8.93	9.15	9.82
CEENG1074300240							8.35	8.35
CEENG1074300246	**9.27**	8.50	**9.03**	8.32	8.55	8.75	**9.11**	8.96
CEENG1074300248	9.25	9.47	9.45	9.50	9.00	9.80	**10.21**	9.51
Total	**9.25**	**9.02**	**9.24**	**9.95**	**9.17**	**9.99**	**9.65**	**9.42**

During the morning, twenty vehicles passed a sharp turn with a high speed. Twelve of the vehicles passed all of the sharp turns ones or more with a high speed. One vehicle CEENG1074300240 passed one of the turns at least ones with a high speed. Vehicle CEENG1074300211 and CEENG1074300225 had only at two turns a high speed passages. Turn 4 and 7 was passed most often with a high speed. At turn 7 two-third of the passages are above the vehicles average. Vehicle CEENG1074300191 has the highest average speed.

Table 7.14: High speed (average per vehicle) at sharp turns for individual vehicles passed during the afternoon hours (in bold the measured decelerations that were stronger then the average high speed)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300159	**9.87**	**10.25**	9.38	9.04	8.66	**9.72**	9.24	9.42
CEENG1074300163		**8.67**	8.56	**8.91**	8.48			8.63
CEENG1074300167	9.57	8.43	9.12	**10.06**	9.38	**10.64**	**11.09**	9.97
CEENG1074300168	9.08	8.79	9.19	9.25	9.20	**10.42**	**10.17**	9.64
CEENG1074300172					8.80	**9.42**		9.18
CEENG1074300176	8.47	8.47	8.96	9.43	**9.80**	**10.01**	**10.18**	9.70
CEENG1074300179	8.48		8.93	8.95	**9.86**	8.98	**10.98**	9.61
CEENG1074300180	9.03	9.22	8.82	8.96	**9.33**	**9.49**	**9.62**	9.25
CEENG1074300184	9.18	8.52	8.91	**9.67**	9.02	**10.46**	**10.76**	9.62
CEENG1074300186	9.04		9.04	**9.45**	8.92	**12.27**	**9.79**	9.44
CEENG1074300191	9.66		8.97	**10.61**	9.46	**10.59**	**10.39**	9.75
CEENG1074300195	8.82	8.83	9.67	9.78	8.61	**12.49**	**9.87**	9.85
CEENG1074300198	**10.40**	8.56	8.95	9.53	**10.41**	8.73	**9.89**	9.69
CEENG1074300200	8.72		9.04	8.93	8.65	8.96	**9.39**	9.00
CEENG1074300211	10.48							10.48
CEENG1074300225	8.95	8.47	9.19	8.98	8.69	9.07	**10.91**	9.42
CEENG1074300227	8.87	8.26	9.15	**9.42**	9.04	**13.96**	**9.62**	9.40
CEENG1074300229		8.26			**8.80**			8.62
CEENG1074300234			9.05	**10.07**	9.05	**10.94**	**10.57**	9.50
CEENG1074300246	8.37				**9.31**	8.89	**10.15**	9.26
CEENG1074300248	8.98	9.39	**9.69**	**9.77**	9.27	**10.42**	**10.31**	9.60
CEENG1074300251					**9.06**	8.30	**9.96**	8.94
Total	**9.21**	**8.92**	**9.18**	**9.54**	**9.23**	**10.54**	**10.07**	**9.56**

During the afternoon, twenty-two vehicles passed at least ones a sharp turn with a high speed. Eleven vehicles passed all of the turns at least ones with a high speed. Three vehicles passed all of the turns except one with a high speed. Turn 7 occurs to be passed by all vehicles except four with a high speed. Turn 6 was passed by all except three vehicles with a high speed. Turn 6 and 7 were passed most often with a speed higher then the vehicles average. At turn 7 only one occurrence was lower then the vehicles average. Vehicle CEENG1074300211 has the highest average speed.

Table 7.15: High speed (average per vehicle) at sharp turns for individual vehicles passed during the rush hours (in bold the measured decelerations that were stronger then the average high speed)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300155	8.97	8.90	**9.99**		9.04	**11.60**	**9.79**	9.39
CEENG1074300159					9.26		**9.47**	9.40
CEENG1074300167	**9.42**	8.85	9.34	**9.36**	9.02	8.97	**9.99**	9.34
CEENG1074300168	**9.44**	**9.45**	8.62	**8.98**		**9.01**	**9.01**	8.97
CEENG1074300176	9.43	8.71	8.92	9.00	9.39	**9.52**	**10.09**	9.46
CEENG1074300179			**8.91**		8.35			8.63
CEENG1074300180	**10.62**	8.85	8.78	8.91	**9.81**		9.19	9.45
CEENG1074300184		8.96						8.96
CEENG1074300186	9.56	8.47	9.22	**12.33**	9.73	**10.14**	**10.30**	10.12
CEENG1074300195	8.76	8.26	**9.21**		8.87			8.94
CEENG1074300198		**9.65**	8.65				8.98	9.23
CEENG1074300211	**8.68**		8.28					8.48
CEENG1074300227		8.28	8.65	8.93	**9.17**	8.84	9.51	8.96

CEENG1074300240							8.35	8.35
CEENG1074300246	**9.27**	8.50	**9.03**	8.32	8.55	8.75	**9.11**	8.96
CEENG1074300248	8.98	**9.44**	8.85	**9.54**	8.64	**10.00**	**9.71**	9.19
Total	**9.37**	**8.94**	**9.09**	**10.20**	**9.14**	**9.51**	**9.67**	**9.33**

During the rush-hours, sixteen vehicles passed a sharp turn at least ones with a high speed. Five vehicles had at least one high speed passage of all turns. Vehicles CEENG1074300184 and CEENG1074300240, had only passed one turn with a high speed. Vehicles CEENG1074300159, CEENG1074300179 and CEENG1074300211 passed two turns with a high speed. Vehicle CEENG1074300186 has the highest average speed.

Table 7.16: High speed (average per vehicle) at sharp turns for individual vehicles passed out of the rush hours (in bold the measured decelerations that were stronger then the average high speed)

	Turn							
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
CEENG1074300159	**9.63**	9.41	9.39	**10.05**	9.09	9.39	9.39	9.46
CEENG1074300163		**8.67**	8.56	**8.91**	8.48			8.63
CEENG1074300167	9.20	8.65	9.24	9.32	9.32	**10.07**	**10.28**	9.53
CEENG1074300168	9.14	8.74	9.34	9.24	9.03	**10.09**	**9.88**	9.45
CEENG1074300172					8.80	**9.42**		9.18
CEENG1074300176	9.01	9.20	9.04	9.30	9.48	**11.72**	**10.07**	9.71
CEENG1074300179	8.77	8.26	8.93	8.95	9.46	8.94	10.30	9.31
CEENG1074300180	9.00	8.96	8.87	**9.93**	9.17	**9.80**	**9.76**	9.38
CEENG1074300184	9.37	9.20	8.98	**9.57**	8.84	**10.35**	**10.13**	9.42
CEENG1074300186	**9.44**	8.98	9.04	**9.45**	8.81	**10.99**	**9.79**	9.42
CEENG1074300191	9.66		8.97	**10.50**	9.76	**10.59**	**10.10**	9.82
CEENG1074300195	8.80	9.18	9.62	9.80	9.67	**12.57**	9.76	9.86
CEENG1074300198	**9.60**	9.11	9.24	**10.02**	**9.62**	9.37	**9.61**	9.59
CEENG1074300200	8.72	**9.13**	**9.04**	8.93	8.81	8.96	**9.12**	9.01
CEENG1074300211	**10.48**		8.28					9.38
CEENG1074300225	8.95	8.47	**9.38**	8.98	8.63	9.07	**10.91**	9.37
CEENG1074300227	8.88	8.27	9.10	9.48	9.38	**13.96**	**9.87**	9.51
CEENG1074300229		8.26			**8.80**			8.62
CEENG1074300230			**11.20**	**10.10**		8.93	9.15	9.82
CEENG1074300234			9.05	**10.07**	9.05	**10.94**	**10.57**	9.50
CEENG1074300246	8.37				**9.31**	8.89	**10.15**	9.26
CEENG1074300248	9.20	9.42	**9.70**	9.58	9.21	**10.00**	**10.33**	9.62
CEENG1074300251					**9.06**	8.30	**9.96**	8.94
Total	**9.18**	**9.01**	**9.26**	**9.71**	**9.21**	**10.46**	**9.89**	**9.52**

Out of the rush-hours, twenty three vehicles passed at least ones a sharp turn with a high speed. Fourteen vehicles passed all of the sharp turns with a speed. Turn 6 was passed by all vehicles except two with a high speed. Three vehicles passed only two from the seven turns with a high speed. At turn 6 and 7 the high speed was more often higher then the vehicles average compared to the other turns.

7.5 Discussion

Sharp turns in combination with a strong deceleration and a high speed differ per vehicle. No spatiotemporal regularity can be determined. A strong deceleration or high speed passage occurs more often at the determined sharp turns for some of the vehicles than for others. There is no temporal difference between the vehicles and the turns.

7.6 Conclusions

The low level events; sharp turns in combination with strong deceleration and high speed can be used to determine to a certain degree the level of driving behavior and passenger comfort. The occurrence of these low level events is rather occasional than a regularity. The average speeds of the vehicles at turns 4, 6 and 7 were higher then at the other turns. This most likely depend on the traffic situation at the given place and time. Sharp turn can be predefined zones on bases of the predefined route. When a vehicle enters these zones, the accelerations and speed should be monitored. The temporal frequency of measuring clearly influences the determination of strong deceleration and high speed occurrences.

When looking to the individual vehicles, it can be noted that some of the vehicles have passed all turns at least ones with a strong deceleration, where others only have incidentals strong decelerations at the passages of the sharp turns.
The defined low level events of a sharp turn in combination with a strong deceleration and high speed can be determined in the movement trajectories of the vehicles. A difference in event occurrence is found between the vehicles.

8 Conclusions and further research

The main objective of this study is to evaluate the capabilities of the measurements collected by the telematic system Live!, which is implemented at the Helsinki public transport. These measurements, collected during the first half of 2009, are used to explain the predefined high level events, in a public transport setup, by means of occurrence of low events in the by Live! collected trajectories.

Three predefined high level events are studied:

- Punctuality
- Route problems
- Driving behavior and passenger comfort

The each defined high level event the corresponding question was posed to be answered:

1. Can the high level event punctuality be explained by a sequence or combination of low level events on stop status and stop passage?
2. Can the high level event of route problems be explained by low level events of expected and unexpected stops?
3. Can the high level event on passenger comfort be explained by a combination low level events on sharp turn, strong deceleration or high speed?

8.1 Conclusions

Stop registration includes a stop status (stop enter, leave or passed) together with a time difference to the original schedule (in this study classified as late, early or punctual). These low level parameters together with the locations of the stops, time of passage and driving direction of the vehicles were used to study the high level event of punctuality. It can be observed that stop passage without stopping (stop status) is a random process, there are no stops that are passed with a higher frequency then others, this parameter does not add any value in explaining punctuality. Driving direction plays an important role in the punctuality, vehicles tend to have a lower percentage of punctual stop passage at the end of their route. There is no clear distinction in punctuality for the different vehicles used on a line (this counts both trams as for busses). A small difference appears during the stop passage at the different hours of the day, so time plays a limited role.

The small differences in punctuality could be caused by the occurrence of route problems.
This high level event is next analyzed using the collected trajectories collected by the Live! telematic system, which include traffic light priority requests made during the travel of a route, and by determination occurrences of possible stop locations. Traffic light priority is only given to vehicles that are back on their schedule. It can be observed that requests are far more often made at the south-west, which is near the city centre, then at the other end of the line, so location plays an important role. Also direction does play a role, vehicles traveling towards the city centre show higher frequencies of priority requests than in the opposite direction. There are small spatial temporal differences for the individual vehicles. Less requests are made during the night and during the rush-hours. The first could be expected, as there is less traffic during the night hours. But during the rush-hours, it would be expected to have more requests, then out of the rush hours.

Possible stop locations based on locations of traffic lights, road intersections, and tram stops explain 95% of the low speed occurrences in the trajectories. From the other 5% most were at locations that should have been included at one of the mentioned categories (traffic lights, road intersections, and tram stops), but they were not described as such in the source data of the OpenStreetMap. There is no spatial temporal regularity in the other stop locations, which means they can easily be detected excluding the known possible stop locations from the event detection.

At locations where stops, or decelerations need to be made due to know stop locations and/or route problems, driving behavior and passenger comfort start playing a role. Locations with a strong deceleration, and sharp turn are further studied. Sharp turns can easily be detected in the source data of the OpenStreetMap. These locations can best be performed dividing the know bus/tram line in segments of 25 to 50 meter. For these segments the turn-angle can be calculated, which can be used for the definition an detection of a sharp turn. Lower and higher segment lengths will result in a over and/or under estimation of the number of detected sharp turns. Differences of driving behavior can be found for the different vehicles, some vehicles show a higher number of sharp turn passage with a strong deceleration then others. No spatial temporal differences can be found.

Overall it can be concluded that by measuring the time and location of vehicles, several derived variables on speed, punctual passage of stops can be calculated. Using these derived variables together with defining zones at predefined locations to explain high level events by changes in spatiotemporal derived variables like acceleration and speed, punctual passage of stops is proven in this study to be possible. Conclusions on the other hand are strong influenced by the availability of reliable and up-to-data source data.

Punctuality is measured at bus and tram stops, these locations can be determined in the trajectories as spatial concentrations of measure points. The determined patterns can be compared to the taxonomy that (Dodge et al., 2008) uses to classify movements patterns, with the difference, that in the study of (Dodge et al., 2008) movements are based on objects that can freely move in space, while in this study, the object movements are restricted to a fixed network.

8.2 Further research

In this study it is shown, high level “real world” events can be determined by one or more low level events that occur in trajectory recordings. The different low level events to explain the predefined high level events are visually explored in this study. The results should be validated in a real time event detection setting, to be able to verify the findings of detecting high level events. It is advised to also implement different tram and bus lines, and to study different high level events like passenger safety, vehicle incidents for both tram and busses.

The boundary limits of low level events could be better defined on basis of the occurrences in the collected trajectories. E.g. a sharp turn is now defined as an arbitrary value, where the values could also be discovered from the collected data. This should be studied in more detail. It might be studied implying different sensor based measurement devices at the vehicles, following the reactions of passengers. One could think of camera registration, that continuous register passenger behavior during the trip, or a camera recording that will start after a certain high level event has been detected.

The same strategy could be followed to measure passenger behavior at stops, to determine which delays are still acceptable, as in this study, the boundaries of being on time are set arbitrary at 60 seconds in front and 60 seconds behind schedule.

The exploration of low level location registrations were analyzed using the TRIAD framework, the framework could be used to determine low level event boundaries like differences between vehicles, temporal differences (determining the exact rush-hours, which might even differ per day or season), and the combination of spatiotemporal differences. The explored events of this study could be a good guidance on where which spatiotemporal events should be studied in more detail.

For this study the data collected by the Mattersoft [3] is used. It contains of high frequency (one measurement per second) measurement on vehicles of the Helsinki public transport. The optimum spatiotemporal scale should be studied in more detail, to see if these high frequencies of data collection are really needed for the purpose of event detection. For some purposes a lower frequency might be more suitable, as different events might be detected on different scales.

The determination of location needs still to be improved. One can think of real-time correction in case the position of vehicles are to far from their original track. The start en end of the measurements recording should be automated, in the current dataset there are to many cases that a trajectory is recorded while a vehicle is not actively driving on its track. This makes it very difficult to compare the collected trajectories, as duration and length widely varies.

Implementation in SWE should be studied in more detail. Event detection on bases of the SES service, together Complex Event Processing (CEP) algorithms, seems a logical platform to continue real-time detection of high level events.

For this reason several strategies for movement registration are described by (Andrienko et al., 2008) should be further explored:

- Time-based recording: positions of entities are recorded at regularly spaced time moments, e.g. every 5 min.
- Change-based recording: a record is made when the position of an entity differs from the previous one.
- Location-based recording: records are made when an entity comes close to specific locations, e.g. where sensors are installed.
- Event-based recording: positions and times are recorded when certain events occur, in particular, activities performed by the moving entity (e.g. calling by a mobile phone).
- Various combinations of these basic approaches.

References

ANDRAE, S. W., S., (Ed.) (2005) *Summarizing GPS Trajectories by Salient Patterns.,* Heidelberg, Wichmann.

ANDRIENKO, N., ANDRIENKO, G., PELEKIS, N. & SPACCAPIETRA, S. (2008) Basic Concepts of Movement Data. *Mobility, Data Mining and Privacy.*

BASHIR, F., KHOKHAR, A. & SCHONFELD, D. (2006) View-invariant motion trajectory-based activity classification and recognition. *Multimedia Systems,* 12, 45-54.

BURKE, J., D. ESTRIN, M. HANSEN, A. PARKER, N. RAMANATHAN, S. REDDY & SRIVASTAVA, M. B. (2006) Participatory Sensing. IN ANDREW T. CAMPBELL, P. B., JOHN S. HEIDEMANN (Ed.) *Proceedings of the 4th International Conference on Embedded Networked Sensor Systems, SenSys 2006.* Boulder, Colorado, USA, ACM 2006.

CALENGE, C., DRAY, S. & ROYER-CARENZI, M. (2009) The concept of animals' trajectories from a data analysis perspective. *Ecological Informatics,* 4, 34-41.

CHU, X. & BUYYA, R. (2007) Service Oriented Sensor Web. *Sensor Networks and Configuration.*

DELIN, K. (2002) The Sensor Web: A Macro-Instrument for Coordinated Sensing. *Sensors,* 2, 270-285.

DELIN, K., JACKSON, S., JOHNSON, D., BURLEIGH, S., WOODROW, R., MCAULEY, J., DOHM, J., IP, F., FERRÃ©, T., RUCKER, D. & BAKER, V. (2005) Environmental Studies with the Sensor Web: Principles and Practice. *Sensors,* 5, 103-117.

DODGE, S., WEIBEL, R. & LAUTENSCHUTZ, A.-K. (2008) Towards a taxonomy of movement patterns. *Inf Visualization,* 7, 240-252.

GONZÃ¡LEZ, M. C., HIDALGO, C. A. & BARABÃ¡SI, A. L. (2008) Understanding individual human mobility patterns. *Nature,* 453, 779-782.

HÃ¤GERSTRAND, T. (1970) What about people in Regional Science? *Papers of the Regional Science Association,* 24, 6-21.

HOWARTH, R., J. & BUXTON, H. (1992) Analogical representation of spatial events for understanding traffic behaviour. *Proceedings of the 10th European conference on Artificial intelligence.* Vienna, Austria, John Wiley \& Sons, Inc.

JOHNSON, N. & HOGG, D. (1996) Learning the distribution of object trajectories for event recognition. *Image and Vision Computing,* 14, 609-615.

KANE, L., VERMA, B. & JAIN, S. (2008) Vehicle tracking in public transport domain and associated spatio-temporal query processing. *Computer Communications,* 31, 2862-2869.

KUSHKI, A., PLATANIOTIS, K. N. & VENETSANOPOULOS, A. N. (2010) Intelligent dynamic radio tracking in indoor wireless local area networks. *IEEE Transactions on Mobile Computing,* 9, 405-419.

LEICK, A. (1990) GPS satellite surveying. *GPS satellite surveying.*

LUCKHAM, D. (2008) The power of events: An introduction to complex event processing in distributed enterprise systems. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics).* Orlando, FL.

MOHNHAUPT, M., NEUMANN, BERND (1991) Understanding object motion: Recognition, learning and spatiotemporal reasoning. *Robotics and Autonomous Systems,* 8, 65-91.

NEUMANN, B. & NOVAK, H.-J. (1983) Event models for recognition and natural language description of events in real-world image sequences. *Proceedings of the Eighth international joint conference on Artificial intelligence - Volume 2.* Karlsruhe, West Germany, Morgan Kaufmann Publishers Inc.

PAUL, M. A., HONICKY, R. J., ALAN, M., CHRIS, M., ERIC, P., SUSHMITA, S. & ALLISON, W. (2009) A vehicle for research: using street sweepers to explore the

landscape of environmental community action. *Proceedings of the 27th international conference on Human factors in computing systems.* Boston, MA, USA, ACM.
PEUQUET, D. J. (1994) It's about time: a conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals - Association of American Geographers,* 84**,** 441-461.
REA, N., DAHYOT, R. & KOKARAM, A. (2004) Semantic Event Detection in Sports Through Motion Understanding. *Image and Video Retrieval.*
SADOUN, B. & AL-BAYARI, O. (2007) Location based services using geographical information systems. *Computer Communications,* 30**,** 3154-3160.
SCHMID, F., RICHTER, K.-F. & LAUBE, P. (2009) Semantic Trajectory Compression. *Advances in Spatial and Temporal Databases.*
TOBLER, W. R. (1970) A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography,* 46**,** 234-240.

Wageningen University Thesis

[A] Visser, Ivo, 2009, Route determination in disaster areas, Using predictions and introducing the option to wait to improve routing results.
[B] Giffen, Hanneke van, 2009, Movement behaviour patterns of tourists in the Grebbelinie area

Web References

[1] http://gpshome.ssc.nasa.gov/
[2] http://www.hel2.fi/liikenteenohjaus/eng/pt_telematics.asp
[3] http://transport.wspgroup.fi/live/
[4] http://www.ict-pronto.org/
[5] http://www.opengeospatial.org/
[6] http://geostandards.geonovum.nl/index.php/5_Sensor_Web_Enablement
[7] http://www.dfrc.ch/OGC.htm
[8] http://www.openstreetmap.org/
[9a] http://aikataulut.ytv.fi/linjat/en/h1_1a.html
[9b] http://aikataulut.ytv.fi/linjat/en/h68.html
[10] http://jeesjees.wordpress.com/page/2/
[11] http://www.siemens.pl/upload/images/TS-VAL_System.pdf
[12] http://www.frommers.com/destinations/helsinki/0053010008.html

Software & Tools

[a] PostgreSQL: www.postgresql.org
[b] QuantumGIS: www.qgis.org
[c] GDAL/OGR: http://www.gdal.org/ogr
[d] ArcGIS: http://www.esri.com/software/arcgis

Appendix 1 Available Live! data

Message format description
==
File buscom20090403_EFENG1060900849_.txt

This file contain information of vehicle logging on route during a day 3.4.2009

Format:
Time Date;id;Message;type;Line;Line letter;direction;departure

Explanation:

Time Date	Time stamp of the vehicle
id	Id of the vehicle
Message	Vehicle is logging to route
Type (20102)	Logging to route
Line	Four-digit route code of vehicle
Line Letter	Additional information of the route
Direction	Direction on route
Departure	Four-digit departure code of vehicle

Example:
00:00:08 03.04.2009;EFENG1060900849;BCOM;20102;1064;N;1;2340

==
File distance20090403_EFENG1060900849_.txt

This file contain information of vehicle which move too far away from correct route

Message format description:
Time Date;id;lost status;line;direction;departure;distance from route;latitude;longitude

Explanation:

Time Date	Time stamp of the vehicle
id	Id of the vehicle
lost status	True if over 300 meters from route, false if the vehicle came back near the route
line	Four-digit route code of vehicle
direction	Direction on route
departure	Four-digit departure code of vehicle
distance from route	Distance in meters from specified route
latitude	Latitude of vehicle
longitude	Longitude of vehicle

Example:
01:54:23 03.04.2009;EFENG1060900849;True;1064N;1;0135;300,527536175972;
60,2516083333333;24,9557533333333

==
File stoplog20090403_EFENG1060900849_.txt

This file contain information of vehicle passing stops on a day 3.4.2009

Message format description:
Time Date;id;line;departure;direction;stop code;status;difference from timetable

Explanation:

Time Date	Time stamp of the vehicle
id	Id of the vehicle
line	Four-digit route code of vehicle
departure	Four-digit departure code of vehicle
direction	Direction on route
stop code	Seven digit code of stop
status	Information of vehicle's location regarding to stops
difference from timetable	Time in seconds between estimated stop pass and our server time

Example:
00:09:29 03.04.2009;EFENG1060900849;1064N;0010;2;1353117;StopEnter;0

==

File trlreq20090403_EFENG1060900849

This file contain information of vehicle getting traffic light priorities on a day 3.4.2009

Message format description:
Time Date;id;line;departure;junction_input;direction;type

Explanation:

Time Date	Time stamp of the vehicle
id	Id of the vehicle
line	Four-digit route code of vehicle
departure	Four-digit departure code of vehicle
junction	junction
input	Traffic light number of the junction
direction	Direction on route
type	0: priority request, 1: priority request ends

Example:
10:20:09 03.04.2009;EFENG1060900849;1064;0947;161_999;2;0

==

File status20090403_EFENG1060900849_.txt

Message format description
Time Date;id;line;departure;latitude;longitude;bearing;direction;acceleration;vehicle type;distance from start

Explanation:

Time Date	Time stamp of the vehicle
id	Id of the vehicle
line	Four-digit route code of vehicle
departure	Four-digit departure code of vehicle
latitude	Latitude of vehicle
longitude	Longitude of vehicle
bearing	Vehicle's physical direction in degrees
direction	Direction on route

acceleration	Acceleration in meters per second
vehicle type	bus or tram
Distance from start	Distance from starting point in meters

Example:
00:00:00 03.04.2009;EFENG1060900849;1064N;2340;60,23590;24,96463;46,52;1;
-0,37;0;9603,83071433139;

Appendix 2 Transport lines

Vehicle: Tram	Vehicle: Bus
1001	1011
1001A	1015
1003T	1016
1003B	1022
1004	1040
1004T	1050
1006	1054
1007A	1058
1007B	1059
1008	1064
1009	1067
1010	1068
	1071
	1077
	1078
	1079
	1080
	1081
	1083
	1084
	1085
	1086
	1087
	1088
	1092
	1094
	1095
	1096
	1097
	1098
	2025
	2042
	2046
	2205
	2505
	4611
	5532

Appendix 3 Transport vehicles

Transport ID: Tram	Transport ID: Bus
CEENG1074300155	EFENG1060400440
CEENG1074300156	EFENG1060400457
CEENG1074300158	EFENG1060900519
CEENG1074300159	EFENG1060900849
CEENG1074300161	EFENG1061000067
CEENG1074300163	EFENG1061000195
CEENG1074300164	EFENG1061000266
CEENG1074300167	EFENG1061000436
CEENG1074300168	EFENG1061000450
CEENG1074300169	EFENG1061900267
CEENG1074300173	EFENG1062200066
CEENG1074300175	EFENG1062200082
CEENG1074300176	EFENG1062200085
CEENG1074300178	EFENG1062200086
CEENG1074300179	EFENG1062200086
CEENG1074300180	
CEENG1074300183	
CEENG1074300184	
CEENG1074300186	
CEENG1074300190	
CEENG1074300191	
CEENG1074300192	
CEENG1074300195	
CEENG1074300198	
CEENG1074300199	
CEENG1074300200	
CEENG1074300201	
CEENG1074300203	
CEENG1074300206	
CEENG1074300207	
CEENG1074300209	
CEENG1074300213	
CEENG1074300215	
CEENG1074300217	
CEENG1074300220	
CEENG1074300223	
CEENG1074300225	
CEENG1074300226	
CEENG1074300227	
CEENG1074300230	
CEENG1074300232	
CEENG1074300233	
CEENG1074300234	
CEENG1074300236	
CEENG1074300238	
CEENG1074300240	
CEENG1074300243	
CEENG1074300245	
CEENG1074300248	
CEENG1074300251	
CEENG1074300252	
CEENG1074300252	