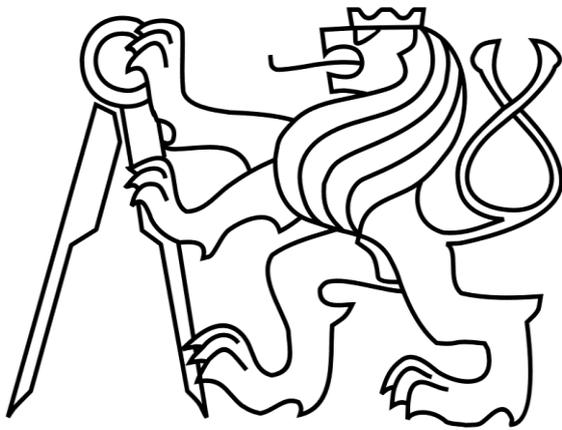


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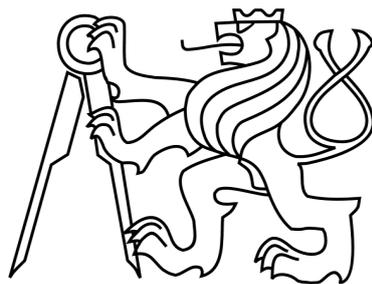
LINKÖPING UNIVERSITY
FACULTY OF SCIENCE AND ENGINEERING



MASTER'S THESIS

2020

Bc. Adam Ulanovský



CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF TRANSPORTATION SCIENCES

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**Model of control and information on a stretch of
road using data from ATC and FCD**

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CZECH TECHNICAL UNIVERSITY IN PRAGUE

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MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

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- Analysis of a selected stretch of road on the highway network in the Czech Republic for gaining sufficient data from SATC and FCD.
- Verification of data penetration from FCD for control and information on a stretch of the highway including own values and data comparison.
- A blueprint for SATC and FCD combination for direction, control possibilities and dynamic information providing including usage of all useful data on a stretch of a road or on the highway.
- Evaluation of model possibilities in VISSIM.



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Příbyl, P., Svítek, M.: Inteligentní dopravní systémy, BEN 2001, ISBN 80-7300-029-6.
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b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

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I confirm assumption of master's thesis assignment.

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Student's name and signature

Prague July 18, 2019

DECLARATION

I hereby declare that the presented thesis is my work and that I have cited all sources of information following the Guideline for adhering to ethical principles when elaborating an academic final thesis. I acknowledge that my thesis is subject to the rights and obligations stipulated by the Act No. 121/2000 Coll., the Copyright Act, as amended, in particular, that the Czech Technical University in Prague has the right to conclude a license agreement on the utilization of this thesis as school work under the provisions of Article 60(1) of the Act.

In Prague on 1st December 2020

.....

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I thank my family and my friends, who were my dear support in time of need, during writing this thesis.

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ABSTRAKT

Tato magisterská práce má za cíl sumarizovat data o dopravě, které má Ředitelství silnic a dálnic k dispozici z vybraného úseku dálnice, konkrétně z dálnice D5 mezi Prahou a Berounem. Zabývá se způsobem a četností sběru dat z dostupných detektorů dopravy, jejich zpracováním a řeší použitelnost dat pro řízení dopravy, například pro liniové řízení dopravy.

ABSTRACT

This master's thesis aims to summarize the data about traffic, that the Directorate of Roads and Motorways has available from a selected section of the highway, specifically from the D5 motorway between Prague and Beroun. It deals with the method and frequency of data collection from available traffic detectors, data processing and deals with the applicability of data for traffic management, such as highway management.

KLÍČOVÁ SLOVA

Plovoucí vozidla, FCD, řízení dopravy, monitorování dopravy, sčítač dopravy, ASD, dopravní simulace, predikce dopravy

KEYWORDS

Floating cars, FCD, traffic control, traffic management, traffic counter, ATC, traffic simulation, traffic prediction

TABLE OF CONTENT

TABLE OF CONTENT	10
LIST OF ABBREVIATIONS.....	12
1 Introduction	13
1.1 Motivation	13
1.2 Aim.....	13
1.3 Research questions	14
1.4 Delimitations	15
2 Background.....	16
2.1 Automatic traffic counters.....	16
2.1.1 Types of ATC's	16
2.1.1.1 Inductive loop detectors.....	17
2.1.1.2 Laser detectors	21
2.1.1.3 ASIM detectors.....	23
2.2 Stationary automatic traffic counters used in the Czech Republic	24
2.2.1 Power supply	25
2.2.1.1 HIPS supply	25
2.2.1.2 Solar panel supply	25
2.2.1.3 Public lighting supply.....	26
2.2.2 Collected data	27
2.2.3 Classification schemes	28
2.2.4 Communication.....	30
2.2.5 Locations of automatic traffic counters	31
2.2.6 Types of used detectors in the Czech Republic.....	31
2.3 Floating cars data (FCD)	35
2.4 Traffic management	38
2.4.1 Collection, processing and storing data.....	38
2.4.2 Highway line traffic management.....	40
3 Theory.....	41
3.1 Quantities and their units used in road transportation.....	41
3.2 Maximum flow evaluation at a given speed	43
3.3 Data prediction and evaluation	44
4 Data analysis	47
4.1 Data verification.....	47
4.2 Floating car data penetration	48
4.3 Comparison of average speeds	51
4.4 Traffic flow prediction.....	53
4.4.1 ETS algorithm tuning on traffic data.....	54

4.4.2 Application of ETS algorithm on traffic data	56
4.5 Level of Service estimation.....	61
5 Summarization and recommendation.....	63
5.1 Data verification task evaluation	64
5.2 Floating car data penetration task evaluation.....	65
5.3 Comparison of average speeds task evaluation.....	65
5.4 Traffic flow prediction task evaluation	65
5.5 Level of Service estimation task evaluation	66
5.6 Other recommendation.....	66
6 Conclusion.....	68
LIST OF FIGURES.....	69
LIST OF TABLES	70
REFERENCES	71
Appendix 1.....	1
Appendix 2.....	2
Appendix 3.....	3
Appendix 4.....	4
Appendix 5.....	5
Appendix 6.....	6
Appendix 7.....	9

LIST OF ABBREVIATIONS

ATC	Automatic traffic counter
FCD	Floating car data
GPS	Global Positioning System
GSM network	Global System for Mobile Communications network
HIS	Highway Information System
HLTM	Highway line traffic management
HM	Highway management
ITIS	The Integrated Traffic Information System
LoS	Level of Service
MAPE	Mean average percentage error
MSE	Mean square error
NTIC	National Traffic Information Centre
SATC	Stationary automatic traffic counter
SDD	Stationary detector data
VBV	Vehicle by vehicle
VSC	Variable speed control

1 Introduction

1.1 Motivation

My motivation for this master's thesis is to present and work with data, which are available in the Road and Motorway Directorate of the Czech Republic and showcase their potential. The point is, that even though there are couple sources of traffic data, which vary in many aspects from the collection interval to degree of reliability, they can provide a range of information about traffic from the specified stretch of road.

From the driver's perspective, the most important thing besides safety on the road while commuting is the travel time from origin to destination. Travel time is a simple quantity, easy to compare, which directly affects a driver's satisfaction with a commute. When he or she takes a ride mostly on the speed limit, commute time is the lowest and there is an expectation, that driver is satisfied with the commute on the selected route. Unfortunately, in many cases this is not fulfilled – there are many reasons, especially near big cities, when there is congested traffic in and out at peak times.

The idea behind this Thesis is to collect all data from the selected stretch of the road, which are available for the Road and Motorway Directorate of the Czech Republic, process them, present them, incorporate them with my measurements, present statistics for the data, to decide whether my approach is applicable for other data, to evaluate my approach on a model, to evaluate the penetration of data and finally to sum my ideas into one conclusion and try to prepare these data as an input for further highway management, which is a scope of the thesis of my colleague Mr. Bc. Vojtěch Smrž. His Thesis builds a basis of highway management on the data which should be an output of this Thesis.

1.2 Aim

This thesis aims to find a way, how to decrease travel time for vehicles in a given stretch of a road and so improve safety for drivers when commuting. This is a complex system of getting data and processing the data to control traffic flow to maintain the highest driver's satisfaction with a commute.

On a selected stretch of the road network – highway D5 between Prague Ring and Beroun – there is already a study about highway line traffic management. This study does not deal with data collection and processing, it deals more on the determination of localities, where exactly would be optimal to build actors of this highway management system to maximize its potential.

This Thesis should verify and bring inputs for future highway management system in the Czech Republic. It also provides inputs for another Thesis written by Mr. Bc. Vojtěch Smrž, which deals more with traffic control by highway line traffic management. This Thesis is more focused on data, describes current ways of collecting data from stationary traffic detectors, specifies technicalities of these data, which information they collect and after this theoretical part, this Thesis deals with practical part, which reflects the needs of the Road and Motorway Directorate of the Czech Republic for expansion of highway line traffic management system around the biggest cities in the Czech Republic.

1.3 Research questions

This Thesis major part deals with a technique, how to provide a good input data for highway line traffic management system when there is a current setting of all data collectors present even when the line traffic management system is built. This reflects on the fact if it is possible to minimize the building cost of a system when omitting to build more traffic counters, as they are now.

Is it possible to build the highway line traffic management system in the current state of the highway?

There is a completely different type of data about traffic flow collected by floating cars data and stationary automatic traffic counters. These differences should be described and by merging these two types of data, the final output should carry the most valid data about traffic state on the stretch of the highway. To get such output of data, there are considered a few techniques to evaluate the data reliability in terms of traffic flow and average traffic speed. How should such a system be designed? How can data from stationary automatic traffic counters improve floating cars data and vice versa? These are to be answered in later chapters.

Because such a system is no failure-free, there is a requirement to minimize the impact of failures on the whole system.

How do failures in data collection affect output data and how to avoid future failures for often reasons?

There must be enough countermeasures to avoid situations, when data collection failure from any point of perspective affects the validity of output data in such way, that the system is not able to work in automatic regime. Only when enough sufficient

countermeasures are applied on data collection and its processing (and further evaluation), there would be a robust system for data collecting, which can deal with a data collection failure in many aspects. Consequences of uncontrolled traffic flow could lead to mistrust in such a system by road users and police.

1.4 Delimitations

This Thesis is focused on one selected stretch of the highway – it is highway D5 between Prague Ring (highway D0) and Beroun. This stretch of the highway is about 14 km long and it is a part of highway D5, which connects Prague with Pilsen and further with Germany.

Because the traffic flow control is a broad theme, there are not active parts of the system for traffic flow control described in this Thesis. Part of the system, which is behind the data collection and its evaluation will be detailed in the Thesis of my colleague, Mr. Vojtěch Smrž.

In the figure below, there is highlighted a part of focused highway D5:

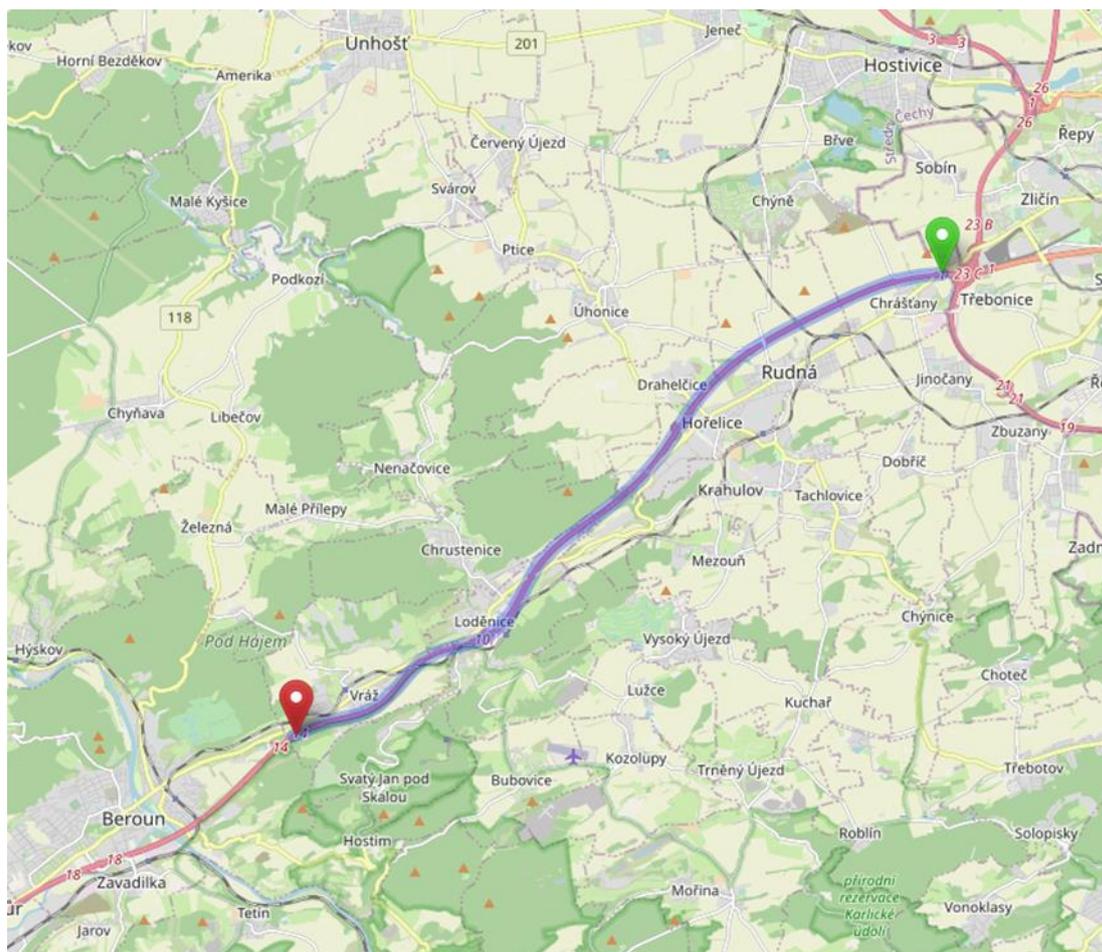


Figure 1: Focused stretch of a road – highway D5 between Prague and Beroun (3)

2 Background

In this part, there are explained principles, on which traffic detectors work and they are described in the Czech Republic conditions. There is also a part of the technical properties for each type of traffic detector and a comparison between them, their advantages, and disadvantages. There is also a reference with experience in the real use of these.

2.1 Automatic traffic counters

A traffic counter is a device, often electronic, used to count, classify, and/or measure the speed of vehicular traffic passing along a given roadway. (1) Automatic traffic counter can be used to collect a whole bunch of other traffic parameters, such as loop occupancy or Level of Service (LoS), which can be used for advanced applications in road management.



Figure 2: Example of a stationary automatic traffic counter – type Wavetronix (15)

2.1.1 Types of ATC's

There are many different types of automatic traffic counters, working on different physical principles. Automatic traffic counters can be divided into two major groups, as follows:

- Intrusive / Non-intrusive
- Stationary / Portable

Intrusive automatic traffic counters are counters, which are “invasive” to environment, in the most cases a road pavement. This is caused by the used technology, which needs to be placed in certain location to collect a data about a traffic. Non-intrusive traffic counters are the exact opposite of intrusive ATCs, but they are often supposed to collect only short period of traffic data.

Stationary traffic detectors, used in the Czech Republic in majority, are placed in certain location, where they are designed to be and provide long-term systematic collection of traffic data. Portable traffic detectors are mainly used in places, where there is not a stationary traffic detector located and there is only short-term data collection needed.

For better visualization, here are some examples in a table:

Table 1: Examples of detection technologies used for car counting classification divided into major groups

	Stationary	Portable
Intrusive	Inductive loop detectors Magnetometric Magnetic	Does not make sense because of the high initial cost
Non-intrusive	Laser detectors Microwave detectors ASIM detectors	Pneumatic detectors

2.1.1.1 Inductive loop detectors

In high-volume locations, where there is expected high traffic flow, especially on highways, intrusive traffic counters and classifiers are vividly used. Data from these detectors are collected in regular intervals and by the lifetime of such traffic counter, such data make a continuous series of data, which are very helpful for traffic statistics, mainly ex-post statistics for National Traffic Census etc.

In the Czech Republic, intrusive detectors are most of all traffic detectors operated by the Road and Motorway Directorate of the Czech Republic. Till the end of the year 2019, there were more non-intrusive detectors in operation by the toll company Kapsch. Because the technology of the toll system changed at the turn of the year, these detectors were turned off and not maintained anymore.

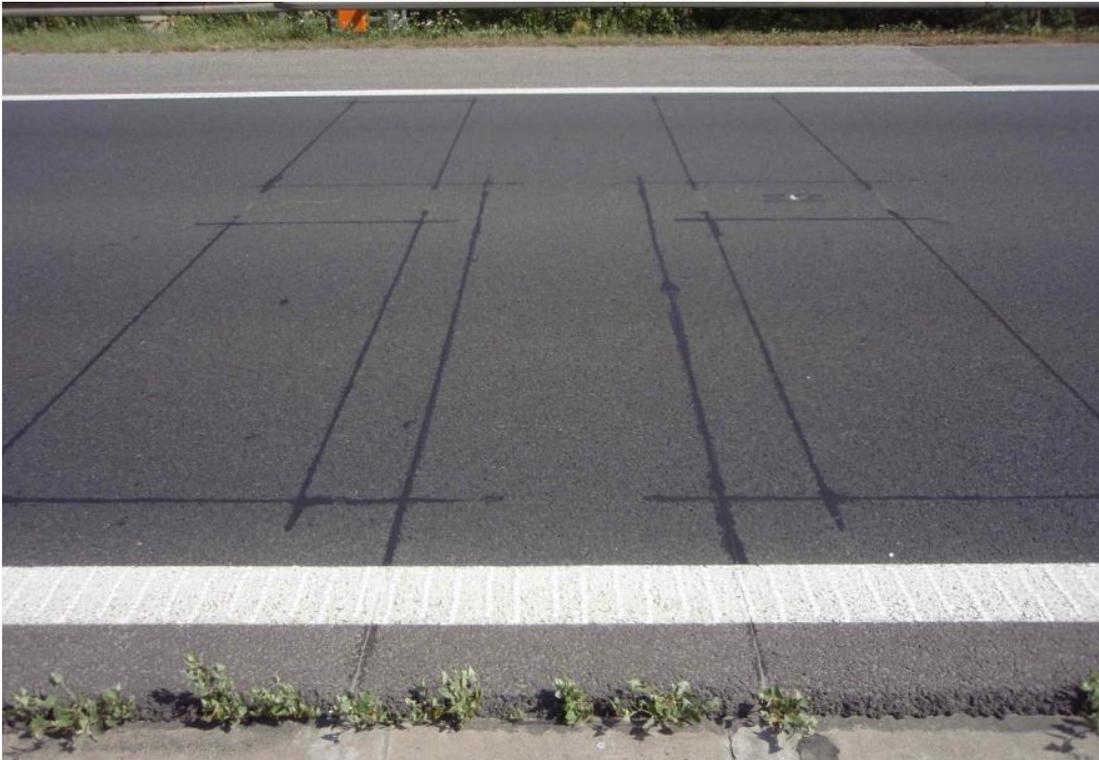


Figure 3: Induction loops used for CrossCount detectors in Czech Republic

In the table below, there is a distribution of traffic detectors used in the Czech Republic on main road classes.

Table 2: Distribution of Intrusive and Non-intrusive detectors in motorways in the Czech Republic

	Intrusive	Non-intrusive
Highways	270	61
1st class roads	116	3
2nd class roads	7	3
	393 (85%)	67 (15%)

From the figure above can be seen, that 85% of all traffic detectors operated by the Road and Motorway Directorate are intrusive. It is caused by the internal rules in the Road and Motorway Directorate, that is specified in the “Requirements for design and quality”. In this document, there is described a specification, when a where a new stationary automatic traffic counter (SATC) should be designed. In the figure below, there is a distribution of inductive loop counters in the Czech Republic in the

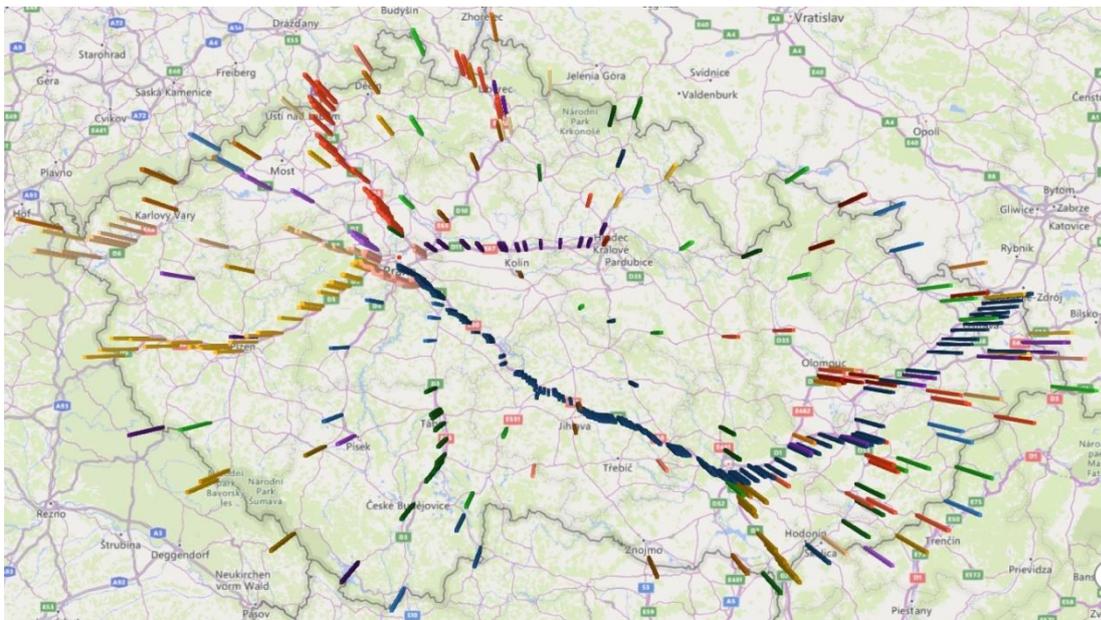


Figure 4: Distribution of inductive loop traffic detectors in the Czech Republic operated by the Road and Motorway Directorate. Each color represents one road name

administration of the Road and Motorway Directorate:

Intrusive detectors consist mainly of traffic detector and induction loops. Some additional part as cables, connectors, communication devices, cameras and more can be added for enhanced functionality, although this is not often used in the Czech Republic. For a better overview, in a figure below there is a distribution of intrusive and non-intrusive traffic detectors presented (based on internal databases in the Road and Motorway Directorate):

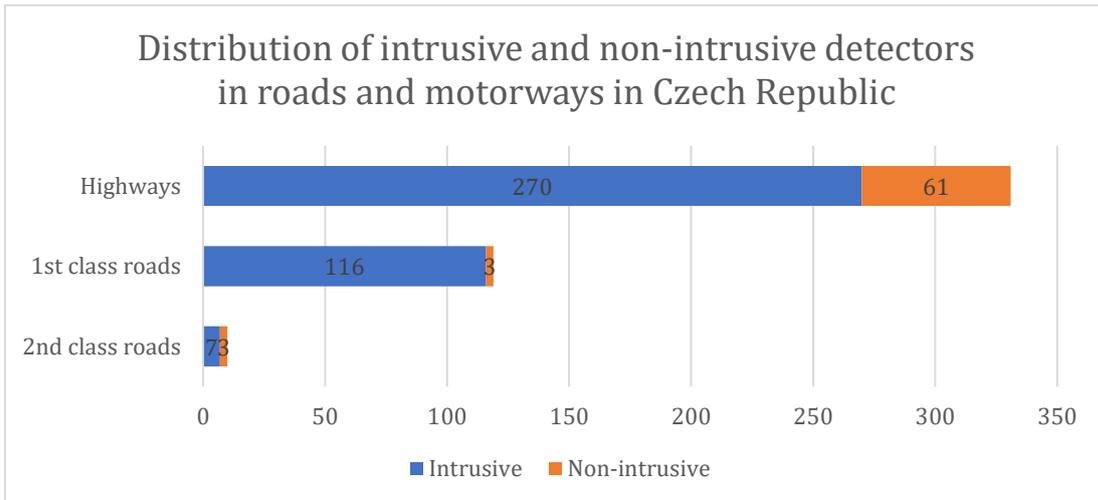


Figure 5: Distribution of intrusive and non-intrusive detectors in roads and motorways in Czech Republic

Inductive loop detectors are mainly stationary due to the high initial cost of a detector and cost of magnetic loops, which are not reusable after installation.

Loop detectors work on electromagnetic principle when a current pass through a loop, which creates an electromagnetic field. This field is then measured in real-time and every time a vehicle passes over this loop; it is like a giant magnet which disturbs an electromagnetic field. This disturbance, also called vehicle signature, can be a vehicle speed and vehicle class derived. In a figure below, there is an example of such vehicle signatures:

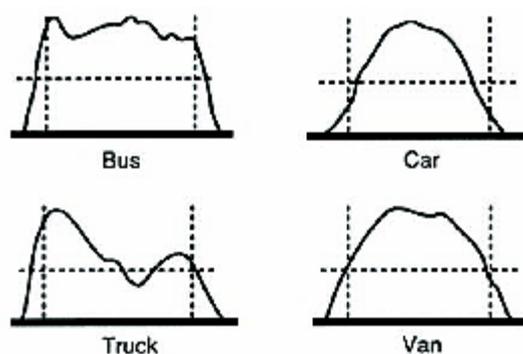


Figure 6: Example of vehicle signatures created by induction loops (16)

As a huge advantage of these detectors is a mature and well-understood technology of measuring data. From this resulting into huge experience base, also in the Czech Republic, as long as this is the main technology used for traffic data collection. Also, it is a very durable method – rain, fog, and snow resistant. To name a few disadvantages, it is an intrusive technology, so it needs a pavement cut and therefore it decreases pavement life. When a loop breaks, it needs to be repaired by cutting a completely new one, which is a time-consuming process and brings many other problems. In a figure below, there is an example from England, how can multiple repairments of induction loops look like:



Figure 7: Close-up look of old and new induction loops cut in the pavement (17)

2.1.1.2 Laser detectors

These detectors may be divided into two groups – active and passive infrared detectors. Active infrared detectors work by transmitting a beam of infrared light and can measure accurate vehicle position, speed, and classify vehicles. Also, there is a huge advantage of this technology, that there is a multiple lane operation possible, which is highly cost-effective. As a disadvantage, to name a few, there is affection on weather – heavy snow or fog can affect accuracy pretty much. In majority, an often and periodic maintenance of lens cleaning is required, so a lane closure must be performed.

This type of detectors was used in the Czech Republic by a toll collection company till 2019. After the change of toll collection method after 2019, those detectors were counted as redundant and their operation was discontinued.

In the figure below, there is shown a basic working principle of laser detectors:

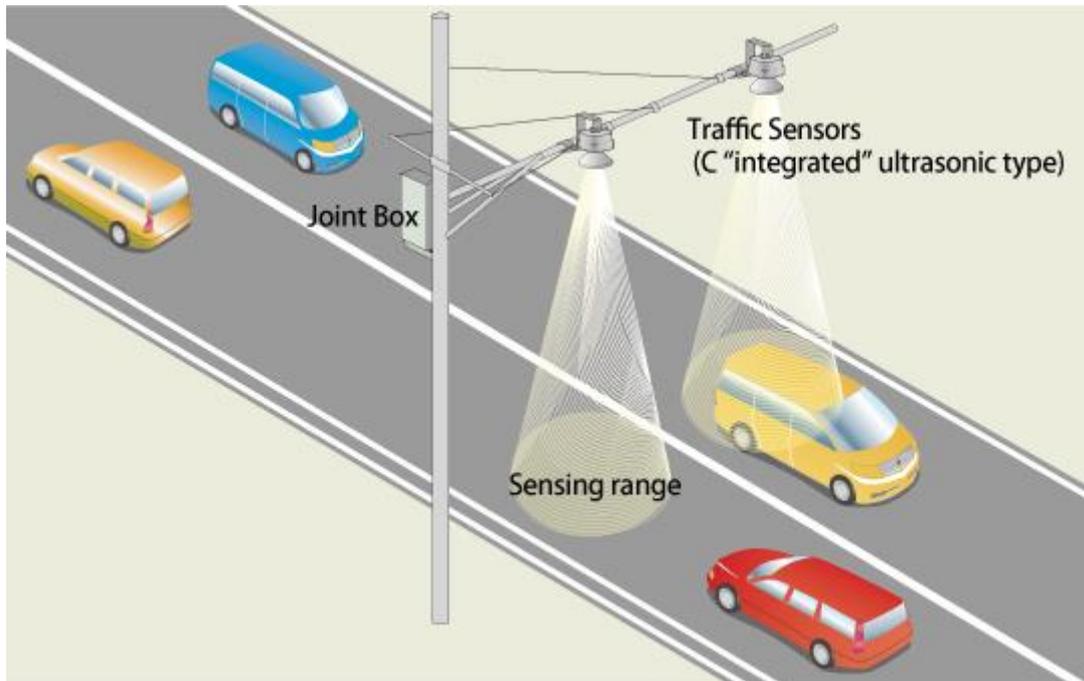


Figure 8: Principle of laser radar traffic counter (21)

In another figure below, there is shown a distribution of previously used laser detectors in the Czech Republic:

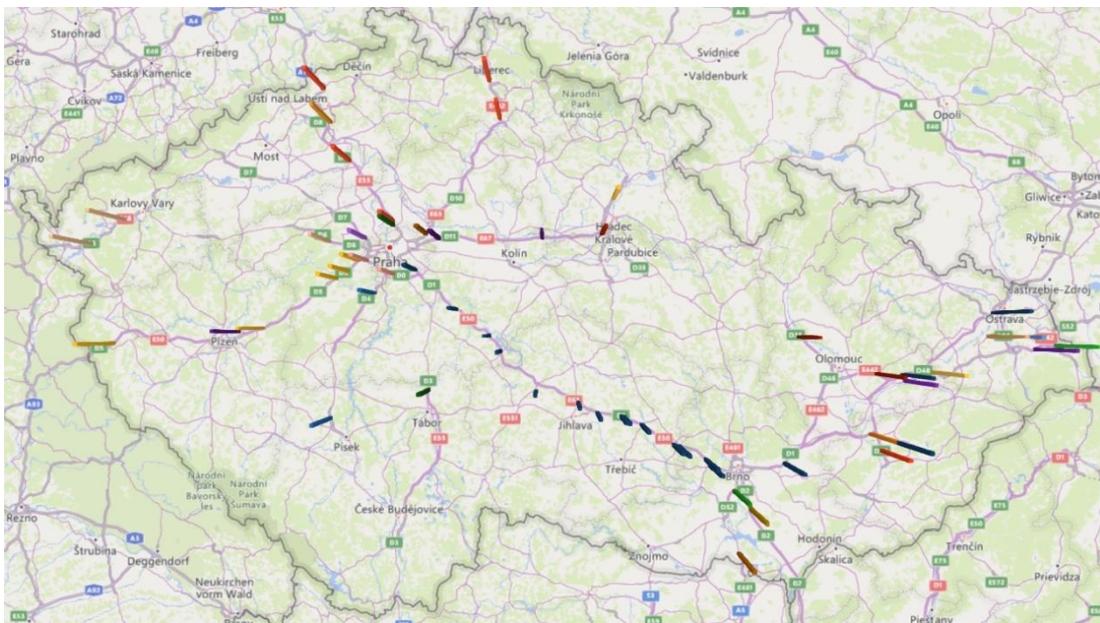


Figure 9: Distribution of laser traffic detectors used previously in the Czech Republic by the Road and Motorway Directorate. Each color represents one road name.

2.1.1.3 ASIM detectors

This is another frequently used technology in the Czech Republic. ASIM detectors, one shown in the figure below:



Figure 10: Example of the ASIM traffic detector

The detector uses three distinct sensing technologies: Doppler radar, ultrasonic and passive infra-red, shown in working principle in the figure below:

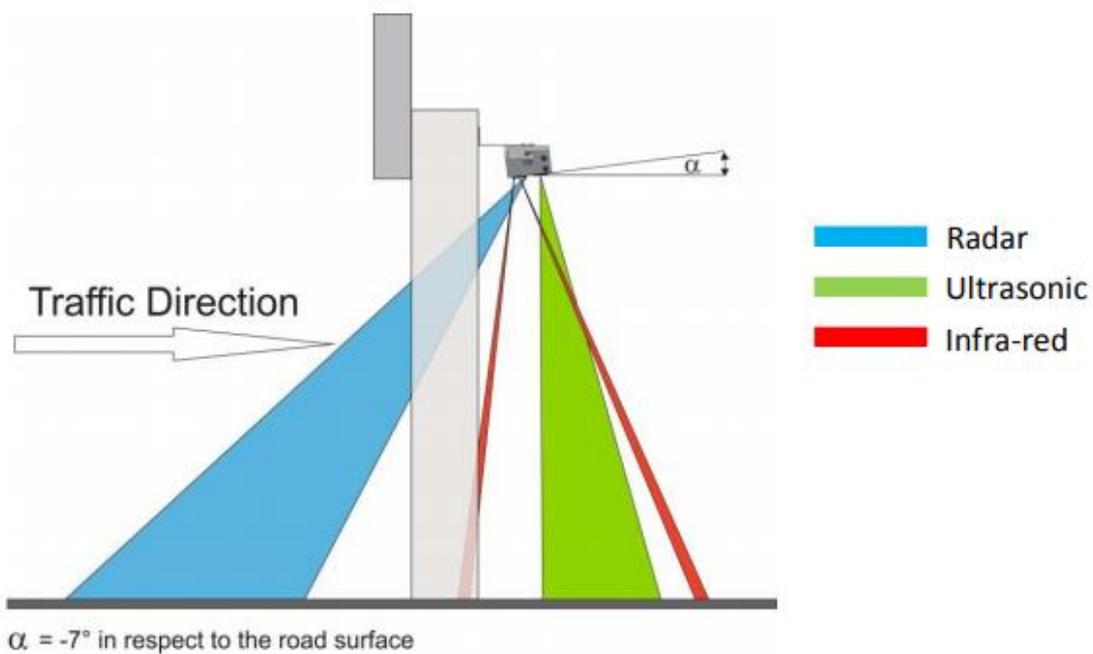


Figure 11: Gantry with the ASIM detector depicting the detection zones

Working principle of such detectors is that traffic detectors measure the speed of each vehicle using the Doppler shift of the reflected microwave frequency. The ultrasonic

sensor system scans the height profile of the passing vehicle and the passive infra-red zones obtain the vehicle position within the observed lane.

In the figure below, there is a distribution of these detectors in the Czech Republic:

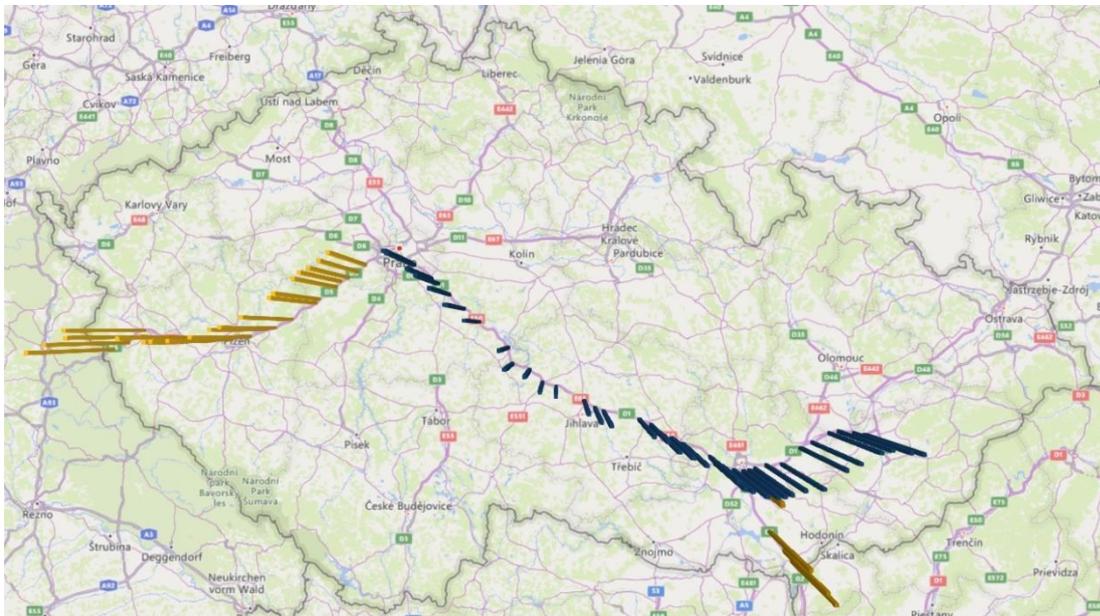


Figure 12: Distribution of the ASIM traffic counters in the Czech Republic operated by the Road and Motorway Directorate. Each color represents one road name.

These systems were built along with previous toll operating systems, which is currently discontinued. Currently, these detectors are still operated, but their function is changed. As long as these detectors are outdated at present, they are not used for vehicle classification anymore, but only for traffic counting. A new function is now primarily operated – detection of the driving in opposite direction.

Among advantages for these detectors are, that they are non-intrusive, and they can be easily adjusted, when a lane closure is prepared, or road is maintained. A very frequently occurring disadvantage is, that because these detectors are made of three different technologies working together, they have a different lifespan and so they are very expensive to maintain after a certain amount of the time.

2.2 Stationary automatic traffic counters used in the Czech Republic

In this chapter, there is a focus on the technical and operational part of SATCs. It describes the power supply used in the Czech Republic conditions, along with communication and describes a data, which are or can be collected by these counters.

2.2.1 Power supply

Due to a range of different places, where SATCs can be located, different types of power supply can be used. For example, supply from the regular electrical distribution grid, where there is 230 V available. All major highways are equipped by the highway information and power system (HIPS). It is a series of optical and electrical cables, which are used to power systems installed on motorways and to communicate with an external server and among each other. When there is no highway information and power system available, the power supply can be substituted by electrical connection via public lightning, when it is possible by connection to other telematics systems (often in highways) etc. In some remote places, often in the mountains, when there is no such option, in last couple years, it is possible to power SATC station by photovoltaic power, generated by a solar panel and stored in large batteries, often as large as ones in cars. A few types of SATCs are designed for such supply and so their power consumption is very low – ones of watts. In a list below, there are some advantages and disadvantages described for each type:

2.2.1.1 HIPS supply

- Advantages
 - Stable power connection
 - Independent of other providers
 - Lowest electricity cost
 - Does not matter power consumption
- Disadvantages
 - From the Road and Motorway Directorate experience, when a technical fault happens, takes too long to repair
 - Available in vast majority only on highways
 - Not available on remote places

2.2.1.2 Solar panel supply

- Advantages
 - Power supply for remote locations
 - Can be fixed in minimum time
- Disadvantages
 - SATC's limited power consumption
 - A requirement of a large battery

- When not maintained, batteries can damage permanently
- Solar panels can be relatively easily stolen
- Near vegetation can avoid direct light on solar panel and power generation decreases



Figure 13: An example of SATC (Marksman 680) powered from solar panel (18)

2.2.1.3 Public lighting supply

- Advantages
 - Available in most places in urban areas
- Disadvantages
 - Supply only during nighttime
 - Duration of supply varies from 5 to 12 hours during the whole year
 - A requirement of a large battery
 - From the Directorate experience, during inauspicious weather, batteries cannot recharge during nighttime fully



Figure 14: An example of SATC (Wavetronix) powered from public lightning (18)

In a figure and table below, there is a presentation of power connection distribution among SATCs under the Directorate administration:

Table 3: Distribution of power connection for detectors in motorways in the Czech Republic

	HIM supply	Solar panel supply	Public lighting supply
Highways	351	0	0
1st class roads	67	51	0
2nd class roads	1	3	2
	393	67	2

2.2.2 Collected data

Traffic data are collected and stored directly in SATC's internal memory and read by the external server with different intervals – depends on the settings and possibilities of SATC. Because each detector type has a different logic of vehicle counting and classification, there are different outputs that one collects. One thing, common for every SATC used in the Czech Republic is, that it measures and counts individually every vehicle – such data are called VBV or “vehicle by vehicle”. These data are stored in internal memory for a defined period. After this period, some detectors make predefined statistics of VBV data, erase them and store only statistics, but some store both and

transfer to the external server everything they collect. Data that can be collected for each vehicle, are:

- Date and time
- Vehicle category
- Lane identification
- Direction
- Freeflow speed
- Car length
- Congestion
 - Whether there is or there is not
 - Estimation of a head of congestion
 - Estimation of length
- Reliability
- Reaction time
- Traffic level or Level of Service (10)
- And more according to detector type and technology

The most common period in which data about traffic flow are stored, when the power supply is provided by HIPS, is an hour. Every hour, an external server sends a request to SATC via HIPS or GSM network, and SATC sends last whole interval of data back to the external server. When any problem occurs, this process is repeated in the next interval, and the external server asks for all data since the last successful transfer. In places, where HIPS is not available, this is done by the GSM network. Depending on power possibilities, communication and collecting data is performed once a day, or even once a week. Extending a length of this interval means, that data from such detectors can be used only for ex-post statistical calculation about traffic flow and are unusable for traffic control. From an operation point of view, extending the longer an interval of communication is, the longer takes to discover any problems with SATCs too.

2.2.3 Classification schemes

A huge focus on data from automatic traffic counters is for vehicle classes, which can an ATC sufficiently enough precisely determine. In general, categorization for automatic traffic counters operated by the Road and Motorway Directorate is in the Czech Republic defined by this table:

Table 4: Vehicle categorization in the Czech Republic used for SATCs (3)

Category	Description
1	Motorcycle

2	Car
3	Car with trailer
4	Van
5	Truck
6	Truck with trailer
7	Truck with a cargo trailer
8	Bus

This classification scheme is from the past knowledge only sufficiently precise scheme with 8 categories, which can be relied on. This “rely” is expressed also in table, which is defined in the Road and Motorway Directorate in “requirements on design and quality” and requires a certain level of sufficient categorization for each vehicle type. Preview of such classification accuracy verification is performed in Appendix 1.

Although, there are many more other classifications schemes currently used. This is because, in past, there was no one scheme defined, but with every new technology came also a new classification scheme, which had to be adjusted for one in Table 4 afterwards.

In these days, on highway D5 there are two classification tables used – one for ASD3 and ASD3u technology, described in Table 4 and one for ASIM technology, shown below:

Table 5: Vehicle categorization in the Czech Republic used only for ASIM technology (3)

Category	Description
1	Motorcycle
2	Car
3	Car with trailer
4	Van
5	Truck
6	Truck with trailer
7	Truck with a cargo trailer
8	Bus
9	Other

As can be seen from the comparison of both tables, the only difference between them is the 9th category of vehicles – Other vehicles. Originally, ASD3 and ASD3u technologies used this category too, but because of a bad experience that there were too much “other” vehicles in a categorization, SATCs were forced to categorize those vehicles to other specific categories and from the experience, this was a good decision.

2.2.4 Communication

An external server can communicate with SATC via HIPS, what is preferred on roadways, where HIPS is available. This method of data transmission and communication is far more reliable than other methods. The second way for communication is via GSM network when in-between external server and SATC is a communication unit with SIM card which arrange connection. This type of connection is used mainly in remote locations, where HIPS is not available. A huge advantage of this method is the possibility of regular connection with the SATC because a physical and manual check of the SATC is super time consuming and expensive.

In a list below, there are some advantages and disadvantages described for each way of communication:

Communication via HIPS

- Advantages
 - Stable connection
 - Independent of other providers
 - Does not matter power consumption
 - Data can be collected even online (1-minute interval)
- Disadvantages
 - From the Road and Motorway Directorate experience, when a technical fault happens, takes too long to repair
 - Available in vast majority only on highways
 - Not available in remote places

Communication via GSM network:

- Advantages
 - Availability of connection on remote places
 - Reduces cost of manual checking SATC
 - Data can be collected even online (when sufficient power supply)
- Disadvantages
 - In some places, the GSM signal can be weak or interrupted by other providers
 - When powered by solar panels, this the most power consuming part of the SATC

2.2.5 Locations of automatic traffic counters

Location of stationary automatic traffic counters in the Czech Republic is based on some past decisions. First detectors, installed in the mid-'90s, were located mainly on the 2nd class roads, where the expectation was, that seasonal traffic flow would be great to capture. Later, there was not any conceptual building of these counters, till the mid-2010s. This time around, when the first Requirements for design and quality for telematics systems took effect, there was written that on highways, between every two intersections, must be placed one SATC (preferably induction loop detector), to capture traffic flow and its composition, particularly. Later, every new part of the highway built in the Czech Republic must follow that rule. When a major reconstruction of a highway is prepared, it is also common to add one SATC between two intersections to fulfil this rule.

Such a systematic approach was not considered for 1st and 2nd class roads. Second-class roads are problematic since the 2010s, because they are not anymore in the Road and Motorway Directorate administration, so it is not possible to build new systems there. First-class roads are on the other hand are not so important for traffic flow statistics, so until 2020 they were not systematically equipped with SATCs. In 2020, there was a systematic approach accepted, that every 1st class road will be equipped with one SATC between two intersections of 1st class roads or highways. This approach is setting a new standard for all new or heavily reconstructed 1st class roads, so future statistics of such roads will be more precise and automated.

2.2.6 Types of used detectors in the Czech Republic

In the Czech Republic road network, there are two detectors by Cross Zlín in operation in these days:

- ASD3
- ASD3u



Figure 15: ASD3 traffic counter in SOS emergency

Stationary automatic traffic counter, type ASD3, is the older type of ATC from Cross Zlín. It is an intrusive vehicle counter and classifier with a wide range of additional collected data about traffic flow. Data from individual lanes are obtained by using a pair of induction loops located in the roadway. Based on the measurement of the change in the electrical parameters of the loops depending on the passage of the vehicle, it is possible to obtain the monitored parameters of the individual vehicle (vehicle combination). This data is evaluated and sent in a standard format on the RS 232

interface (ON-LINE mode) or stored in the counter's memory. Data can be transferred from the memory to a PC equipped with the appropriate CROSS ASD 3 software via the RS 232 interface. Remote access to the data in the memory via a GSM modem connected to the RS 232 interface is also supported.

Upgraded type of this counter, type ASD3u, is a newer and latest type of traffic counter and classifier used in the Czech Republic by Cross Zlín. The principle of counting and classifying vehicles is the same as in the type ASD3, there are some new features, as connectivity when an Ethernet is supported, or success of vehicle classification is enhanced.



Figure 16: Rectangular induction loops for ASD3 traffic counter

Another widely spread type of automatic traffic counters in the Czech Republic is by Clearview Intelligence:

- Marksman 660
- Marksman 680

As well as types ASD3/ASD3u, these are both too intrusive vehicle counter and classifier with a wide range of additional collected data about traffic flow. Data from individual lanes are obtained by using a pair of induction loops located in the roadway. These two detectors differ from ASD3/ASD3u only by operational parameters – as the

main advantage they have a very low power consumption – therefore they are supposed to be installed on remote places when only solar power is provided.

The Marksman 660 is yet an out of a supported version of ATC. It is a 30 years old technology but still used in the Czech Republic, with almost 50 operational units to end of the year 2019. This technology is in retreat and in many cases will be replaced by an upgraded version of ATC – the Marksman 680.

The Marksman 680 is a new and upgraded version of the Marksman 660 vehicle counter. It keeps all advantages of its predecessor and along with this brings many features, which helps to maintain the operation of traffic counting even when an accident happens. Also, it provides more functions to monitor and track the lifespan of this counter, which result in more reliable data collection than from its predecessor.

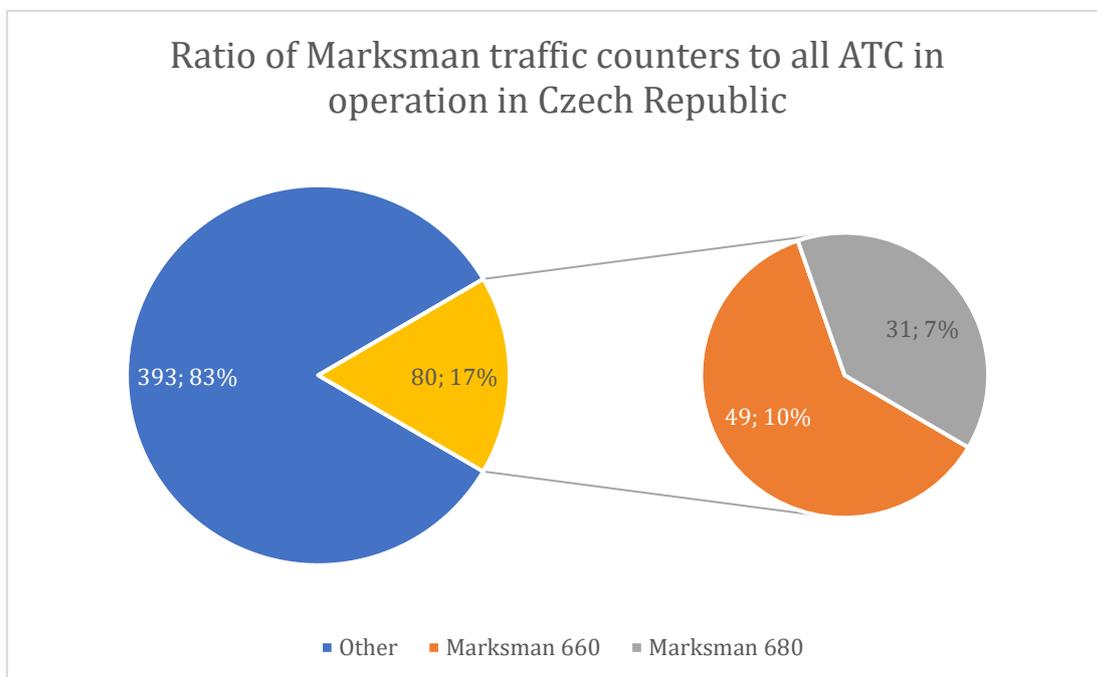


Figure 17: Ratio of the Marksman traffic counters to all SATC in operation in the Czech Republic

There are a few other minor types of automatic traffic counters used in the Czech Republic, such as:

- ASIM from ASIM Technologies
- LD4 from Siemens
- Others

ASIM traffic counters are counters which features a range of different detectors to omit each other disadvantages. These counters consist of:

- Doppler radar/microwave traffic detectors
- Passive infrared traffic detectors
- Ultrasonic traffic detectors

By the end of 2019, there were 61 of almost 400 SATCs installed in the Czech Republic by the Road and Motorway Directorate this type. Along with the change of the toll collection system, these detectors became redundant. Advantage of this technology is, that it is non-intrusive, which is the only still operated non-intrusive technology installed on Czech highways. As the main disadvantage is a high operational cost, where the main part is maintenance. This technology consists of a range of detectors with different life spans and this causes high maintenance demands. Also, this technology needs a specific location above the roadway, so the expansion of this technology is limited and costly. In the figure below, there is a rearview on the ASIM traffic counter.



Figure 18: Rear view on ASIM traffic counter (19)

2.3 Floating cars data (FCD)

Floating car data are data collected directly from vehicles over satellite. Vehicles provide their geolocalization and some additional data, which can vary from one to another market. Vehicles are set to send data via GSM, and they act like a moving sensor. FCD provides, in opposition to data from SATCs, a Langragian description of movement. (4)

Basic usage of this data is to determine the speed of traffic flow. As far as there is information about the position of the vehicle, which is varying in the time, some more additional parameters can be determined, like:

- Delay
- Freeflow speed
- Freeflow time
- Congestion
 - Whether there is or is not
 - Estimation of a head of congestion
 - Estimation of length
- Reliability
- Reaction time
- Traffic level

In the Figure below, there is a simple scheme, how is data from FCD Fleet collected:

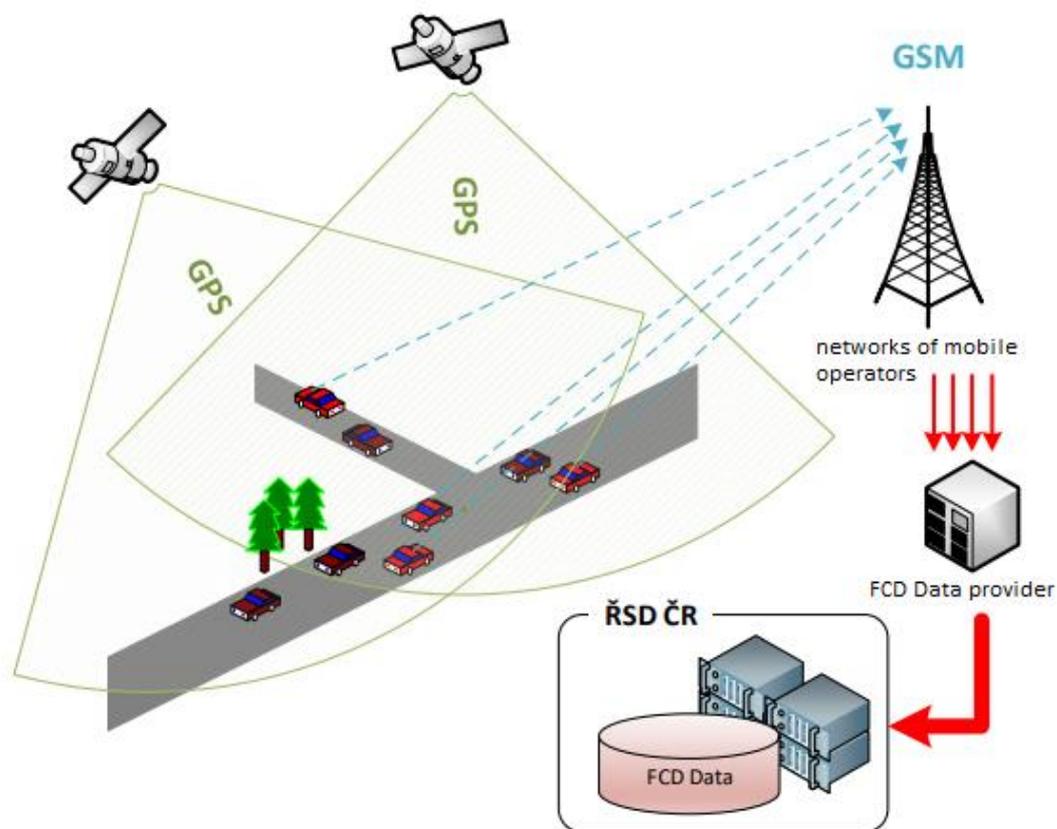


Figure 19: FCD Data collection scheme (2)

In the Czech Republic, there is a fleet of 150 000 vehicles, when approximately 84 000 unique vehicles are present in the network every day. Data from each vehicle in-network

is transmitted through GSM network every one minute as a message, with defined primary key – this means, that when there are full 84 000 vehicles present in a network, there is transmitted a volume of 2,6 Gb (0,325 GB) data per day. This amount of data is processed as big data (2). In the figure below, there is shown a network, in which there are FCD data computed and worked with. It includes all roads of the first and second class, all highways and some of the important road of the third-class road network. The network is divided into segments of approx. 2 km:

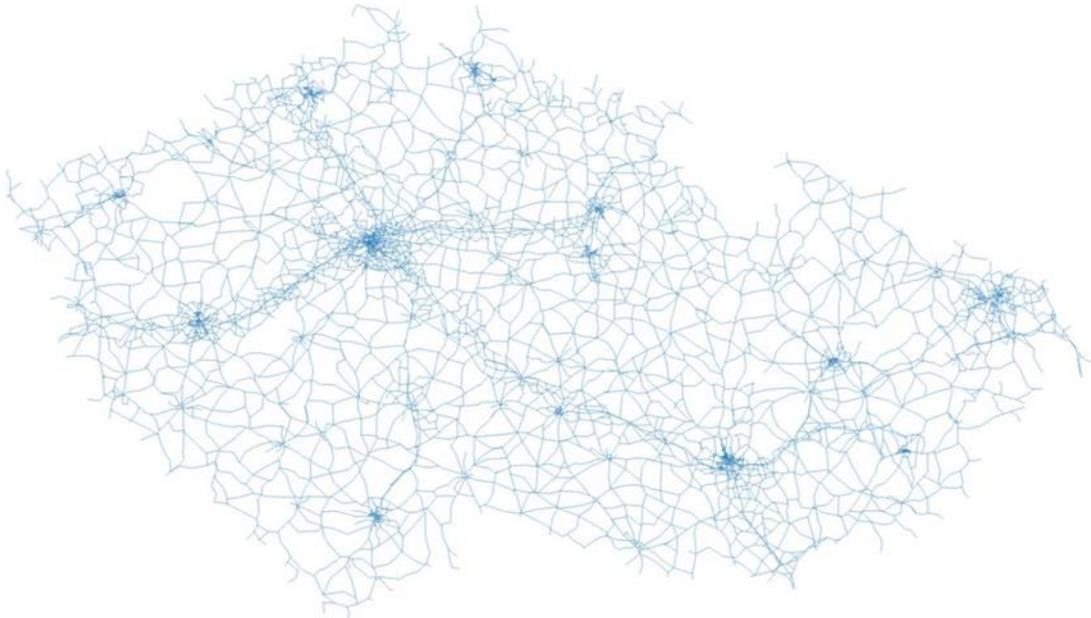


Figure 20: Network of roads and highways for FCD data processing (20)

Length of segments varies from 1 to 3,5 kilometers at most. This is caused mainly because of intersections when the segment must be split up in the center of an intersection.

Segments on a D5 highway in the scope of this thesis are visualized by in figure in Appendix 7.

As there can be seen, there is covered almost 32 thousand of kilometers of the road network, which is quite enough detailed for the whole Czech Republic. Coverage of floating car data is shown in a figure below – it shows in 5 color scale how well are roads and highways in the Czech Republic are covered with floating cars:

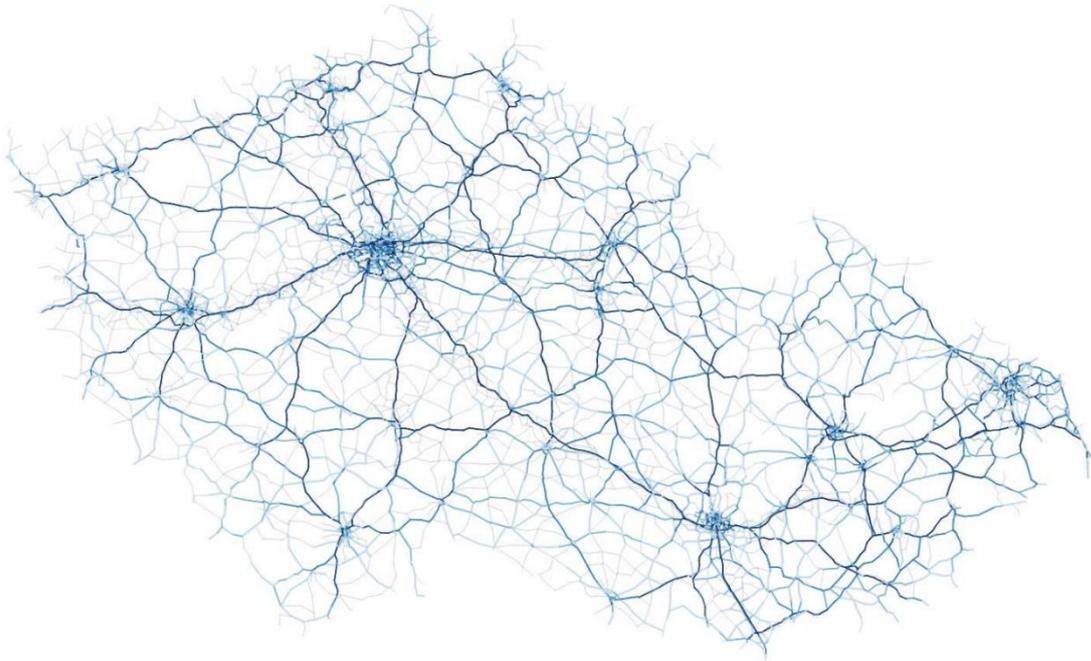


Figure 21: Five-color scale showing how well are roads and highways in the Czech Republic covered with FCD (20)

All those segments are categorized into 9 types. This categorization is based on:

- The average speed on the segment
- The average number of trucks on the segment
- The average number of cars on the segment

2.4 Traffic management

2.4.1 Collection, processing and storing data

Traffic management of road traffic is a system of complex road traffic control, which deals with collecting, processing, and storing data from all road traffic related systems.

Data from both sources in this Thesis – from traffic counters and floating cars are collected through The Integrated Traffic Information System for the Czech Republic (ITIS). The Integrated Traffic Information System for the Czech Republic is a joint project of the Czech Ministry of Transport, Czech Ministry of Interior, Czech Road and Motorway directorate, and a number of other public administration bodies, organizations, and institutions, public and private persons and subjects from all over the Czech Republic that cooperate on the project. The ITIS is a complex system environment for the collection, processing, sharing, distribution, and publishing of traffic information and data on the current traffic situation and information about roads, their parts, and accessories. (4) The main goal of the ITIS project implementation is the information support of processes for:

- the provision of the passability and practicability of roads for the maximum time and over the maximum portion of Czech territory possible,
- the increase of safety and fluency of traffic through creating a reliable, safe, and environmentally friendly road traffic system.

The National Traffic Information Centre (NTIC) is the central technical, technological, operation and organization station of the ITIS. It is an operation station providing the collection, processing, evaluation, verification and authorization of traffic information and data 24/7. The NTIC is run by the Czech Road and Motorway directorate based on Government Decree No. 590 from May 18th, 2005 and in accordance with art. 124, par. 3 of Act No. 361/2000 Coll. It:

- controls the quality and accuracy of the supplied traffic information,
- controls the submission of information by the individual participating bodies, organizations, institutions, persons, and subjects and in case of their failure to observe their obligations or the methodical procedure solves the problem,
- monitors the life cycles of the incidents until their resolution and full traffic restoration,
- provides traffic information and data to all subscribers, maintains the operation of traffic information and data publication and distribution systems.

In Appendix 5, there is a complete scheme of NTIC and its subsystems. To visualize only a data flow from ATCs and floating cars, the simplified scheme is below:

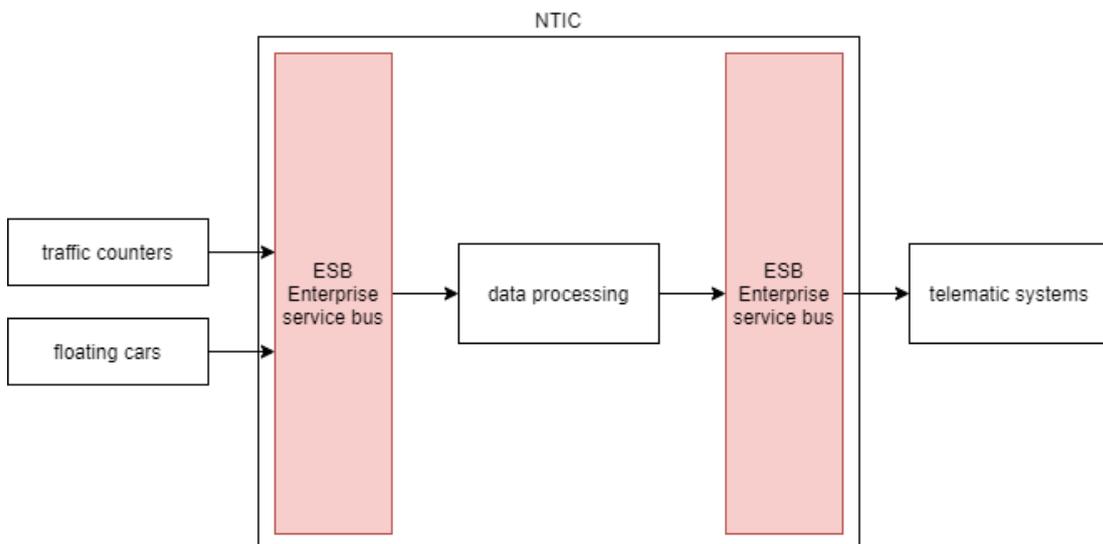


Figure 22: Simplified data flow from traffic counters and floating cars to other telematic systems (29)

In the figure above can be seen the data flow from data sources to data receivers. In case of this thesis, on the left side of the figure above, there are data sources, which are

in the scope of this thesis. Data flows to NTIC, where are processed and all algorithms are applied. Then they are sent to actors of telematic system, such as highway line traffic management and others.

2.4.2 Highway line traffic management

Highway line traffic management is a telematic system consisting of gates with variable mandatory or prohibitory traffic signs above or beside the road. Detectors monitoring the traffic flow characteristics, such as traffic density, intensity, or average speed are also part of the system. The gates are approx. 1,000 to 1,500 meters apart. (5)

The highway line traffic management system gradually decreases the speed or alters the organization of traffic into lanes so that the movement of the lines of vehicles is as smooth and safe as possible. As vehicles may safely drive with shorter following distances at lower speeds, the traffic flow is better harmonized. The result is that more vehicles may pass through the given section, more continuously and faster (although the actual speed is lower). Highway line traffic management increases the smoothness of the traffic flow and reduces the probability of queue formation and their potential size. (5)

In the figure below, there is an example of highway line traffic management in operation:



Figure 23: Example of highway line traffic management in operation

3 Theory

In this chapter, there are presented methods and ways that are used in data analysis described from the theoretical point of view.

3.1 Quantities and their units used in road transportation

To begin with, there is a need to clarify basic units and their units describing road transportation and those which are used in this Thesis. They are used in transportation statistics, planning and their related fields. (5)

Table 6: Basic quantities, their description and units used in road transportation (6)

Quantity	Description	Unit
Flow	Number of vehicles passing a point during a given time	$Q(x, t) = \frac{\Delta N}{\Delta t} \left[\frac{veh}{h} \right]$ $Q \left[\frac{veh}{h} \right] - \text{traffic flow}$ $N [veh] - \text{number of vehicles}$ $t [h] - \text{time}$
Speed	Measured at a single point: time-mean Measured on a section as an average of instantaneous vehicle speeds: space-mean	$V(x, t) = \langle V_{\alpha} \rangle \left[\frac{km}{h} \right]$ $V_{\alpha} - \text{mean speed}$
Travel time	Time the vehicle takes to pass the length of a road	$TT = \frac{\Delta s}{\Delta v} [t]$ $s [km] - \text{length of a road}$ $v \left[\frac{km}{h} \right] - \text{speed}$
Density	Number of vehicles present per unit length of road at a given moment	$\rho = \frac{Q(x, t)}{V(x, t)} = \frac{\Delta N}{\Delta s} \left[\frac{veh}{km} \right]$
Occupancy	The proportion of time that a vehicle is present over the detector	$o = \frac{t_v}{\Delta t} [\%]$ $t_v [s] - \text{time of the occupied detector}$ $t [s] - \text{time}$
Time headway	Time passed between two vehicles measured front-to-front	$\Delta t = t_2 - t_1 [s]$

Time gap	Time passed between two vehicles measured rear-to-front	$\Delta t = t_2 - t_1 [s]$
Delay	Difference between actual and average travel time	$v = v - v_a \left[\frac{km}{h} \right]$
Level of service	Qualitative measure to relate the quality of motor vehicle traffic service	1 2 3 4 5 or A B C D E F [-]

In the table above, there are most used quantities in road transportation, which define vehicle and time behaviour in the road network. Each of the quantity is later clarified separately.

Traffic flow represents the number of vehicles passing a point during a given time period. It is commonly used for its simple imaginability. Units are often used vehicles per hour.

Speed is a basic quantity, which represents a time derivative of length that the vehicle passes. In transportation, another commonly used quantity is harmonic speed, which better represents actual speed measured in more points. It is a ratio between the total distance that the vehicle travels over the sum of time for each segment. Most used unit is kilometres per hour.

Travel time is the cost for the time that one spent on transport and represents the time of passing a selected length of the road. Travel time is the most important factor when it comes to the satisfaction of road users with their commute and it is also the major contributor to the Level of service quantity. It is measured mostly in seconds.

Density is the number of vehicles present per unit length of road at a given moment. It is hard to measure because usually, it is very hard to catch all vehicles in one moment in the given length of the road. This quantity's unit is usually vehicles per kilometre.

Occupancy is a proportion of time that a vehicle is present over the detector. It is a basic ratio between the time, that vehicle is present over the detector to all the time between two cars passing the detector. As it is a ratio, the unit is a percentage.

Time headway is the time that passed between two heads of vehicles. In fact, for loop detectors, it is the time between two vehicles, that just hit induction loops. It is often stated in seconds.

The time gap is a measure of the time between the rear bumper of the first vehicle and the front bumper of the second vehicle, where headway focuses on front-to-front times. The gap is usually reported in units of seconds. (5)

Delay is the difference between actual and average travel time, which is often based on speed limit and length of the segment of the road. The unit is mostly seconds.

Level of service (LoS) is a qualitative measure used to relate the quality of motor vehicle traffic service. LoS is used to analyse roadways and intersections by categorizing traffic flow and assigning quality levels of traffic based on performance measure like vehicle speed, density, congestion, etc. (6) In the Czech Republic, there is commonly used a range of numbers to describe LoS. In the USA is commonly used letters as classification. LoS can be determined based on range of parameters. In the Czech Republic, FCD are received in one-minute intervals along with evaluated LoS, which is dependent only on actual speed. All speeds, which are evaluated from traffic flow are categorized and each category is described by one LoS. More common way to evaluate LoS is based on two parameters – density and flow or density and speed (10):

$$\langle Q_i; \rho_i \rangle \xrightarrow{\otimes} \langle \Delta_i \rangle$$

To determine the LoS from two sets of parameters, these techniques can be used:

- Polynomial regression of 2nd order
- Fuzzy expert rules
- Neural network (10)

3.2 Maximum flow evaluation at a given speed

This chapter describes the theoretical part of how is in this Thesis computed a maximum flow value at a certain speed.

To begin, there are three parameters given:

- Mean desired speed in free traffic
- Mean desired time gap
- Maximal density
- Number of lanes

Mean desired speed in free traffic is a mean value of the speed of all vehicles in a model. Mean desired time gap is a value of mean times passed between two vehicles measured rear-to-front. Maximal density is a value, which describes a maximal number of vehicles in one lane at the desired speed.

Firstly, the time gap and maximal density are recalculated for the desired number of lanes according to these equations:

$$T_{i \text{ lanes}} = \frac{T}{i} [h]$$

T - time gap for one lane

i - number of lanes

$$(\rho_{max})_{i \text{ lanes}} = \rho_{max} \cdot i \left[\frac{veh}{km} \right]$$

ρ_{max} - maximal density for one lane

i - number of lanes

With these two calculated values, the maximum density in certain speed (density at maximal capacity) can be calculated:

$$\rho_c = \frac{1}{V_0 T_i + \frac{1}{(\rho_{max})_{i \text{ lanes}}}} \left[\frac{veh}{km} \right]$$

V_0 - desired speed in free traffic

T_i - time gap for i lanes

$(\rho_{max})_{i \text{ lanes}}$ - maximal density for i lanes

Maximum flow at a certain speed is therefore computed as follows:

$$Q_{m,v} = \rho_c v \left[\frac{veh}{h} \right]$$

v - actual speed in $\frac{km}{h}$

3.3 Data prediction and evaluation

By the data prediction is meant a predictive analysis based on statistical techniques when an analysis of current and historical data is performed and based on this knowledge a prediction about future unknown data is performed. In the case of this Thesis, there are analyzed historical data, from which data patterns are found. These patterns are repeated with a defined period and so future data can be predicted based on historical data. When a prediction is performed, there can be measured reliability of prediction by Mean Square Error (MSE) and Mean Absolute Percentage Error (MAPE). This is a statistical way to measure and compare the reliabilities of predictions. Mean square error is defined by:

$$MSE = \frac{1}{n} \sum_{i=1}^n (x_i - \hat{x}_i)^2$$

where:

- n is number of observations
- x_i is actual value

- \hat{x}_i is estimated value (11)

Mean absolute percentage error is defined by:

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left| \frac{x_i - \hat{x}_i}{x_i} \right|$$

where:

- n is number of observations
- x_i is actual value
- \hat{x}_i is estimated value (11)

This data prediction can be performed by various methods, in this Thesis, there was chosen one method at the beginning and with this method, further predictions are performed and evaluated. This method is called Triple exponential smoothing (Holt-Winters).

Why this method? Because this method is used for data, which show trend and seasonality (periodicity). These two parameters are crucial for data prediction for traffic data. Triple exponential smoothing is defined by the set of equations: (6)

$$S_t = \alpha \frac{y_t}{I_{t-L}} + (1 - \alpha)(S_{t-1} + b_{t-1})$$

$$b_t = \gamma(S_t - S_{t-1}) + (1 - \gamma)b_{t-1}$$

$$I_t = \beta \frac{y_t}{S_t} + (1 - \beta)I_{t-L}$$

$$F_{t+m} = (S_t + mb_t)I_{t-L+m}$$

where:

- y_t is the observation
- S is the smoothed observation
- b is a trend factor
- I is the seasonal index
- F is the forecast at m periods ahead
- t is denoting time period
- α, β, γ are constants, that must be estimated in such a way that the MSE of the error is minimized (6)

As long as it is an optimization algorithm, there is no possibility to predict data this way manually. To solve this, there are a few implementations of this algorithm is widely used programs, such as R, Python, Stata, LibreOffice, or Microsoft Excel. (7)

In this Thesis, there was chosen to analyze data and perform data prediction in Microsoft Excel 365, where is a function FORECAST.ETC implemented. Exponential smoothing forecasting in Excel is based on the AAA version (additive error, additive trend and additive seasonality) of the Exponential Triple Smoothing (ETS) algorithm, which smoothes out minor deviations in past data trends by detecting seasonality patterns and confidence intervals. (8)

There is multiple times data prediction performed on a different set of data. Data prediction is performed for the same time on traffic flow quantity and average vehicle speed. From all of these data predictions, there are MSE and MAPE computed, which show, how much does predicted data differ from actual values. After that, there is a conclusion, which shows, which type of traffic data can be predicted with sufficient MSE and MAPE values and which not.

4 Data analysis

In this chapter, there is described data processing, data prediction and its evaluation, which is the main part of this Thesis. In the end, there is a conclusion based on performed predictions.

4.1 Data verification

Own measurement was performed on September 17th, 2020 between 1 PM and 2 PM, so exactly one hour of recording. Traffic flow data were obtained by processing video recording of actual traffic flow, which was taken on a highway flyover above D5 highway on chainage of 3,345 km. This road is marked as 3rd class road marked as III/00518. Exact GPS position of where the recording was performed is WGS84 (GPS): N = 50.0383 E = 14.2251.

The recording was then analyzed ex-post by manually counting the numbers of cars and trucks in the traffic flow in both directions. As a similar measurement is performed during the test operation for other automatic traffic counters, the categorization of vehicles into 8 categories was also performed here, as required by the „Requirement for design and quality“ valid for the Road and Motorway Directorate .

The resulting table clearly shows the numbers and shares of individual categories together with tolerated and intolerable changes between vehicle categories. The table is presented in Appendix 1.

The table in Appendix 1 shows the number of vehicles in the direction to Pilsen, that were manually counted – 1780. This number was then compared with 1773 vehicles, which recorded an automatic traffic counter in the same stretch of the road by 7 vehicles more. The ratio of this difference in the number of vehicles to the measured number of vehicles is given in the upper left grey field.

The undetected vehicles listed after the „bus“ column in the figure above represent vehicles that the traffic counter did not register or did not record. This phenomenon occurs most often in motorcycles, which is because motorcycles often travel off-center through the induction loops, which prevents the counter to register these motorcycles effectively. For other categories, this error is very little desirable.

The next blue columns show the sum of all manually added vehicles of the given category and the percentage of correctly classified vehicles to all vehicles of the given category. In the last column is the smallest sufficient value of the correct classification of the vehicle category. These values arose from the long-term experience of experts at the Directorate, where these tables were implemented around the year 2010.

The same comparison was also performed in the opposite direction to Prague with the result in Appendix 2.

It is clear from both of the figures in the Appendix 1 and Appendix 2, that it is realistic to count traffic very accurately with the technology of a stationary automatic traffic counter working with electromagnetic induction. In one case, the 99.5% success rate in the vehicle census and the other case 100%, these are numbers exceed expectations by far. As for the accuracy of the classification of vehicles into individual categories, the success rate is a few per cent lower, but it is necessary to take these numbers into context - motorcycles are, as mentioned above, problematic to count by induction loop technology, as they require a certain type of vehicle passage for their functionality. through loops, which can (but does not have to) be often violated by motorcycles. Furthermore, with modern vans, it is difficult to distinguish between the van and the light truck - in some cases, this difference can only be seen from the technical certificate of the vehicle, which is physically impossible for the counter to record. The last problematic category is buses - these are then, depending on whether they are articulated or not often confused with lorries or lorries with a trailer, which is shown in the table as "tolerated confusion".

The purpose of this measurement was to verify the data provided by the automatic traffic counter. The verification consisted of comparing the number of vehicles in individual vehicle categories, the success of the vehicle classification and the total number of vehicles, measured in both direction in one location of automatic traffic counter. The results are shown in the table below:

	To Pilsen	To Prague
Counted vehicles	99,4 %	100 %
Success of vehicle classification	97,5 %	94,7 %

These results are more than satisfactory, and therefore with this measurement, it is possible to declare the data from traffic counters valid so that it is possible to work with them as with real data.

4.2 Floating car data penetration

In this part of the work is compared data from stationary automatic traffic counters (SATCs) and floating cars. It aims to get an overview of the number of floating vehicles in the total number of vehicles. An intention behind this is to make possible to predict whether and how much to rely on data from floating vehicles, as the basic premise is that if for a given time interval represents only a small number of floating vehicles, it is

assumed that these vehicles will not represent traffic with sufficient confidence in the specified segment and time.

In the MS Excel spreadsheet, data from floating vehicles and SATCs with the smallest common sample of data - i.e. hourly aggregations of traffic data - were arranged side by side. As the data on floating vehicles also provide information on the number of passenger and freight vehicles individually, the data from the automatic traffic counters were also adjusted to the same format so that the first four categories, i.e. motorcycles, passenger cars, passenger cars with trailers and vans, were summed up as passenger cars and similarly the remaining four categories and those declared as freight vehicles.

Since the idea is that the number of floating vehicles is always lower than the number of all vehicles (these data are collected by SATCs), the ratio of the number of floating cars to the total number of SATC vehicles for both vehicle categories (passenger and truck) was performed. To the final figure was then also added data about average speed from both sources to visualize the correlation between penetration and average speed. The figure is presented in Appendix 3 and below is a table that emerged from this figure:

Table 7: Average penetration of data about traffic flow and average vehicle speeds

Date	Average penetration			Average speed	
	Passenger cars	Trucks	Total	FCD	SATC
14.9.2020	19%	17%	18%	106,79	107,51
15.9.2020	20%	16%	17%	106,02	107,24
16.9.2020	22%	22%	21%	108,03	106,73
17.9.2020	20%	19%	18%	108,42	107,57
18.9.2020	19%	22%	18%	107,94	105,82
19.9.2020	9%	7%	9%	118,37	111,43
20.9.2020	9%	6%	8%	115,83	112,00
Average	17%	16%	16%	110,16	108,34

For better visualization, the following figure is more detailed graph documenting only Tuesday (15.9.2020) of the figure above:

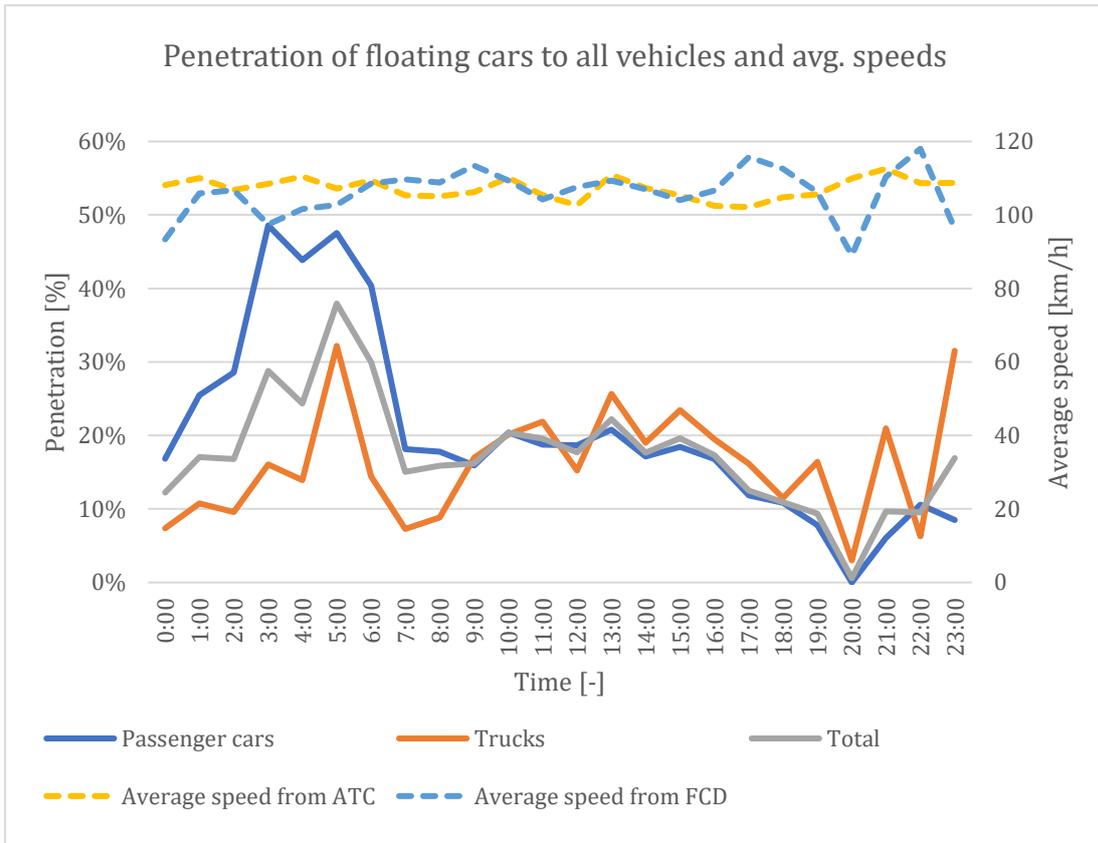


Figure 24: Penetration of floating cars to all vehicles and average speeds on Tuesday

From the figure in the Appendix 3 can be seen, that the penetration of data from ATC from 2,3 km and FCD from 2 to 4,3 km stretch of the highway in the direction to Pilsen is highly dependent on the time of the week.

Passenger car penetration is highly dependent on the time of the week and the day because it reaches peaks of almost 50 per cent penetration in morning peak hours, afterwards, it lowers to almost 20 per cent. During the weekend, penetration is again the highest on morning peak hours reaching about 25 per cent, but in other times it lowers between 5 to 10 per cent. This all is caused by the fact, that the most floating cars are travelling out of Prague at morning peak times travelling passengers to work in this direction.

Trucks penetration is not that dependent on the time of the week and the day, it is not very clear the morning peak hours as they are in passenger cars. Its penetration varies between 10 to 30 per cent and with some outliers, as can be seen in Appendix 3. This is caused mainly by the fact, that trucks use the road network in the night because of lower traffic possibility. In the weekend, due to heavy truck ban on highways in the Czech Republic, there can be seen that in many times the penetration is zero or almost zero. The conclusion is that when a traffic model for traffic control should be highly dependent

on FCD about trucks, it would be not much accurate especially on the weekend when there is a minimum penetration measured.

Total penetration shows the ration between all vehicle from FCD and SATC data.

There is also another point to mention. As long a stretch of the road, which was analyzed in this task is approx. 2,3 km long, there can be a question made – what is a relationship between average traffic speed and computed penetration? This whole task relies on the premise, that one vehicle detected by SATC is detected also one time on the whole segment of floating cars. Known is the time interval, in which floating cars are periodically measured and the length of the segment, which is 2,3 km. From the basic equation defining the average vehicle speed:

$$v = \frac{s}{t} = \frac{2,3 \text{ km}}{1 \text{ min}} = \frac{2,3 \text{ km}}{\frac{1}{60} \text{ h}} = 138 \frac{\text{km}}{\text{h}}$$

It shows, that if one vehicle should be counted only one time in this segment, it would travel at least 138 km/h. As can be seen in Appendix 3 or Table 6, the average speed is during working days around 100 km/h, which means that chosen way to compute the penetration of traffic flow data is not chosen wisely. Computed ratios are lower than computed in this task and it means, that it is not possible to rely on the data which were computed in this task. Therefore, the information of how many vehicles of all vehicles passed through a point in highway network must be evaluated differently.

4.3 Comparison of average speeds

This part of the thesis aims to show the relationship between average hourly speeds from stationary automatic traffic counters and average speeds from data from floating vehicles. It also tries to answer the question of how much the speed data from SATC differs from the data from floating cars when the speed data from floating vehicles are considered valid. It is important to note that two different averages are envisaged in this chapter – time-mean speed and space-mean speed. In simple terms, the space-mean speed is the distance travelled divided by an average travel time, whereas the time-mean speed is an average of individual vehicle speeds. (8) There is a relationship between these two mean speeds, and it is:

$$v_T = \frac{\sigma_M^2}{v_M} + v_M$$

In this equation, v_T is the time-mean speed, v_M space mean speed and σ_M^2 the variance of the space means speed. (9)

To compare the data with each other, the data were obtained from the SATC in a non-aggregated form, and thus for each lane in one direction. Subsequently, the weighted average overall vehicle categories were calculated, corresponding to the average speeds in the individual hours and lanes. Furthermore, these data were also obtained from FCD from the same day. Here, a weighted average was similarly calculated for the data from each hour to produce hourly aggregations of data for comparison with SATC. The result was recorded in the table below:

Table 8: Computation of difference between space and time mean speeds using formula

Hour	$v_T \left[\frac{km}{h} \right]$	$v_M \left[\frac{km}{h} \right]$	σ_M^2	Computed $v_T \left[\frac{km}{h} \right]$	Difference between v_T and computed v_T
0	102,63	110,55	357,77	113,79	11%
1	103,71	106,70	394,94	110,41	6%
2	100,25	100,38	173,43	102,10	2%
3	105,67	90,08	33,32	90,45	14%
4	102,83	96,66	245,86	99,20	4%
5	101,00	104,21	191,11	106,04	5%
6	98,29	110,68	94,25	111,53	13%
7	98,14	112,47	93,82	113,30	15%
8	101,13	113,17	42,21	113,54	12%
9	100,63	110,66	43,38	111,05	10%
10	98,63	112,95	140,29	114,19	16%
11	96,63	112,47	89,85	113,27	17%
12	101,38	114,64	89,51	115,42	14%
13	98,25	107,91	57,49	108,45	10%
14	102,13	115,03	70,33	115,64	13%
15	100,00	113,40	31,67	113,68	14%
16	98,13	117,32	61,95	117,84	20%
17	100,75	116,35	56,19	116,83	16%
18	101,00	117,59	114,41	118,57	17%
19	105,38	111,94	232,55	114,02	8%
20	103,38	116,24	331,85	119,10	15%
21	99,29	114,00	237,51	116,08	17%
22	106,88	110,42	420,09	114,23	7%
23	102,00	106,36	407,79	110,20	8%
AVERAGE	101,17	110,09	167,15	111,62	10%

For better visualization, below is a graph showing the distribution of differences:

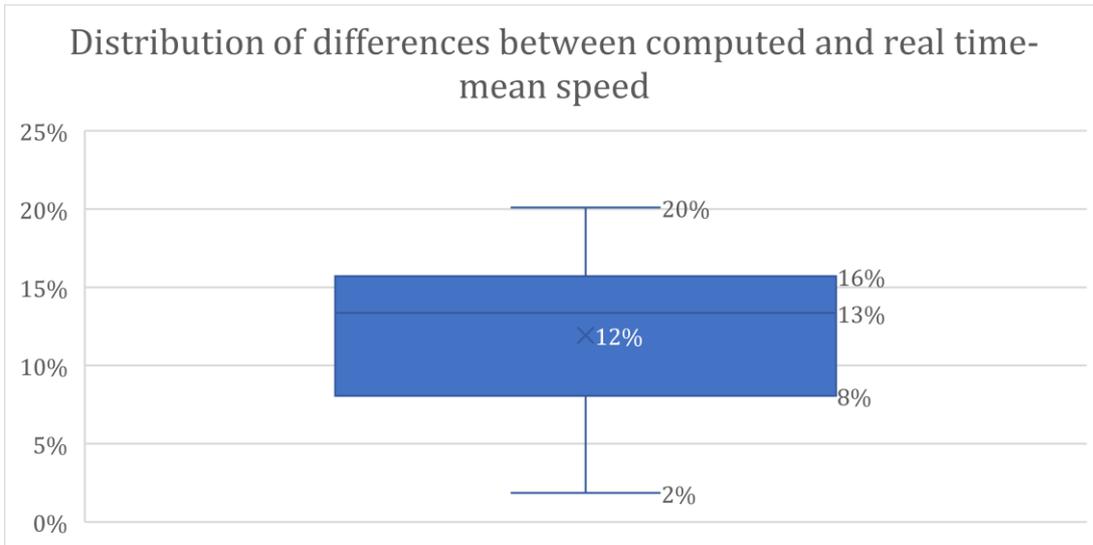


Figure 25: Distribution of differences between computed and real time-mean speed

To sum this up, the average difference between the data from SATCs and floating vehicles is about 10%, which provides a good starting position for deciding, whether the data from SATCs are better than data from floating cars. For future usage, this parameter should be manually verified using an external and professional tool to measure vehicle speeds. Otherwise, it is not possible currently declare which data are accurate more than the other and by which constant.

4.4 Traffic flow prediction

In this, the most important part of the practical part of this work, the author's approach to data from floating vehicles and automatic traffic counters as a whole and his conception of this data as a basis for line traffic control is described and explained.

As described in the chapters above, both data from automatic traffic counters and data from floating cars have their negatives and positives. Both data sets primarily carry other important information, wherein the case of loop traffic detectors it is the number of vehicles and the composition of the traffic flow, so in the case of floating vehicles it is mainly the exact speed valid for smaller sections (segments) of the road, such as the currently dimensioned SATC position.

The question is why to predict the traffic flow data when these data are aggregated by traffic counters and floating cars? This concept is fine, but only if everything is working properly - so there are no defects or faults in the ATC power supply system or on the communication route. Furthermore, there is the assumption that the traffic counter is sufficiently calibrated and thus provides valid data. The SATCs loops must also be in perfect condition, as even minor damage to the upper layers of the pavement of the road can cause them to detune or even become inoperable. From the experience at the Road

and Motorway Directorate these problems are not exceptional and when a problem occurs, typically with induction loops, it is being solved in a matter of months. Such a delay is not tolerable for a highway line traffic management, and therefore it is necessary to consider the short-term replacement of real-time data until the moment of resumption of traffic. As follows from the above that in the described way it is possible to solve short-term unplanned system outages in the order of minutes, typically a communication failure (need to restart the server or other components, etc.). For long-term failures, the presented method of data prediction is not suitable because data prediction is not able to accurately predict traffic only from historical data in a long interval ahead. Also, data prediction when no other data is available from loop detectors cannot determine any random situations in traffic, such as minor traffic jams or small road accidents.

For data prediction, a model was chosen that calculates or predicts a future value based on existing (historical) values by using the AAA version of the Exponential Smoothing (ETS) algorithm. The predicted value is a continuation of the historical values in the specified target date, which is a continuation of the timeline. (10) This algorithm is briefly described in 3.3 Data prediction and evaluation.

This algorithm was first implemented into data from one stationary automatic traffic counter, located in 4,2 km in the direction to Pilsen. For simplicity, the only direction to Prague was analyzed. Highway management should be implemented for this direction primarily.

4.4.1 ETS algorithm tuning on traffic data

In this chapter, there is described, how was the Exponential Smoothing algorithm implemented onto hourly traffic data from SATC (located on 4,2 km and in direction to Prague).

MS Excel version of the AAA version of the Exponential Smoothing (ETS) algorithm uses three parameters, which need to be set before the application of the algorithm. They are:

- Dataset
- Seasonality
- Data completion

Seasonality is a numeric value, which indicates to the algorithm to use patterns of this length as the seasonality. Data completion is an optional parameter, which indicates, whether an algorithm should use zeros for missing values, or if it should use an average value of the neighboring points. The second option is the default. (11) Dataset is an array

of historic values, which are used as training data to estimate the desired value. This array can be very variable in terms of its length.

To determine the best option of parameters used for traffic data, multiple sets of parameters were applied and then evaluated. The evaluation was based on MSE and MAPE, and MAPE was also divided into two parts by the beginning of the morning peak hour and the end of the evening peak hour. These two intervals are:

- From 6 AM to 8 PM
- From 8 PM to 6 AM

As long as evaluated data ought to be used for highway management, traffic flow from 8 PM to 6 AM is not high enough to be considered as crucial.

There were performed five data predictions when every time different set of parameters were used, as shown in the table below:

Table 9: Set of parameters used for algorithm tune

Algorithm	Dataset	Seasonality	Data completion
Based on previous working week	Complete 5 previous working days	24 hours	Default
Based on previous day	Complete 1 previous working days		
Based on two previous days	Complete 2 previous working days		
Based on three previous days	Complete 3 previous working days		
Based on all previous days	All data from 6.1. to the predicted hour		

For each set of parameters, there was a data prediction performed and estimated values compared to true data from SATC, used MSE and MAPE, MAPE also divided for both intervals, defined above. In Appendix 4, there is an evaluation of these predictions. To sum it up, in the table below, there are results:

Table 10: Evaluation of data prediction with given sets of parameters

	MSE	MAPE	MAPE 6 AM-8 PM	MAPE 8 PM-6 AM
Based on the previous working week	20939	12%	7%	20%
Based on the previous working day	39874	14%	9%	21%
Based on two previous working days	26341	13%	8%	20%
Based on three previous working days	23284	14%	8%	25%
Based on all previous days	15203	12%	7%	22%

In the table above can be seen, that the best option is to use the last set of parameters for the algorithm, therefore to use all available past data as the dataset, use seasonality of one day (24 hours) and to complete missing data by the averaging two neighboring.

Examples from working sheets are in Appendix 6.

4.4.2 Application of ETS algorithm on traffic data

In this chapter, there is described how was the algorithm, chosen from the previous chapter, used for data prediction, how to predict the data in the one-minute interval when there are only hourly predictions and pros and cons of the used method.

To begin with, in the previous chapter, the algorithm used for data prediction is proposed to predict the traffic flow in the next hour from all data before the predicted hour. This is based on the idea, that there is a clear pattern in each day, when it comes to hourly traffic flow, as shown in the figure below:

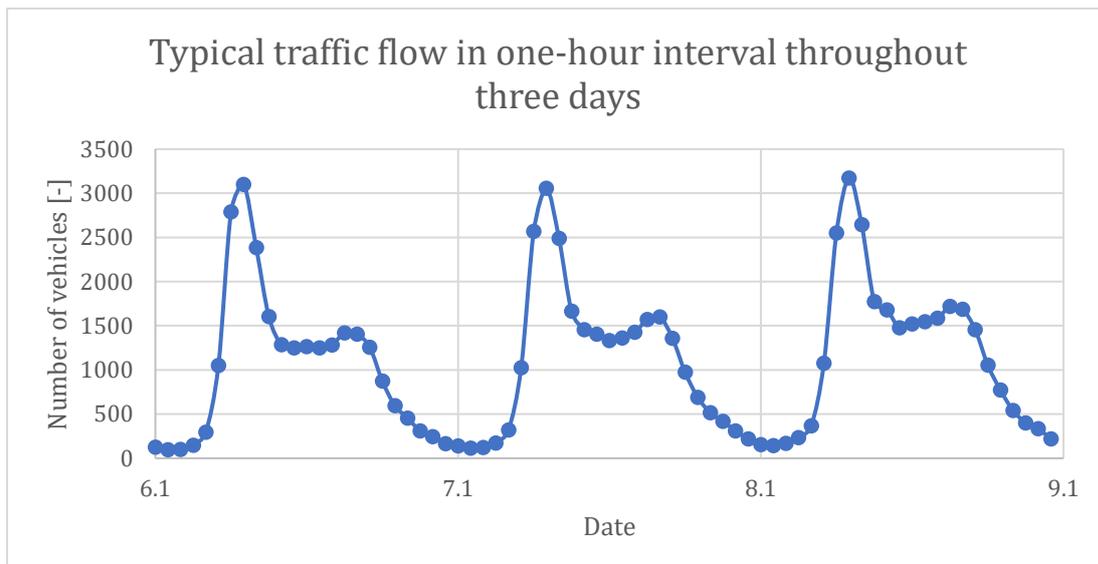


Figure 26: Typical traffic flow in one-hour interval throughout three days

In a figure above can be seen, that there are clear examples of morning and afternoon peak hours when the traffic flow reaches its local maximum and therefore there is proposed demand for traffic management. But traffic management cannot be done, when there are only one-hour time intervals of traffic flow available. To get one-minute intervals of traffic flow, there are two ways of doing it with current hardware settings – use the data from floating cars and estimate the traffic flow based on them, or find a mathematical way to estimate the traffic flow in one-minute interval ahead.

Examples from working sheets are in Appendix 6.

The first option – to use the data from floating cars – has many major limitations. To begin, there is a problem, that FCD does not carry information about actual traffic flow in each minute when the traffic prediction is needed. This problem is based on a fact, that only during morning peak hours there is a certainty, that at least one floating car passes one segment of the road network. Another thing is that although there are two consecutive minutes occupied with FCD, it does not mean that there are two cars. It creates more and more error in the traffic flow estimation. To illustrate these problems, in the table below, there is shown, how many one-minute intervals are occupied with the information of the traffic flow in floating cars data:

Table 11: Table showing the number of minutes when at least one car passes through one segment of floating cars (this is segment 2-4,3 km from Prague to Pilsen)

Hour/date	14.IX	15.IX	16.IX	17.IX	18.IX	19.IX	20.IX
0		38	40	20	40	28	3
1		37	43	39	38	15	12
2	44	38	48	35	24		
3	36	36	42	48	37	21	8
4	43	37	45	44	46	10	4
5	56	56	52	52	54	21	9
6	60	60	60	54	59	30	19
7	60	60	60	60	60	55	24
8	60	60	60	60	60	56	30
9	60	57	60	60	59	51	43
10	58	60	58	60	60	48	55
11	60	60	57	60	58	44	53
12	57	59	60	59	57	50	39
13	59	58	58	60	59	46	46
14	60	60	58	58	57	48	44
15	58	58	59	57	58	52	59
16	59	57	60	59	58	48	50
17	57	57	58	60	46	47	53
18	59	58	58	59	51	51	52

19	59	53	54	58	52	50	50
20	54	3	56	46	43	26	47
21	51	30	44	50	40	25	53
22	42	33	34	48	36	22	35
23	52	34	43	39	36	29	44

In the table above can be seen, that only highlighted hours in the whole week can be fully described by the data from floating cars, and so in other times, data prediction based on last-hour would not work. There may be found and estimated some complex methods, how to do that, but they are out of the scope of this Thesis and so they are not considered furthermore here.

The second way, how to predict the traffic flow from the past data is to find a mathematical way, how to estimate this data in the one-minute interval. The chosen way is presented to details and there are presented its pros and cons.

To begin, a method is presented from the theoretical point of view – as shown in the figure above, traffic flow can be visualized as an XY graph, where every point in the graph shows the value of traffic in each hour. When these points are connected, it creates a pattern, which is repeating throughout days and weeks, when there is no major disturbance. From the analytical point of view, a join of two points representing traffic flow in each hour is the estimation of the traffic flow between those two points. Because there are points, and the progress of traffic flow between the two is considered as linear, the linear function is estimated, and it is valid for all time intervals between the considered two points.

The same happens when there is no or error data received, so the current and estimated traffic flow considered, linear function between these two is computed and the data are predicted for and computed for each minute.

From the practical point of view, it is presented an actual algorithm of traffic data estimation as described above:

To begin, there is a traffic flow of one day and two hours of that day are considered:

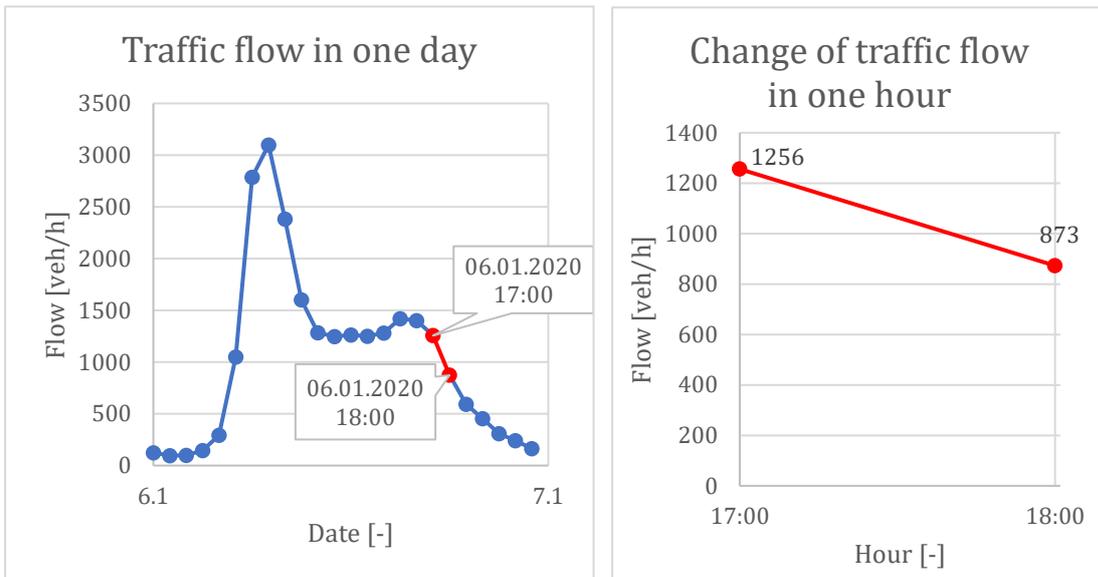


Figure 27: Graphs showing an average traffic flow for one day and specified hour

In the left figure above, there is a traffic flow pattern in one typical day, showing hourly data about traffic flow. For a further step in the algorithm, there is an only one-time interval (one hour long) chosen, in this example between 5 PM and 6 PM, which represents a decrease of traffic flow between these two times. In the right figure, there is only represented interval shown in the separated figure to explicitly show the linear course of a function in this model.

In the figure below, there is this exact interval shown divided into 60 intervals, representing one minute in the whole interval of one hour:

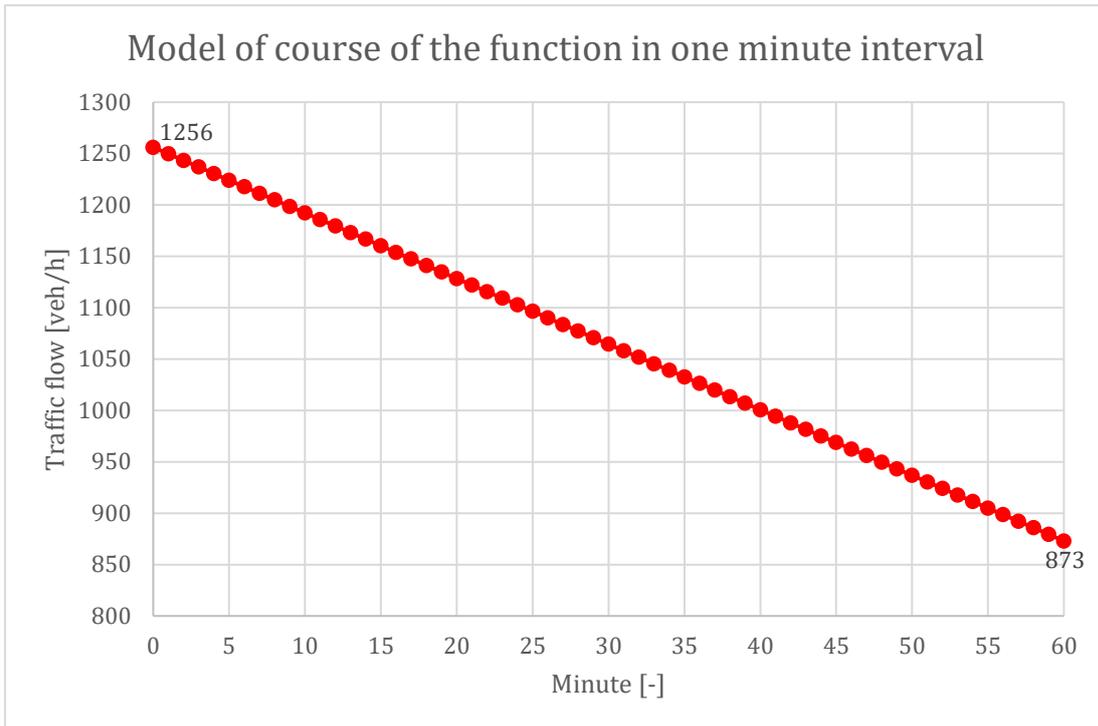


Figure 28: Model of course of the function in one-minute interval

In the figure above, there is a linear function representing one-minute intervals of the two data, as described in previous parts.

The idea behind implementing this algorithm is to evaluate, whether the received data from SATC is reasonable and expected. When there is any problem with received valid data, it may help with the data as inputs for further traffic management. Because in current settings of traffic counters there is no possibility to receive one-minute interval traffic data in the stretch of the highway between Prague Ring and Beroun, this is the simplest way how to determine the traffic flow intensity out of hourly data. It was chosen because the pattern of one-minute traffic flow may vary very much in different days and the pattern of data may be very hard to capture and therefore predict.

To evaluate the success of this algorithm, there was a data prediction performed, similarly as in chapter 4.4.1. The algorithm was tested only on working days and as training data was used the smallest sample of data needed for algorithm initialization. The algorithm was evaluated after every day by MSE and MAPE and MAPE was similarly as in chapter 4.4.1 divided into two parts, from 6 AM to 8 PM and vice versa. Evaluation of using this algorithm is in Appendix 4. Box plots are showing all important ranges of error in data prediction. From this box plot is clearly shown, that the algorithm based on all previous historic data is the most successful by providing the lowest values of errors.

To sum this algorithm up, there is shown, that this method can be implemented with current stationary traffic counters settings because as an input it is only an hourly data taken and the traffic in next hour is predicted. Between these two information, which can be represented as points in a diagram, there is a linear function modelled and from that can be each further minute traffic flow estimated. Then, some threshold of traffic flow can be estimated and when the estimated traffic flow reaches its value, the traffic management can reduce maximal speed in highway or do any other action.

The mentioned threshold can be considered as maximal traffic flow at a certain speed of traffic flow. This parameter can be calculated by the algorithm described in chapter 3.2. The given set of parameters can be adjusted by for every stretch of the road, so any technical parameters of the highway can be included in the computation.

There are a few pros and cons of this data prediction and one-minute traffic flow estimation. As pros could be considered relatively low computational demand, clear and not complicated algorithm, which should be easy to imagine even for people out of traffic management. As cons are considered, this algorithm uses a huge approximation of course of the function between two points. This course is quite likely non-linear and there are many factors, which can disturb the course of this function rapidly. Although, without further information, there is not a possibility to omit these disturbances. Floating cars data can help this function, but as long as the penetration of the data is relatively low in peak hours of the day (when the traffic management is highly needed), there is a problem to merge this data to get relevant information. Furthermore, as described in previous chapters, floating cars data carry more valid information about speed on a highway segment, than about traffic flow.

4.5 Level of Service estimation

To get extra information to the data, which should be taken as input for highway line traffic management, there is a possibility to compare the actual traffic flow with the computed maximal traffic flow at a certain speed, as mentioned above. This information could help the further algorithm for highway line traffic management to be more precise when evaluation of traffic state. That extra information should be called Level of Service estimation, when multiple choices of LoS determination are possible, as shown in 3.1.

The comparison for this Thesis was performed on one-hour interval data on a dataset between 6th and 26th January 2020, where traffic flows and average speeds were provided by the SATC, located in km 4,3. Data about traffic speed could have been provided by the FCD, but due to extensive computational requirement, which exceeded limits of the author's PC.

In the figure below, there is data of traffic flow from a working week between 6th and 10th of January showed along with computed maximal flow at the capacity of the highway:

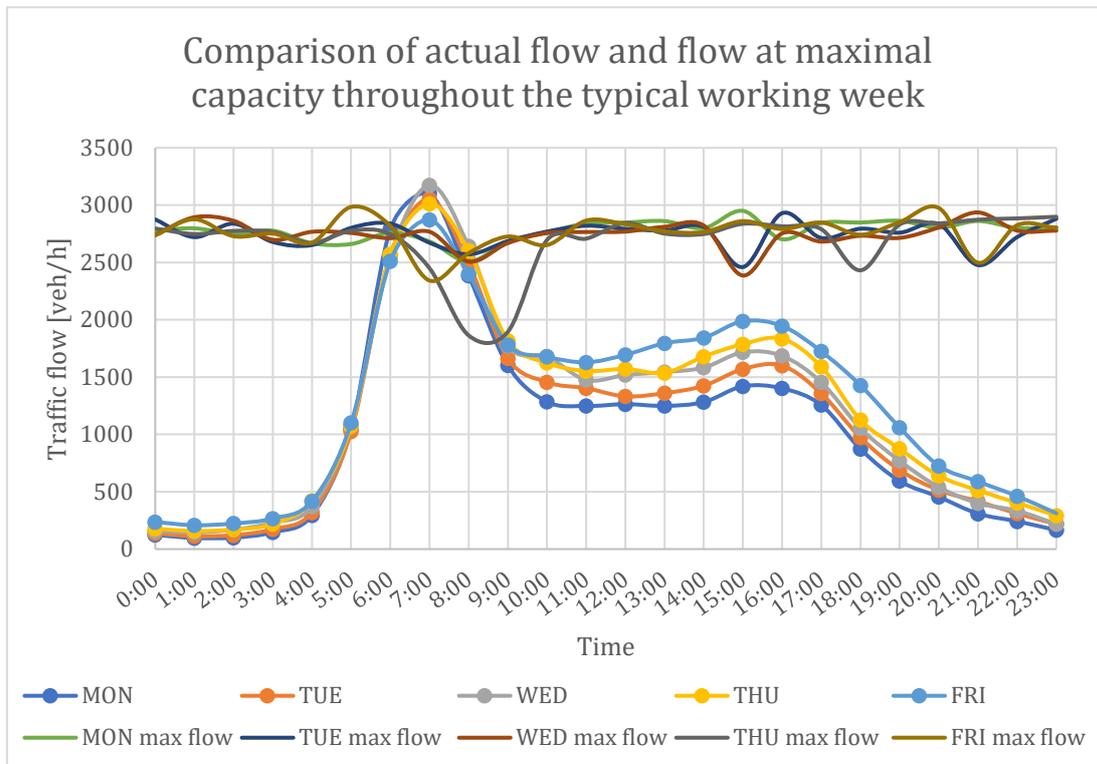


Figure 29: Comparison of actual flow and flow at maximal capacity throughout the typical working week

As can be seen in the figure above, the main problem with the capacity of the highway is between 6 AM and 9 AM. This period is crucial for highway line traffic management because it should mitigate the capacity drop, as visible on WED and THU lines. According to this task, data about actual traffic can contain also other important information, which needs to be defined precisely before the actual highway line traffic management operation.

When comparing only actual and maximal traffic flow for maximum speed, for given stretch of highway, which consists of 2 lanes, it is 3231 vehicles per hour, visualized in Appendix 6. In figure above, there are as “max flow” described computed maximum flows at average speeds, detected by SATC. These parameters can describe LoS in any way, in this Thesis it is not further specified.

5 Summarization and recommendation

In this part of this Diploma Thesis, the findings that were acquired during the writing of this thesis as well as during the work for the Road and Motorway Directorate from the author's experience are summarized. Also, there are proposed future steps, which should be considered and analyzed furthermore for better and more accurate data input for the highway management system.

The current state of traffic management using highway line traffic management in the Czech Republic is insufficient. By relying only on one data source from induction loop detectors, this system is very vulnerable in terms when any error of actual traffic data happens, the system is not able to reveal this problem and therefore will compute with a large error or invalid data. Also, there are multiple data sources available – different types of stationary traffic detectors and floating cars data, but they are not merged at present. There are some known issues in highways management, which are well known too. For example, when something happens with induction loops and they need to be repaired or even renewed, this process takes too much time (sometimes up to 6 months) and such data receive failure is unacceptable. Because this problem is heavily present at present time, highway line traffic management operates mainly in manual mode, when an operator of this system manually evaluates, when traffic reaches a critical point and manually perform a change on variable speed limits signs and other actors. This control management decreases the efficiency of this system rapidly and highway line traffic management does not meet its expectations when it was built.

Because this is a very huge and complex topic for the scope of this Thesis, this Thesis focuses on inputs, which are available at present and in a form, in which are received (with current hardware and software settings). In the desired stretch of the road, there are three types of available data – data from induction loop detectors received in the one-hour interval, data from ASIM non-intrusive detectors received in the one-hour interval and floating cars data, which are received in one-minute intervals. A figure below shows a location of both technologies on a given stretch of the highway:

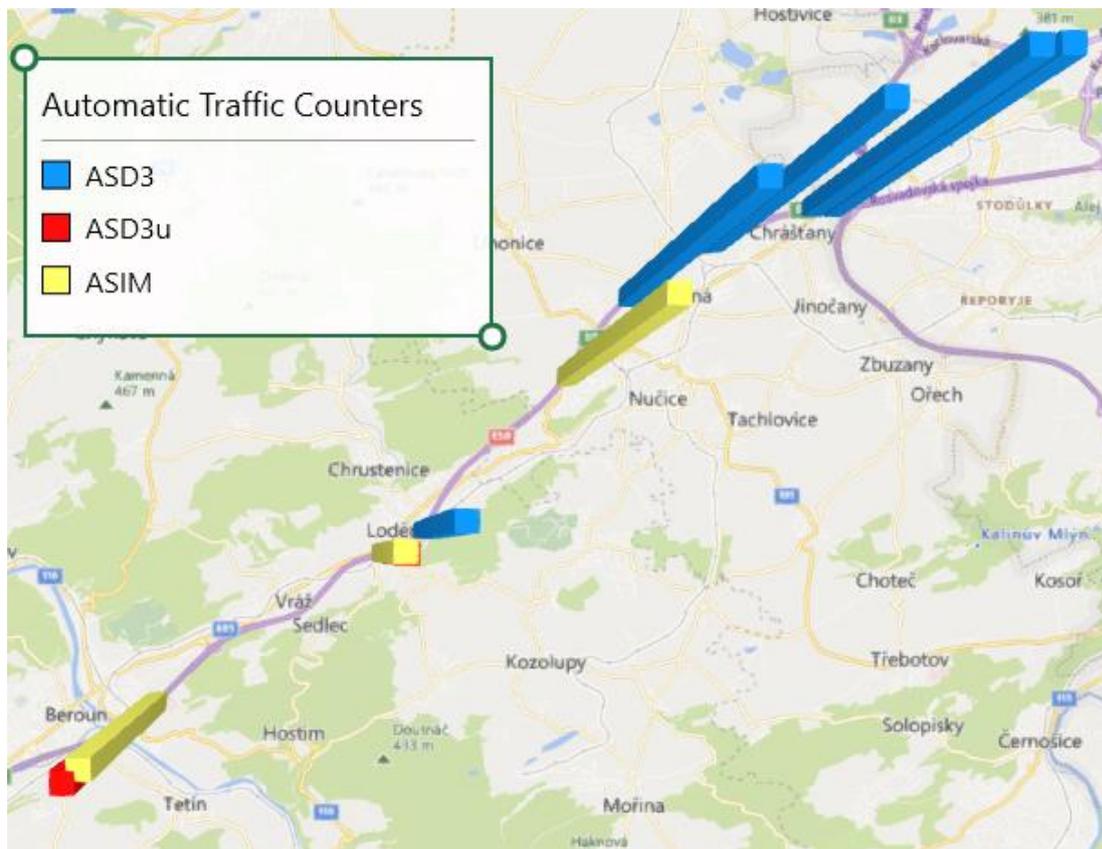


Figure 30: Locations of SATC on D5 highway between Prague Ring and Beroun

5.1 Data verification task evaluation

In this work was proven, that the information received about actual traffic flow from SATCs is highly accurate. The success rate of vehicle counting was over 99%, which means very accurate data collection. At present, the Road and Motorway Directorate does not make any systematic data collection verification. This means, that after the SATC is built and the success rate of data collection is tested, it is not tested anymore during the lifespan of such SATC. This creates a huge information gap when the Road and Motorway Directorate does not have a continuous information base about how accurate the SATC in the whole Czech Republic is collecting data. The closest to this process is a process of preparing a yearly census of the traffic, which is at present done by two people in the whole Road and Motorway Directorate, and they only can with sight expertise determine, whether there is any problem with the data, in terms of classification. From the author's point of view, this is heavily insufficient and there is a huge requirement to make a systematic data evaluation mechanism, which will compare the data in the complex.

5.2 Floating car data penetration task evaluation

Floating car data penetration was originally a task given by the Road and Motorway Directorate. The idea was simple, just to count all vehicles in one hour from one segment of the road and divide this number by all vehicles, which passed through one SATC. After understanding the data, periodicity of vehicle counting from two different sources it leads to the point when such calculation was performed, but its informative value was highly doubted. This was caused by the fact, that measuring techniques in both data sources were incomparable. Floating cars data shows, how many vehicles came across one segment in one minute every minute. SATC counts number of vehicles which pass through a point in the highway. In general, floating cars data provides a Lagrangian description of the vehicle movement, whereas SATC provides an Eulerian description of the vehicle movement. Another important point is, that because the SATC counts every vehicle only one time when a floating car should be counted only once, it would have to travel at a certain speed, which is for 2,3 km long segment 138 km/h – 8 km/h faster than maximum speed. When comparing to average speeds, around 100 km/h, it creates a certainty, that many vehicles are counted more than one time in floating cars data. Therefore, it is impossible to compare these two data and they can only be as a supplement for each other.

5.3 Comparison of average speeds task evaluation

When the number of vehicles is impossible to compare between mentioned sources of data, the other thing is a comparison of average speeds. Every SATC, operated by the Road and Motorway Directorate can collect data about average vehicle speeds and floating cars carry this information too (although, that at present no one uses these data and SATCs are not calibrated for speed collection, therefore the data from these detectors may be wrong). Because of that, a comparison of these speeds was performed. But, due to other description of vehicle movement, it is required to convert space-mean speed to time-mean speed, as described in 4.3 to be able to compare these vehicle speeds directly. This difference evaluation was performed for one whole day, as shown in Table 8. The outcome is extensively statistically described in Figure 25. The median differences are 12%. This value is not further analyzed or described, because average vehicle speeds are not used for any purpose in the Road and Motorway Directorate in general at present. Also, because the author of this Thesis did not have any kind of professional vehicle speed meter, there is not a way, how to determine right values, without further analysis.

5.4 Traffic flow prediction task evaluation

Traffic flow prediction intention was to create an algorithm, which can help to substitute short-term failures in data collection, to avoid the collapse of the automatic

regime of highway line traffic management. At present, this failure in data collection is present permanently. It is caused by the long-term insufficient maintenance of this system in general. The current algorithm, which deals with the data from loop detectors, which were built only for highway line traffic management, is not prepared to deal with any other sources of data. When any disturbance occurs, it is also not prepared to compare disturbed data with the data from the past to distinguish, whether it is an expected or unexpected value of traffic flow or average speed.

The second very important purpose of data prediction, based on historical data, is to be able to distinguish expected and unexpected data values. Sometimes, all parts of the systems seem to be working well, but there can be unnoticed error or failure, which will lead to data distortion, which will not be visible on the first sight. By comparing received and expected values it will take some time to adjust the algorithm and till then, there is a time to discover such failure and make a countermeasure for it. This is a known method, used widely, in Kalman filter etc.

5.5 Level of Service estimation task evaluation

In the last task, there was performed a level of service evaluation. It was done by calculating a maximum traffic flow of a given stretch of a highway at the certain speed. As shown in Figure 29, it shows, that the crucial time frame, when the actual traffic flow is expanding over the calculated maximum flow is between 6 AM to 9 AM. Common sense would tell, that this is not possible, but because the calculated maximum flow is computed with the range of constants, which may vary in time, such overflow is reasonable.

At the present time, Level of Service is only estimated from floating cars data. This LoS is determined only by the actual speed on a given segment. This is very simple, but yet straight forward method by estimating LoS. To be the LoS more durable and complex, maybe the more advanced method should be considered, for example the combination of two parameters – traffic flow and speed. Traffic flow is simply measured by the stationary ATC and speed can be determined in every segment separately, so between two intersections, very accurate information about LoS can be this method evaluated.

5.6 Other recommendation

Important thing for traffic analysis is a vehicle classification. As shown in chapter 4.1, its success varied between 94% to 98%. These are great numbers but defines only overall classification rate. Classification accuracy of each vehicle class, as shown in Appendix 1, is highly dependent on vehicle type and varies from 50% to 98%. This is due to an experience, that the difference between some vehicle types is quite small and

therefore it leads to misclassification. For example, in currently used classification scheme in the Czech Republic by the Road and Motorway Directorate, it is almost impossible for the SATC to distinguish between large SUV, which belongs in "Car" category and small "Van". The difference between them is so small, that for classifier in the SATC is this hardly noticeable from the vehicle signatures created by induction loops. On the other hand, this classification scheme is now implemented into many technical conditions used by a variety of other people, so it would be very hard to change anything on it.

6 Conclusion

The aim of this Thesis was to summarize knowledge about data collection, which is performed on highway D5 between Prague and Beroun at present and its usage for traffic management on highways. There was made an introduction to data sources, which are available for the Road and Motorway Directorate. There are three data sources available - stationary automatic traffic counters, ASIM technology and data from floating cars. Data from them are not processed further and none of these data sources are used for the traffic control at the present time.

Therefore, there was set several tasks, which should evaluate possibilities of merging all available sources of data to one and its usage for traffic management, especially highway line traffic management.

As described in previous chapters, data from stationary automatic traffic counters and floating cars should be used for traffic estimation, but wisely. Both data sources have their own advantages and limitations, which should be compromised or better eliminated by merging data types together for one utilized information about traffic flow.

After the utilized estimation of traffic flow, this source of data should be used for traffic control, especially highway line traffic management, which is in near plans to be built by the Road and Motorway Directorate. Highway line traffic management is in a scope of Thesis by Mr. Bc. Vojtěch Smrž, which deals further with the data and implements and evaluates the highway line traffic management in the same stretch of the highway D5. That Thesis should also deal with LoS estimation based on average traffic speed or other parameters to bring a result for line traffic management, which will increase the capacity of the highway and decrease travel times from origin to destination to minimum.

This Thesis should be further used for advanced data comparison with advanced models of traffic flow and average speed. Also, it should be used for traffic model, which is currently in development in the Road and Motorway Directorate. After applying all recommended points in this Thesis, people in the Road and Motorway Directorate should be able to better understand differences between collected data, their advantages, and disadvantages.

Finally, there should be prepared a data uniformization to data stream, which will combine all data sources to one unified data stream, which will be usable for a wide range of telematic systems in the Czech Republic, such as:

- highway line traffic management,
- ramp-metering.

LIST OF FIGURES

Figure 1: Focused stretch of a road – highway D5 between Prague and Beroun (3)	15
Figure 2: Example of a stationary automatic traffic counter – type Wavetronix (15)	16
Figure 3: Induction loops used for CrossCount detectors in Czech Republic	18
Figure 4: Distribution of inductive loop traffic detectors in the Czech Republic operated by the Road and Motorway Directorate. Each color represents one road name	19
Figure 5: Distribution of intrusive and non-intrusive detectors in roads and motorways in Czech Republic.....	20
Figure 6: Example of vehicle signatures created by induction loops (16).....	20
Figure 7: Close-up look of old and new induction loops cut in the pavement (17)	21
Figure 8: Principle of laser radar traffic counter (21).....	22
Figure 9: Distribution of laser traffic detectors used previously in the Czech Republic by the Road and Motorway Directorate. Each color represents one road name.....	22
Figure 10: Example of the ASIM traffic detector.....	23
Figure 11: Gantry with the ASIM detector depicting the detection zones	23
Figure 12: Distribution of the ASIM traffic counters in the Czech Republic operated by the Road and Motorway Directorate. Each color represents one road name.....	24
Figure 13: An example of SATC (Marksman 680) powered from solar panel (18).....	26
Figure 14: An example of SATC (Wavetronix) powered from public lightning (18).....	27
Figure 15: ASD3 traffic counter in SOS emergency	32
Figure 16: Rectangular induction loops for ASD3 traffic counter	33
Figure 17: Ratio of the Marksman traffic counters to all SATC in operation in the Czech Republic	34
Figure 18: Rear view on ASIM traffic counter (19).....	35
Figure 19: FCD Data collection scheme (2).....	36
Figure 20: Network of roads and highways for FCD data processing (20).....	37
Figure 21: Five-color scale showing how well are roads and highways in the Czech Republic covered with FCD (20)	38
Figure 22: Simplified data flow from traffic counters and floating cars to other telematic systems (29)	39
Figure 23: Example of highway line traffic management in operation	40
Figure 24: Penetration of floating cars to all vehicles and average speeds on Tuesday	50
Figure 25: Distribution of differences between computed and real time-mean speed..	53
Figure 26: Typical traffic flow in one-hour interval throughout three days.....	56
Figure 27: Graphs showing an average traffic flow for one day and specified hour	59
Figure 28: Model of course of the function in one-minute interval	60
Figure 29: Comparison of actual flow and flow at maximal capacity throughout the typical working week.....	62
Figure 30: Locations of SATC on D5 highway between Prague Ring and Beroun	64

LIST OF TABLES

Table 1: Examples of detection technologies used for car counting classification divided into major groups	17
Table 2: Distribution of Intrusive and Non-intrusive detectors in motorways in the Czech Republic	18
Table 3: Distribution of power connection for detectors in motorways in the Czech Republic	27
Table 4: Vehicle categorization in the Czech Republic used for SATCs (3)	28
Table 5: Vehicle categorization in the Czech Republic used only for ASIM technology (3)	29
Table 6: Basic quantities, their description and units used in road transportation (6) .	41
Table 7: Average penetration of data about traffic flow and average vehicle speeds.....	49
Table 8: Computation of difference between space and time mean speeds using formula	52
Table 9: Set of parameters used for algorithm tune.....	55
Table 10: Evaluation of data prediction with given sets of parameters	56
Table 11: Table showing the number of minutes when at least one car passes through one segment of floating cars (this is segment 2-4,3 km from Prague to Pilsen)	57

REFERENCES

1. **Wikipedia**. Traffic count. [Online] [Citace: 30. 09 2020.] https://en.wikipedia.org/wiki/Traffic_count.
2. **Pokorný, Ondřej**. *Systém pro plošné kontinuální monitorování dynamiky dopravních proudů na strategické síti komunikací ČR*. [Prezentace] Brno : VARS BRNO a.s., 2020.
3. **ŘSD ČR**. PPK-ITS_08-18_final. [Online] [Citace: 29. 11 2020.] https://www.rsd.cz/wps/wcm/connect/1ba04541-2904-4042-ad2f-849b6d7ce5e5/PPK-ITS_08-18_final.pdf?MOD=AJPERES.
4. *Mapování a analýza FCD dat*. **Boyarkin, Ivan, Tichý, Tomáš a Růžička, Jiří**. Praha : Nakladatelství Silniční společnosti, 2016. 0322-7154.
5. **ŘSD ČR**. ITIS. *The Integrated Traffic Information System for the Czech Republic (ITIS)*. [Online] [Citace: 30. 11 2020.] <https://portal.dopravniinfo.cz/en/itis>.
6. —. Road line traffic control. [Online] [Citace: 30. 11 2020.] <https://portal.dopravniinfo.cz/en/telematic-applications/road-line-traffic-control>.
7. **Wikipedia**. Units of transportation measurement. *Wikipedia*. [Online] 2020. [Citace: 31. 07 2020.] https://en.wikipedia.org/wiki/Units_of_transportation_measurement.
8. **S O Notley, N Bourne and N B Taylor**. INS003.pdf. *TRL Insight Report INS003*. [Online] TRL, 2009. [Citace: 31. 07 2020.] <https://trl.co.uk/sites/default/files/INS003.pdf>.
9. **University of Idaho**. Traffic Flow Parameters. [Online] [Citace: 27. 11 2020.] https://www.webpages.uidaho.edu/niatt_labmanual/chapters/trafficflowtheory/theoryandconcepts/TrafficFlowParameters.htm.
10. **Wikipedia**. Level of service (transportation). *Wikipedia*. [Online] 2020. [Citace: 31. 07 2020.] [https://en.wikipedia.org/wiki/Level_of_service_\(transportation\)](https://en.wikipedia.org/wiki/Level_of_service_(transportation)).
11. **Faltus, Vladimír**. *TDP L01 Introduction and overview*. [presentation] Prague : autor neznámý, 2018.
12. **Kim, Sungil a Kim, Heeyoung**. *A new metric of absolute percentage error for intermittent demand forecasts, International Journal of Forecasting*. místo neznámé : <http://www.sciencedirect.com/science/article/pii/S0169207016000121>, 2016. 0169-2070.
13. **6.4.3.5. Triple Exponential Smoothing**. [Online] [Cited: 11 12, 2020.] <https://www.itl.nist.gov/div898/handbook/pmc/section4/pmc435.htm>.
14. **Wikipedia**. Exponential smoothing - Wikipedia. [Online] 12. 11 2020. [https://en.wikipedia.org/wiki/Exponential_smoothing#Triple_exponential_smoothing_\(Holt_Winters\)](https://en.wikipedia.org/wiki/Exponential_smoothing#Triple_exponential_smoothing_(Holt_Winters)).
15. **4Bits Ltd**. *Forecast in Excel: linear and non-linear forecasting methods*. [Online] [Citace: 12. 11 2020.] <https://www.ablebits.com/office-addins->

blog/2019/03/20/forecast-excel-linear-exponential-smoothing-forecasting-models/.

16. FHWA. *Travel Time Data Collection Handbook*. [Online] [Citace: 20. 10 2020.] <https://www.fhwa.dot.gov/ohim/handbook/chap1.pdf>.

17. Knoop, Victor, Hoogendoorn, Serge a Zuyleen, Henk van. Empirical Differences between Time Mean Speed and Space Mean Speed. [Online] [Citace: 20. 10 2020.] <https://victorknoop.eu/research/papers/tgf07.pdf>.

18. Microsoft Office 365. FORECAST.ETS function. [Online] [Citace: 20. 10 2020.] <https://support.microsoft.com/en-us/office/forecast-ets-function-15389b8b-677e-4fbd-bd95-21d464333f41>.

19. doc. Ing. Pavel Hruběš, Ph.D. Floating car data for traffic management applications. *Portál ČVUT*. [Online] 2017. [Citace: 18. 07 2020.] <https://portal.cvut.cz/wp-content/uploads/2017/04/HP2011-23-Hrubes.pdf>.

20. Ministry of Transportation. Transport Yearbook 2016. [Online] [Citace: 18. 07 2020.] https://www.sydos.cz/cs/rocenka_pdf/Rocenka_dopravy_2016.pdf. 1801-3090.

21. Microsoft Corporation. Bing Maps. *Bing Maps*. [Online] 2020. [Citace: 30. 07 2020.] <https://www.bing.com/maps>.

22. CrossCount Control unit | Cross. [Online] [Citace: 18. 09 2020.] <https://www.cross-traffic.com/en/crosscount-control-unit/>.

23. Facebook. Facebook Cross Zlín. [Online] [Citace: 30. 09 2020.] <https://www.facebook.com/cross.zlin/photos/a.254234708330261/777452499341810/>.

24. Centrum dopravního výzkumu, v. v. i. [Online] [Citace: 22. 10 2020.] <https://www.cdv.cz/file/automaticke-scitace-dopravy/>.

25. FHWA, Office of Research, Development, and Technology, Office of Operations, RDT. [Online] 03. 08 2016. [Citace: 22. 10 2020.] <https://www.fhwa.dot.gov/publications/research/operations/its/06108/01.cfm>.

26. Los Angeles Automated Traffic Surveillance. ATSAC. [Online] 1997. [Citace: 22. 10 2020.] <https://people.duke.edu/~ng46/topics/traffic.htm>.

27. Seznam.cz. Mapy.cz. [Online] [Citace: 22. 10 2020.] <https://mapy.cz/>.

28. ASIM Technologies. [Online] [Citace: 22. 10 2020.] <https://fccid.io/R2DTT29X-453/User-Manual/User-Manual-430340>.

29. Doc. Ing. Pavel Hruběš, Ph.D. *Sledování kvality FCD systému*. [Prezentace] Praha : FD, Ústav dopravní telematiky, 2020.

30. *Traffic / pedestrian sensors*. [Online] Kyosan Electric Mfg. Co., Ltd. [Citace: 05. 11 2020.] https://www.kyosan.co.jp/images/products/img_traffic04_01_en.png.

31. ŘSD ČR. ndis-schema.jpg. [Online] [Citace: 01. 12 2020.]
<https://portal.dopravniinfo.cz/public/files/gallery/19/ndic-schema.jpg>.

Appendix 1

The success of vehicle classification for the counter in km 4.2 in the direction to Pilsen

No. of vehicles: 1780

99,40%	1 (Motorcycle)	2 (Car)	3 (Car with trailer)	4 (Van)	5 (Truck)	6 (Truck with trailer)	7 (Truck with cargo trailer)	8 (Bus)	x (UNDER detected)	Classification accuracy		
1 (Motorcycle)	27								8	34	77,8%	50%
2 (Car)		1490		10						1499	99,4%	98%
3 (Car with trailer)		2	25							27	92,9%	90%
4 (Van)		11		84	11				2	108	77,1%	50%
5 (Truck)				2	27					29	93,3%	85%
6 (Truck with trailer)						25			1	26	96,1%	85%
7 (Truck with cargo trailer)						6	40			46	87,5%	85%
8 (Bus)							2	10		11	83,3%	60%
x (OVER detected)										97,53%		

proper classification
97,53%

tolerated misclassification max. 10%
2,47%

tolerated misclassification max. 2%
0,00%

Appendix 2

The success of vehicle classification for the adder in km 4.2 in the direction to Prague.

No. of vehicles: 1816

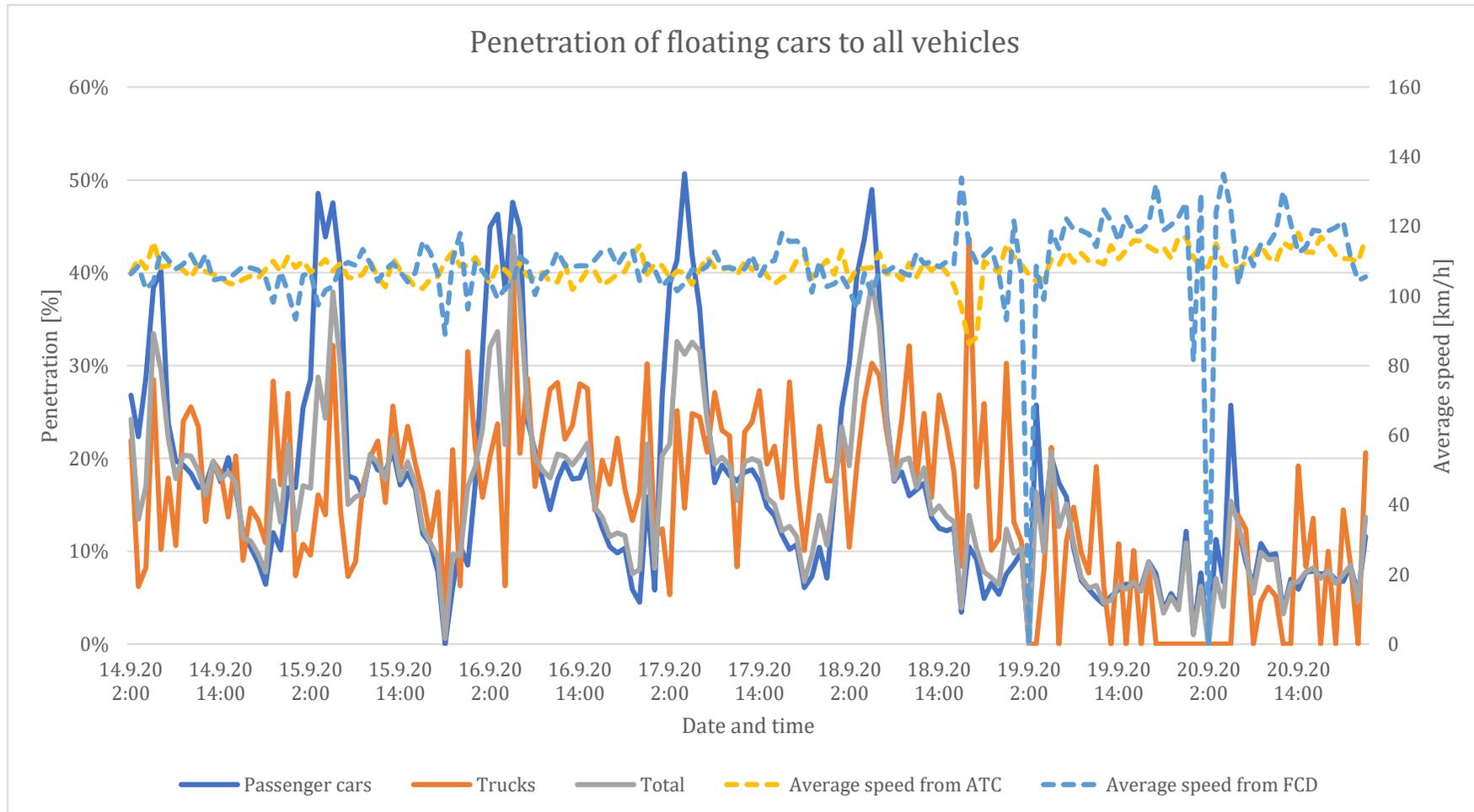
100,00%	1 (Motorcycle)	2 (Car)	3 (Car with trailer)	4 (Van)	5 (Truck)	6 (Truck with trailer)	7 (Truck with cargo trailer)	8 (Bus)	x (UNDER detected)	Classification accuracy		
1 (Motorcycle)	51								0	51	100,0%	50%
2 (Car)		1070		1					0	1071	99,9%	98%
3 (Car with trailer)			22						0	22	100,0%	90%
4 (Van)		30		98	1				0	129	76,1%	50%
5 (Truck)				1	39			2	0	42	92,1%	85%
6 (Truck with trailer)						60	2		0	62	96,4%	85%
7 (Truck with cargo trailer)			21		6	35	376	1	0	439	85,6%	85%
8 (Bus)							0	0	0	0	-	60%
x (OVER detected)										94,46%		

proper classification
94,46%

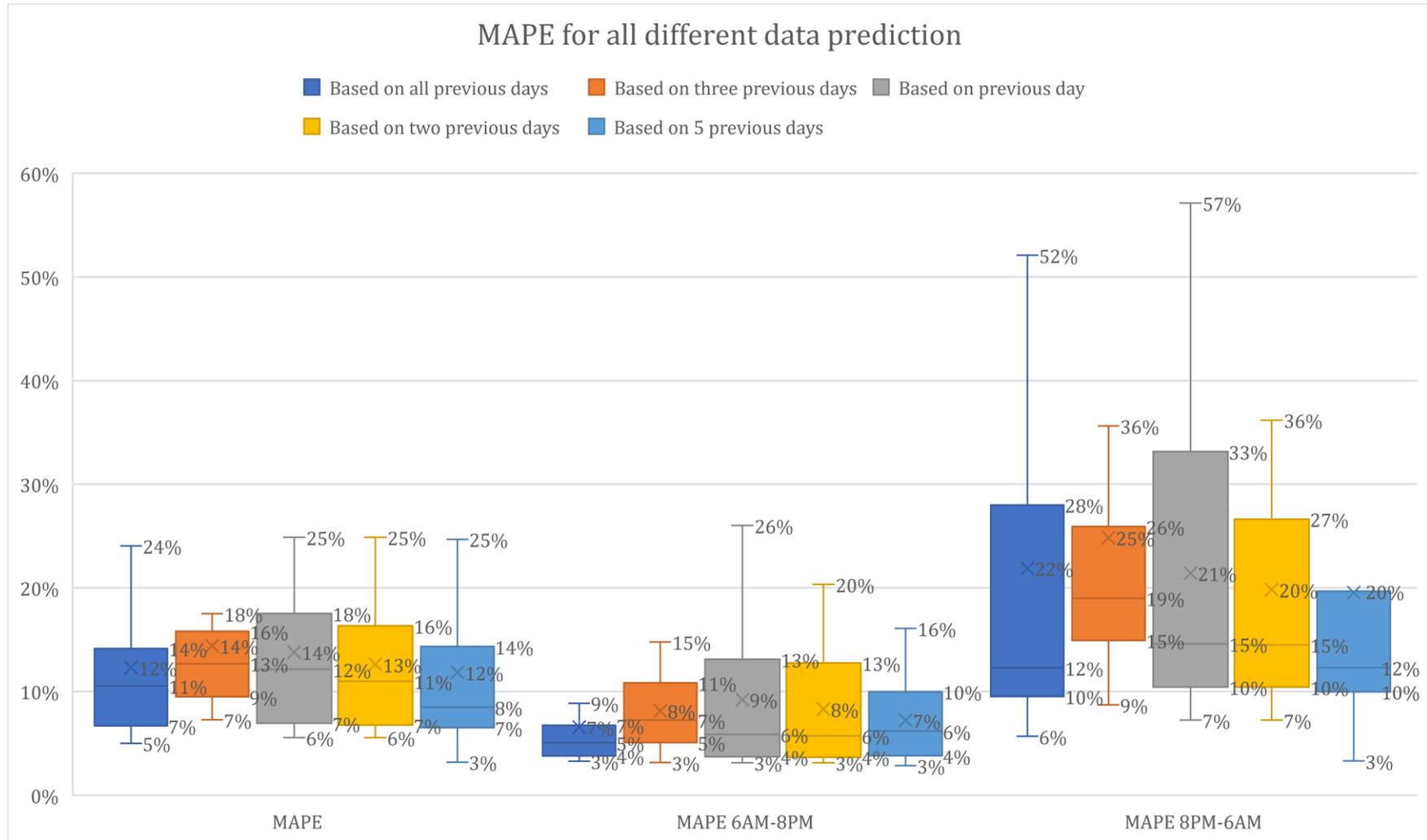
tolerated misclassification max. 10%
4,38%

tolerated misclassification max. 2%
1,16%

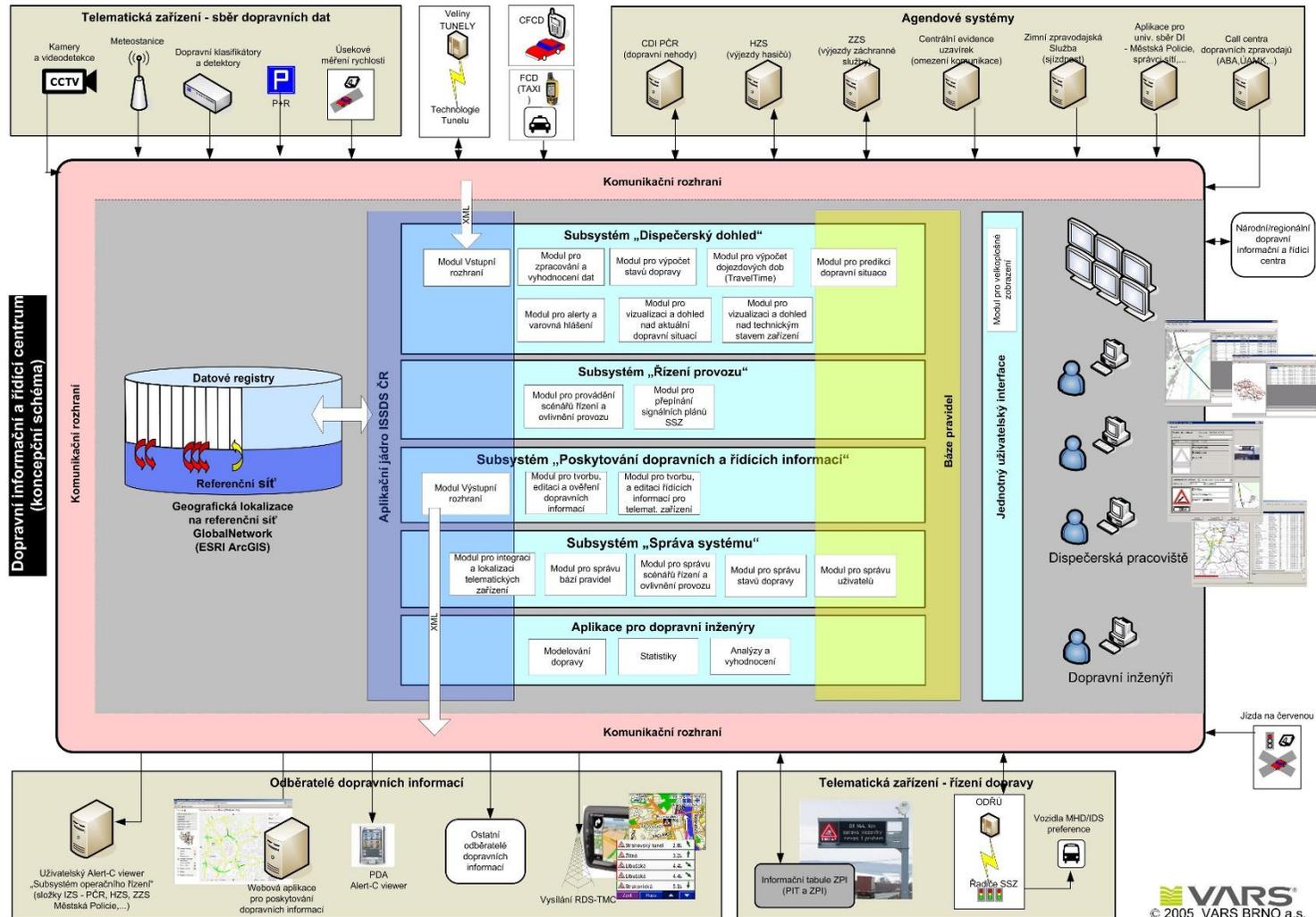
Appendix 3



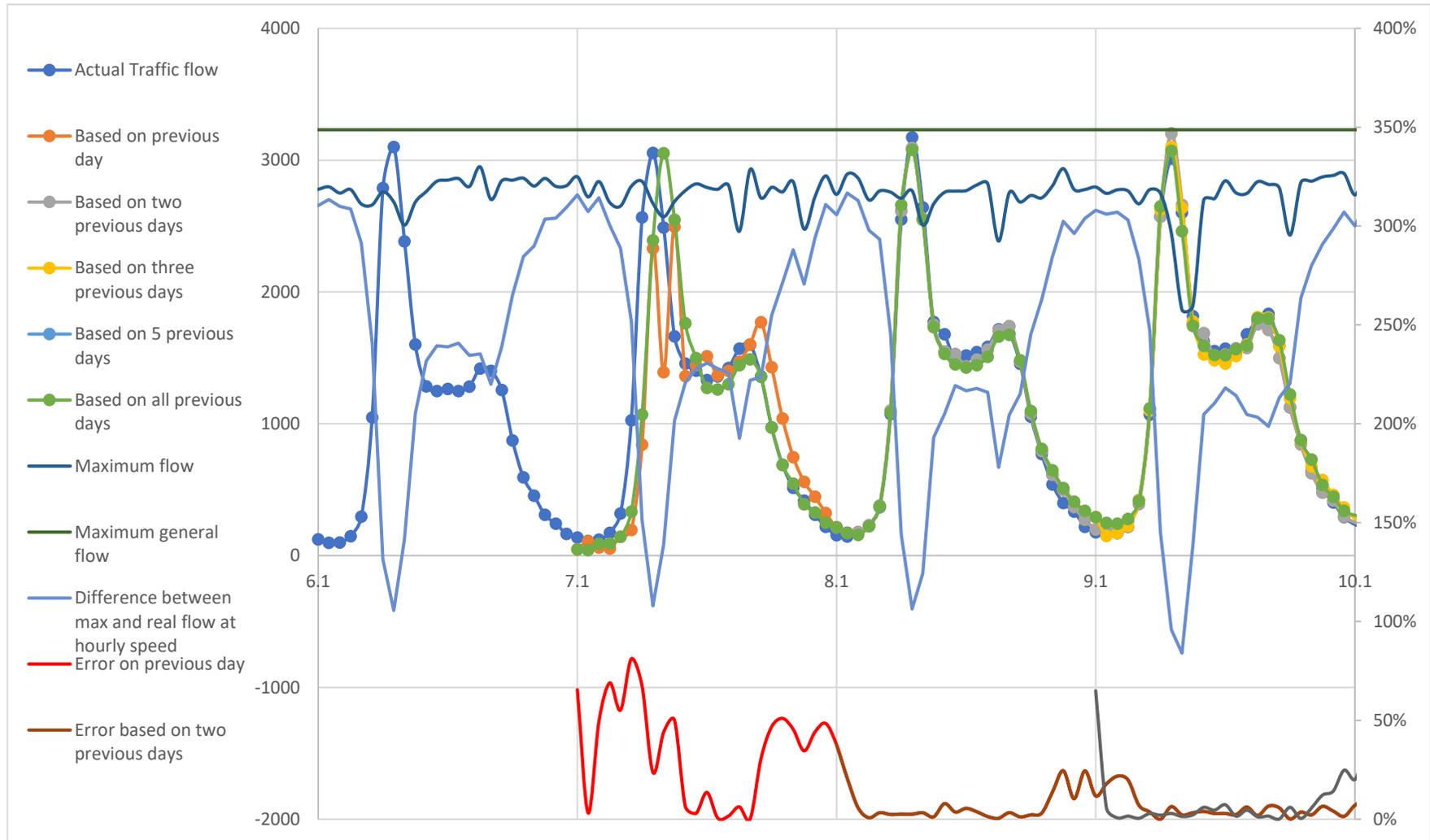
Appendix 4

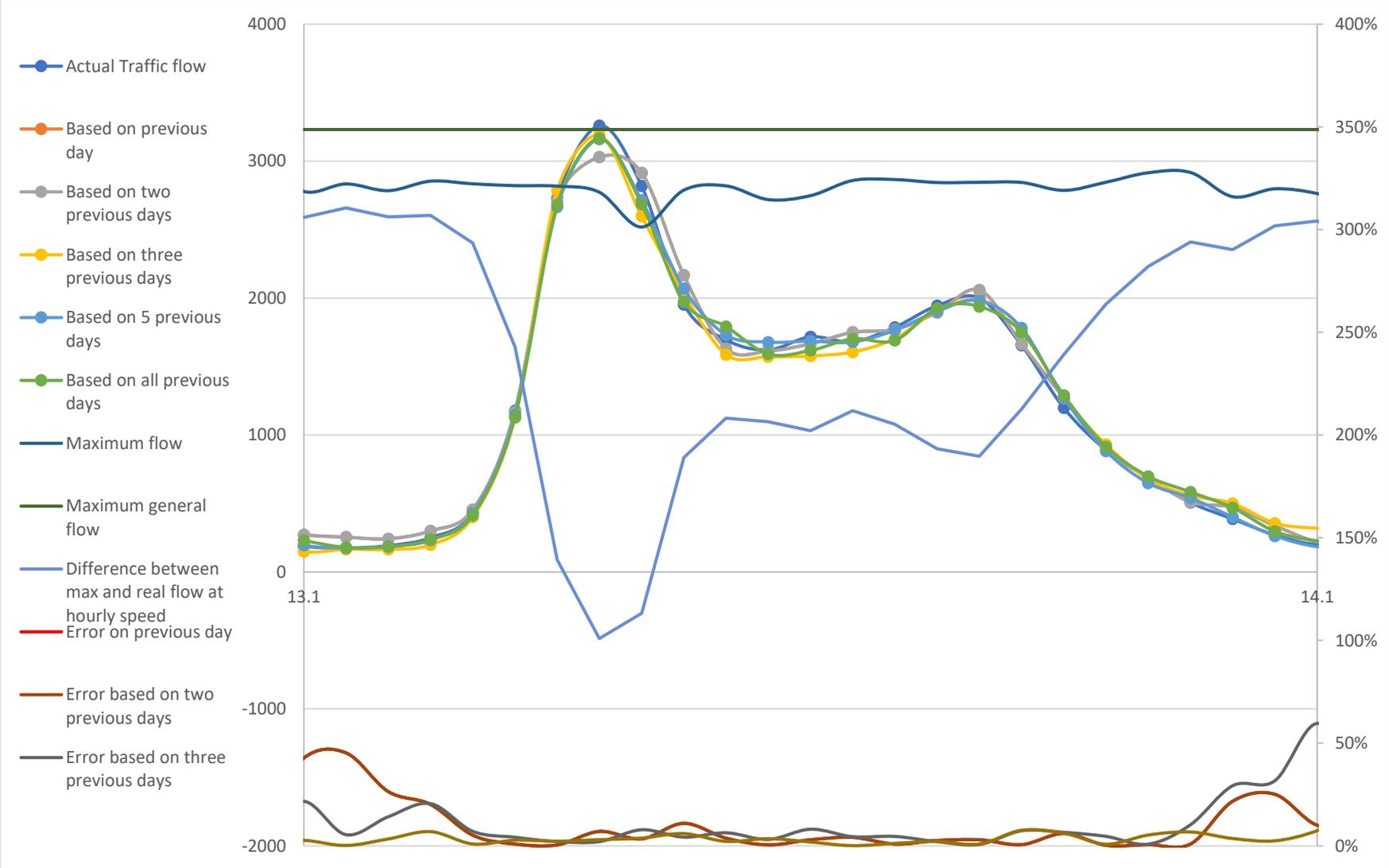


Appendix 5



Appendix 6





			Actual Traffic flo	Actual spe	Based on 5 previous days		Based on two previous days			Based on previous day									
MON	13.01.2020	11.01.2020 0:00	150	105,07	407	65947	171%	282	17332	88%	282	17332	88%						
		11.01.2020 1:00	151	102,33	353	40656	134%	159	66	5%	159	66	5%						
		11.01.2020 2:00	152	99,56	339	34859	123%	196	1929	29%	196	1929	29%						
		11.01.2020 3:00	183	104,25	203	399	11%	230	2163	25%	230	2163	25%						
		11.01.2020 4:00	379	102,71	348	991	8%	402	538	6%	402	538	6%						
		11.01.2020 5:00	1189	103,25	1055	17867	11%	1141	2270	4%	1141	2270	4%						
		11.01.2020 6:00	2798	99,64	2649	22173	5%	2543	65076	9%	2543	65076	9%						
		11.01.2020 7:00	3290	99,86	3313	524	1%	3159	17032	4%	3159	17032	4%						
		11.01.2020 8:00	2535	103,93	2712	31352	7%	2815	78612	11%	2815	78612	11%						
		11.01.2020 9:00	1784	107,57	1752	1006	2%	1918	17966	8%	1918	17966	8%						
		11.01.2020 10:00	1481	108,08	1638	24593	11%	1687	42468	14%	1687	42468	14%						
		11.01.2020 11:00	1412	104,43	1450	1444	3%	1696	80778	20%	1696	80778	20%						
		11.01.2020 12:00	1406	106,42	1480	5475	5%	1751	118916	25%	1751	118916	25%						
		11.01.2020 13:00	1379	105,29	1469	8156	7%	1798	175156	30%	1798	175156	30%						
		11.01.2020 14:00	1438	102,29	1455	281	1%	1426	135	1%	1426	135	1%						
		11.01.2020 15:00	1588	109,00	1637	2398	3%	1618	881	2%	1618	881	2%						
		11.01.2020 16:00	1652	97,88	1598	2873	3%	1838	34534	11%	1838	34534	11%						
		11.01.2020 17:00	1463	107,86	1403	3658	4%	1507	1911	3%	1507	1911	3%						
		11.01.2020 18:00	1075	108,00	1091	267	2%	1185	12018	10%	1185	12018	10%						
		11.01.2020 19:00	753	107,36	773	382	3%	707	2109	6%	707	2109	6%						
		11.01.2020 20:00	540	108,57	532	60	1%	MSE	MAPE	434	11179	20%	MSE	MAPE	434	11179	20%	MSE	MAPE
		11.01.2020 21:00	422	95,38	419	10	1%	11060	22%	384	1449	9%	28766	16%	384	1449	9%	28766	16%
		11.01.2020 22:00	337	107,90	330	48	2%	MAPE 6-20h	MAPE 20-6h	287	2502	15%	MAPE 6-20h	MAPE 20-6h	287	2502	15%	MAPE 6-20h	MAPE 20-6h
11.01.2020 23:00	225	107,00	230	22	2%	4%	51%	167	3369	26%	12%	23%	167	3369	26%	12%	23%		
TUE	14.01.2020	12.01.2020 0:00	188	112,07	166	483	12%	33	23873	82%	33	23873	82%						
		12.01.2020 1:00	190	104,67	176	188	7%	109	6573	43%	109	6573	43%						
		12.01.2020 2:00	195	109,86	204	78	5%	138	3206	29%	138	3206	29%						
		12.01.2020 3:00	223	102,36	246	520	10%	182	1679	18%	182	1679	18%						
		12.01.2020 4:00	386	109,93	392	31	1%	374	136	3%	374	136	3%						
		12.01.2020 5:00	1097	106,43	1073	592	2%	1192	8932	9%	1192	8932	9%						
		12.01.2020 6:00	2638	106,07	2557	6565	3%	2777	19376	5%	2777	19376	5%						
		12.01.2020 7:00	2946	101,93	3057	12241	4%	3131	34077	6%	3131	34077	6%						
		12.01.2020 8:00	2776	104,79	2537	56945	9%	2211	319507	20%	2211	319507	20%						
		12.01.2020 9:00	2063	108,06	1840	49755	11%	1741	103894	16%	1741	103894	16%						
		12.01.2020 10:00	1585	108,81	1915	108656	21%	1502	6848	5%	1502	6848	5%						
		12.01.2020 11:00	1522	112,06	1610	7775	6%	1365	24496	10%	1365	24496	10%						
		12.01.2020 12:00	1580	107,64	1634	2953	3%	1370	43953	13%	1370	43953	13%						
		12.01.2020 13:00	1652	114,06	1653	1	0%	1360	85281	18%	1360	85281	18%						
		12.01.2020 14:00	1687	113,63	1637	2486	3%	1711	564	1%	1711	564	1%						
		12.01.2020 15:00	1806	113,31	1817	124	1%	1623	33659	10%	1623	33659	10%						
		12.01.2020 16:00	1960	114,13	1798	26294	8%	1708	63746	13%	1708	63746	13%						
		12.01.2020 17:00	1588	108,50	1681	8735	6%	1549	1508	2%	1549	1508	2%						
		12.01.2020 18:00	1192	107,86	1199	51	1%	1200	63	1%	1200	63	1%						
		12.01.2020 19:00	823	109,14	921	9651	12%	870	2214	6%	870	2214	6%						
		12.01.2020 20:00	621	108,13	556	4179	10%	MSE	MAPE	635	207	2%	MSE	MAPE	635	207	2%	MSE	MAPE
		12.01.2020 21:00	451	107,21	479	765	6%	12590	7%	534	6892	18%	33015	15%	534	6892	18%	33015	15%
		12.01.2020 22:00	408	107,33	353	3076	14%	MAPE 6-20h	MAPE 20-6h	428	388	5%	MAPE 6-20h	MAPE 20-6h	428	388	5%	MAPE 6-20h	MAPE 20-6h
12.01.2020 23:00	278	111,71	284	30	2%	6%	7%	314	1293	13%	9%	24%	314	1293	13%	9%	24%		

Appendix 7

