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MONITOROVÁNÍ DOPRAVNÍHO PROUDU PLOVOUCÍMI VOZIDLY

Diplomová práce

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ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
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Při zpracování diplomové práce se řiďte osnovou uvedenou v následujících bodech:

- Představení/analýza/úvod do plovoucích vozidel
- Přehled/analýza telematických (inteligentních dopravních) systémů využívajících data z plovoucích vozidel na území České republiky a v zahraničí
- Analýza a zpracování dat z plovoucích vozidel na území Vídně (přesnost, kvalita, rychlostní profily, atd.)
- Identifikace problémových míst (vznik kongescí) na území Vídně a navržení nápravných opatření
- Budoucí směr vývoje inteligentních dopravních systémů a využití dat z plovoucích vozidel

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Rozsah průvodní zprávy: minimálně 55 stran textu (včetně obrázků, grafů a tabulek, které jsou součástí průvodní zprávy)

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Potvrzuji převzetí zadání diplomové práce.

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Prohlášení

Předkládám tímto k posouzení a obhajobě diplomovou práci zpracovanou na závěr studia na ČVUT v Praze Fakultě dopravní.

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ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

Fakulta dopravní

MONITOROVÁNÍ DOPRAVNÍHO PROUDU PLOVOUCÍMI VOZIDLY

Diplomová práce
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Aleš Ječmen

ABSTRAKT

Předmětem diplomové práce „Monitorování dopravního proudu plovoucími vozidly“ je analyzovat stávající technologie plovoucích vozidel a podat přehled telematických systémů používajících tuto technologii, a to jak v České republice, tak v zahraničí. Dále je cílem zpracovat data z plovoucích vozidel z taxi vozidel na území Vídně a využít je jako podpůrný nástroj pro dopravní inženýry k identifikaci dopravních kongescí. V poslední řadě si práce klade za cíl stručně popsat budoucí vývoj mobility a inteligentních dopravních systémů.

Klíčová slova:

plovoucí vozidla, FCD, GPS FCD, GSM FCD, XFCD, kongesce, V2V, V2I, ITS, inteligentní dopravní systémy

ABSTRACT

The aim of the master’s thesis “Traffic Monitoring by Floating Car Data” is to analyse the contemporary use and technology of Floating Car Data (FCD) and provide an overview of intelligent transportation systems (ITS) using this technology both in the Czech Republic and abroad. Furthermore, it aims to process FCD from taxi vehicles in Vienna and use them to support traffic engineers in identifying traffic congestion. Lastly, the future of mobility as well as the development of ITS is described.

Key words:

Floating car data, FCD, GPS FCD, GSM FCD, cellular FCD, extended FCD, XFCD, congestion, vehicle to vehicle, V2V, vehicle to infrastructure, V2I, ITS, intelligent transportation systems

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Abbreviations

ABS	Anti-lock Braking System
ASC	Automatic Stability Control
BTS	Base Transceiver Station
CFCD	Cellular Floating Car Data / GSM Floating Car Data
DLR	German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt)
DSC	Dynamic Stability Control
DSRC	Dedicated short-range communications
ETC	Electronic Toll Collection
FCD	Floating Car Data
FTP	File Transfer Protocol
GATS	Global Automotive Telematics Standard
GFCD	GPS Floating Car Data
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ITS	Intelligent Transportation System
MAC	Media Access Control
MOTIV	Mobility and Transport in Intermodal Traffic
OBU	On Board Unit
PC	Personal Computer
PND	Portable Navigation Device
PTA	Personal Travel Assistance
RFID	Radio-frequency Identification
SIM	Subscriber Identity Module
SMS	Short Message Service
SOCRATES	System of Cellular Radio for Travel Efficiency and Safety
TMC	Traffic Message Channel
TPEG	Transport Protocol Experts Group
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VAO	Verkehrsauskunft Österreich
VERDI	Vehicle Relayed Dynamic Information
WLAN	Wireless Local Area Network
XFCD	Extended Floating Car Data
XML	Extensible Markup Language

1 Introduction

Transport continues to play a key role in the development of the world economy and its function is thus of crucial importance when building and creating our society. However, the rapid increase in number of vehicles, severe weather conditions, and frequent traffic accidents often result in traffic congestion which can be observed mostly on urban roads all over the world. Therefore, in order to make the road transport as effective as possible and lessen its environmental footprint as well as make it a safer mode of transport, it is necessary to introduce appropriate measures for traffic monitoring and management in real-time. Intelligent transportation systems (ITS) offer a good solution for coping with excessive traffic which is predicted to increase even more in the forthcoming years. The conventional method of collecting traffic information is no longer able to timely and accurately reflect the traffic condition on today's roads. Floating Car Data (FCD), an advanced ITS technology, is a method for collecting traffic information where vehicles act as mobile sensor nodes that are equipped with a location detecting and communication device. The use of FCD as means of overcoming the limitations of fixed monitoring technologies continues to proliferate. It addresses the issues associated with current methods of traffic monitoring such as the expense of installing and maintaining stationary detectors and their limited coverage resulting essentially in providing static nature of information about traffic status. Thus, road authorities as well as public transport bodies are increasingly using FCD as a tool for gathering and dissemination of improved travel information services. Nonetheless, there still remains much untapped potential of this technology.

This paper aims to provide a comprehensive overview of FCD technologies covering their historical use, fundamental principles, and data processing methodologies. Additionally, an extended version of FCD (XFCD) is introduced and described in more detail. This is followed by a general description of advantages and disadvantages mainly in comparison with stationary detectors. In the context of an ever-increasing number of commercial vehicles using FCD technology, the second part of this paper focuses on FCD processing and interpretation. Due to close cooperation with ITS Vienna Region, an autonomous transport management project operating across three regions in Austria, FCD from over 700 taxis within Vienna region during a week in March of 2014 were used as data supplier. Using a data processing methodology more than 6 and half million of FCD samples were analysed and subsequently a powerful tool for congestion identification, designated mainly to support traffic engineers in dealing with traffic variation, was introduced.

2 Floating Car Data

This chapter aims to firstly introduce the FCD concept and also describe its historical use. Then, it focuses on the different technologies that are used as part of the various FCD concepts. Subsequently, the latest FCD technology known as extended Floating Car Data (XFCD) is presented in further details. This is followed by the data acquisition principal of (X)FCD method and its data processing overview. The chapter concludes with a comparison between the (X)FCD technologies and stationary detectors.

2.1 Introduction

The FCD technology, also referred to as Floating cellular data, is a reliable and cost-effective way to gather accurate traffic data for a wide-area road network. It is based on the collection of both real-time data, which are being transmitted from vehicles equipped with mobile phones or GPS-based devices to control centre using wireless communication technology, and historical information that is saved on the internal memory of the vehicles' devices. This way each vehicle act as a traffic probe and an anonymous source of information providing data on the vehicles' speed, location and travel time. These data are then used as a primary source of traffic status and information for ITS which help increase the knowledge of traffic performances and travel patterns (Wu et al. 2013, 1578-1584). As it is thus possible to identify actual traffic conditions such as congestion and calculate travel times from point A to point B easily, a better understanding of traffic flow can be achieved. Therefore an optimized road network with an efficient movement of traffic can be developed and traffic congestion problems mitigated.

By contrast to the conventional traffic sensors and detectors such as traffic cameras, number plate recognition or induction loops embedded in the roadway, FCD is a non-intrusive way of acquiring traffic data as there is no need for additional hardware being installed on the road network. This makes the usage of the FCD method a more attractive and cheaper alternative (Sevlian n.d.). However, it is also important to point out that the current general consensus does not intend to replace the conventional stationary traffic sensors with the FCD, but to supplement their acquisition of traffic information with the use of advanced technology. This is because both systems still have some deficiencies. The infrastructure sensors retrieve information from static points of the road which are spaced far apart (in some cases several kilometres). Thus it does not provide an accurate picture of the actual traffic situation. This is where the floating vehicles come in and attempt to correct this deficiency by retrieving dynamic information on the traffic status. Unfortunately, the penetration's level of FCD currently available is quite low and therefore still insufficient to provide us with a complete picture of road traffic (Naranjo et al. 2012, 107-109).

The FCD technology encompasses three different methods for collecting traffic data. These methods are based on the usage of a Global Positioning System (GPS), mobile network, and vehicle re-identification, and are described in more detail in Chapters 2.3, 2.4, and 2.5 respectively.

2.2 History of Floating Car Data

The first attempts to use vehicles which "float" along the traffic flow for data acquisition were made in Germany around the mid-eighties. These breakthroughs were made by Siemens as part of their Ali- and Euroscout systems and by Philips that introduced a System of Cellular Radio for Travel Efficiency and Safety (SOCRATES) concept. The basic principle of these systems and concepts was to allow dynamic guidance to a destination through the road network by using vehicles participating in the system that could provide information on the traffic status. Thus, they used floating vehicles to record speed-related parameters and vehicle's position which were then transmitted to the control centre (Huber et al. 1998, 2). In addition, the SOCRATES concept allowed not only the vehicle-to-control-centre communication but also the other way around. This made it the "only pan-European transport telematics service offering two-way communication for a range of applications and service" (Catling et al. 1993, 319).

In April 1996, the two largest private telematics service providers in Germany – Mannesmann Autocom GmbH and Tegaron – used the same basic principle of FCD and carried out a field trial known as Vehicle Relayed Dynamic Information (VERDI) which lasted until September 1997. Approximately 850 vehicles were equipped with OBUs during the trial enabling the use of various telematics services and delivering information on the current traffic situation to the control centre. The VERDI experiment verified some of the assumptions made about the technical feasibility and commercial viability of such telematics projects. Furthermore, it identified some of the technical difficulties and commercial issues which were essential to tackle before introducing such systems on a commercial basis. The project's outcomes resulted in standardisation proposal of Global Automotive Telematics Standard (GATS) (Larima 1997).

Even though all of the field trials showed that FCD-based technology had beneficial effects on providing users with an accurate picture of the actual traffic status, a certain penetration of the

FCD-equipped vehicles had to be fitted with the system to enable control centres produce reliable traffic reports. The recommended proportion varies, but is usually between 1 and 5 % depending on the required level of quality of traffic information. If such conditions are not satisfied, FCD can be used as a supplementary source of information especially in areas with a small number of traffic sensors (for example rural roads) and on specific sections of road within urban areas using induction loops, traffic cameras and so forth. The data gathered from the conventional traffic sensors can be then corrected and validated with the FCD's outputs (Huber et al. 1998, 3).

2.3 GPS Floating Car Data

The basic principle of GPS Floating Car Data (GFCD) acquisition method lies in the use of two systems – a Global Navigation Satellite System (GNSS) and a Global System for Mobile Communications (GSM). The former is a system of satellites providing autonomous geo-spatial positioning with worldwide coverage (What is GNSS? 2015). Thus, electronic devices using GNSS are able to determine their location, expressed in longitude and latitude coordinates, to great precision using time signals transmitted along a line of sight by radio from satellites (source). Whereas the latter ensures that the vehicles' data are then communicated to control centres with the service provider through General Packet Radio Services (GPRS) or Short Message Service (SMS). Both technologies – GNSS and GSM – are integrated into an on-board unit (OBU) which can usually be found in a fleet of taxis, company car vehicles, monitoring systems for localization of stolen vehicles, or in an automotive navigation systems. For a schematic diagram of how GFCD works see Figure 2.1 (Hrubers et al. 2010, 13-15).

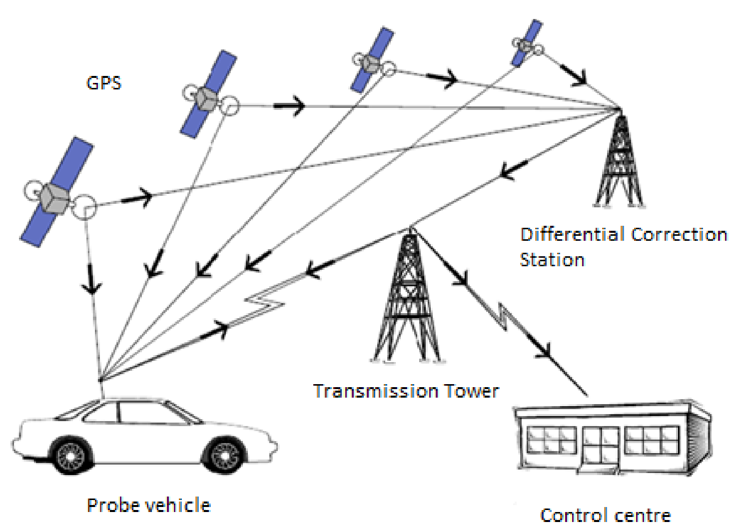


Figure 2.1 Communication scheme of a GFCD-based application (Leduc 2008, 6)

Even though an increasing number of commercial (for example taxi and public transport fleets) and private vehicles are nowadays being equipped with the OBUs supporting the GNSS and GSM technologies, the usage of this method is subjected to a large enough number of such equipped vehicles (Yong-Chuan 2011, 5541-5543). This is to ensure that the real-time traffic information services, which are mostly made available online today (for example DopravniInfo.cz), can be based upon a representative statistical sample and thus offer accurate and useful information about traffic to their users. That is also why the GFCD method prevails in urban areas which are densely occupied with taxis and public transport vehicles that usually have the OBUs installed in them and provide wide coverage of transportation infrastructure (Leduc 2008, 5-7).

For highways and motorways it is necessary to ensure that the penetration of vehicles equipped with the OBUs is at least one vehicle in a 15 minute interval for the monitored section of a given highway. Ideally, passage of 20 vehicles during a 5 minute interval is required. In addition, the monitored vehicles should not only be of one type (such as a freight vehicle, police car, ambulance, and so forth) (Hrubes et al. 2010, 14).

2.4 GSM Floating Car Data

GSM Floating Car Data (CFCD) is an approach for deriving travel times based on the information from mobile cell phones. This technique uses cellular network data (GSM), which is why it is also known as Cellular Floating Car Data method. A general overview of how the CFCD method works is depicted in Figure 2.2.

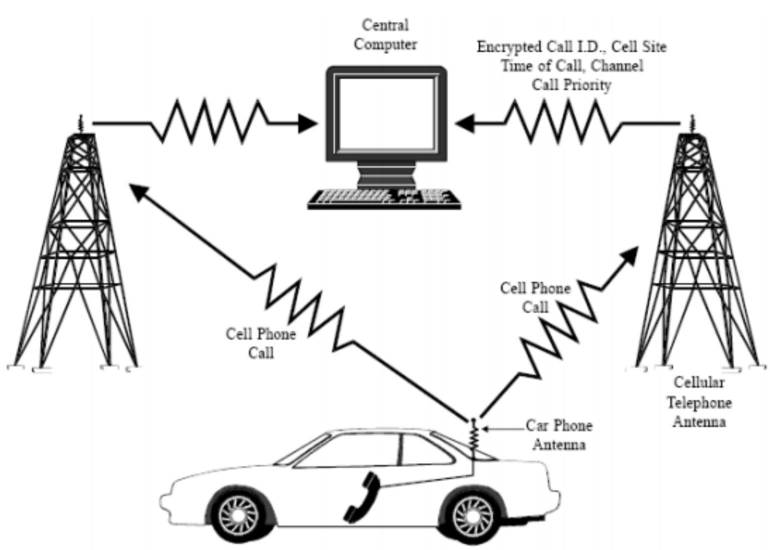


Figure 2.2 Cellular Floating Car Data method using cellular mobile phones (Leduc 2008, 7)

One of the CFCD great advantages over the GFCD technology is the fact that it requires no additional infrastructure, hardware in cars or along the road as every switched-on mobile phone acts as a traffic probe and provides traffic services providers with anonymous source of information. Furthermore, it offers great coverage of road networks and needs less maintenance for it is much faster to set up (Leduc 2008, 6; Hrubes et al. 2010, 14).

The localization of vehicles works on the premise that a high proportion of cars contain one or more mobile phones which periodically transmit their presence to the mobile phone network, even when there is no voice connection established. Therefore, as a vehicle moves, so does the signal of any mobile phone which is in the vehicle. The vehicle's position is then localized using triangulation method and the hand-over data stored by the network operator. In principle, a mobile network is divided into areas, usually in the shape of a hexagon, in accordance to the coverage of a single base transceiver station (BTS). When the signal of a mobile phone in the vehicle is passed to a different BTS, which is referred to as a hand-over spot, a monitoring point emerges and can be then consequently monitored as can be seen in Figure 2.3 (Leduc 2008, 6; Roebuck 2012, 25; How iTraffic Works 2009).

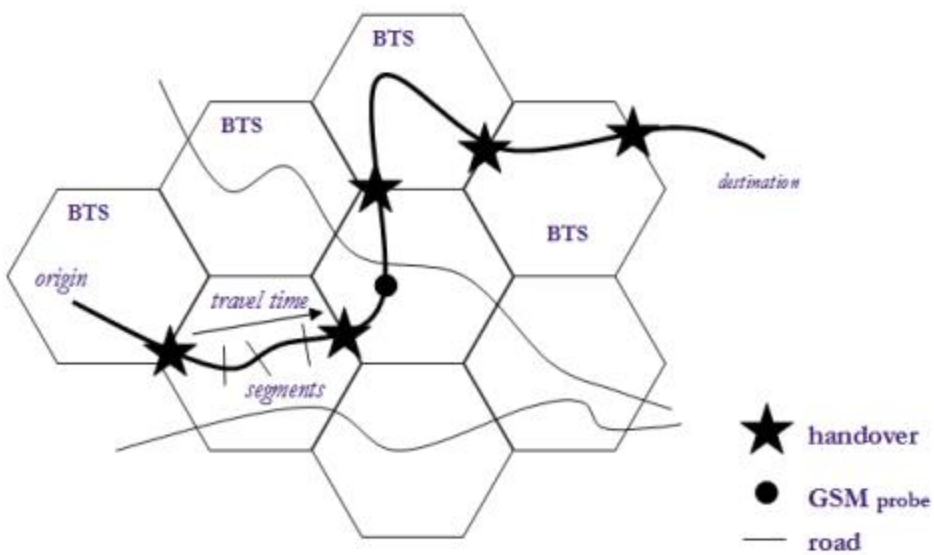


Figure 2.3 The exchange of information among stationary antennas (Maerivoet and Logghe 2006, 2)

Nowadays, as roads are heavily congested, there are more vehicles, more phones and therefore more probes in traffic flow. This provides especially urban areas with more precise information on vehicles' position as the metropolitan areas have more BTS antennas, which in theory increases the accuracy. However, in general GSM localization is less accurate than GPS based systems, which is why complex algorithms must be used to extract high-quality data. The GSM's degree of imprecision can be quite high (as many as 300 meters), but is partially compensated by the large number of mobile devices (Leduc 2008, 6). Such a high level of imprecision can usually be seen on roads and highways outside cities which are within areas with lower number of BTSs. Also, a special care must be taken into account while there is a high speed railway track near the road as it could be misinterpreted as an incredibly fast moving vehicle. Similarly, in areas where there is one BTS serving two or more parallel routes, the triangulation method could get complicated and yield a misleading piece of information. That is also why the popularity of the CFCD method has been declining since the early 2010s (Hrubes et al. 2010, 15).

2.5 Vehicle re-identification

The last method – vehicle re-identification – is rather different from the methods presented so far. Both the GFCD and CFDC ways of gathering data use a centralized approach. It means that there is a traffic information centre that collects, processes, maintains and supplies all traffic information by using a mobile network.

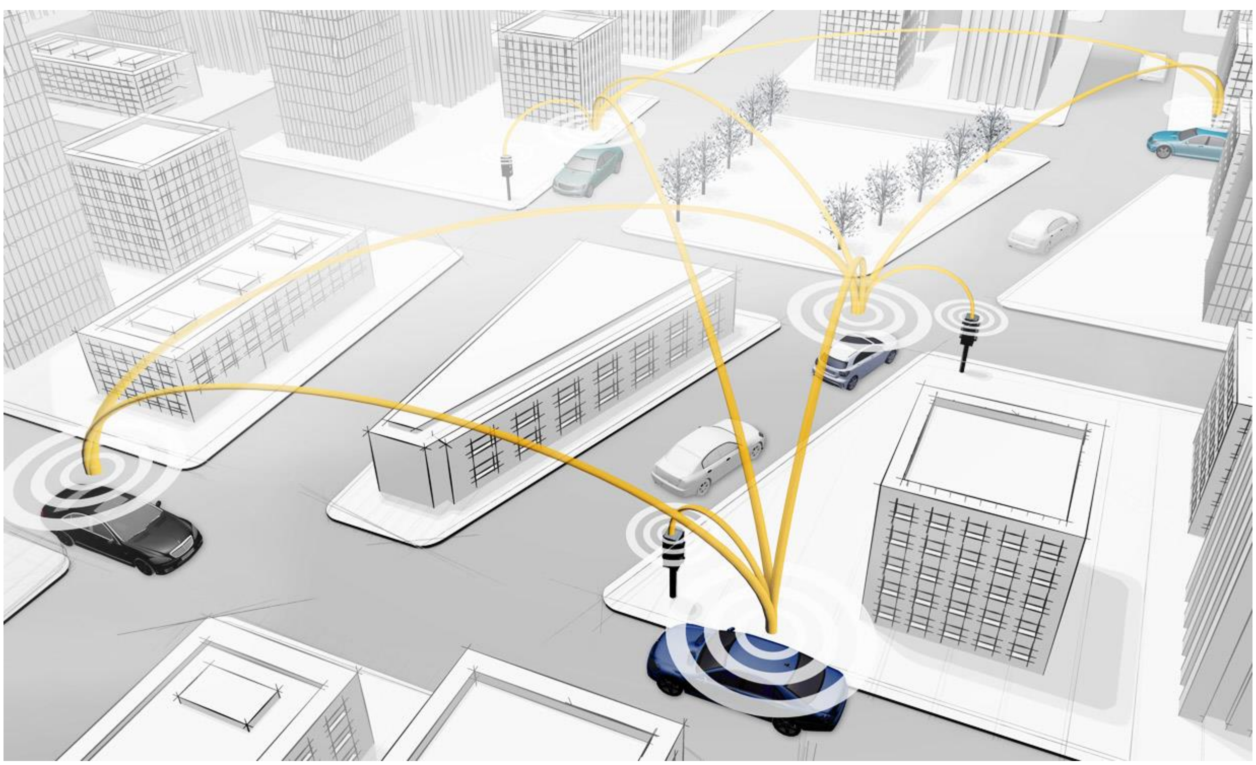


Figure 2.4 “Dialogue” between vehicles and infrastructure on the road (Car-to-x communication 2015)

On the other hand, the vehicle re-identification uses a distributed (decentralized) approach which assumes that vehicles share the traffic information among each other by using a local wireless technology, such as radio-frequency identification (RFID), or between vehicles and sets of detectors or devices mounted along the road (Harding et al. 2014). As the exchange of information includes both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, it is also being referred to as emergent cooperative technologies (systems) in ITS (Sotelo et al. 2012). Both communications methods – V2V and V2I – are depicted in Figure 2.4.

The principle behind this method is based on the fact that a vehicle is equipped with a device using GNSS (similar to the GFCD method, except that it uses microwave technology instead of GSM for communication) to identify its location or the vehicle's location is determined only in a given section of the road which is within the reach of the mounted detector. This way each of the mounted detectors assigns a unique serial number to a device in the vehicle at one location so that it could be detected (re-identified) again at another location further down the road. The uniqueness of the vehicle's device is usually ensured by using the Machine Access Control (MAC) address from detectors utilizing Bluetooth technology or RFID for Electronic Toll Collection (ETC) transponders which can be read at toll collection points (for example toll bridges) but also at non-toll collection points as well (Tarnoff et al. 2009). San Francisco Bay Area's 5-1-1 service, which is a transportation and traffic information website, is a good example of taking advantage of the possibility to obtain traffic flow data from the non-toll collection points. It used electronic toll tags to track vehicles as they traversed Bay Area freeways in order to provide driving times. New York City's Midtown in Motion Programme is another example of monitoring traffic using vehicle re-identification method as it uses RFID readers to track movement of E-ZPass, which is an electronic toll-collection system used in the United States (E-ZPass Group – About Us 2015). However, due to a public controversy over the use of these information it ceased employing this method and commenced using the GFCD technology instead (Hill 2013).

Although the emergent cooperative technologies represent the direction which the transportation industry will likely be heading, it is obvious that it will require a huge investment in device infrastructure. This is one of the main disadvantage of this method as it is necessary to install intelligent devices along the roads, which given the density of road network can be a tremendous effort.

2.6 Extended Floating Car Data

There exists also the so-called second generation of FCD system known as Extended Floating Car Data (XFCD) which contains not only information about a vehicle's position and time, but it offers additional data coming from various vehicle sensors. The bus systems of modern vehicles contain switches, sub-systems and detectors that are either as part of standard or special equipment in the vehicle. As all these data can be obtained in digital form, it is easy to register them without great complexity and use them as sources of traffic and environmental information (Messelodi et al. 2009). Some of the following sources are of particular interest with regard to vehicle data acquisition:

- navigation data
- indicator/hazard, wiper/rain sensor
- driver assistance systems (for example ABS, ASC, and DSC)
- light system (break and fog light)
- brake, friction, crash/airbag, doors
- temperature (external thermometer and the air-conditioning system)
- steering angle, gear, speed, acceleration (Lerner 2005, 7)

The possibility of gaining these types of data goes far beyond what is measurable by using FCD. Figure 2.5 shows the wide range of data and systems used for the XFCD acquisition.

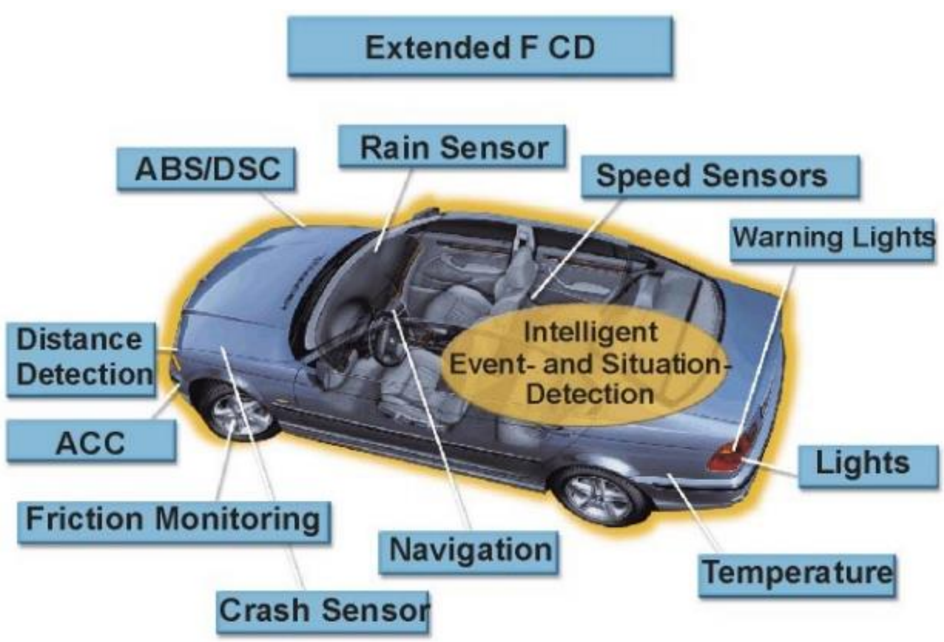


Figure 2.5 Vehicle sensors and signals for XFCD acquisition (Huber et al. 1998, 5)

In terms of data processing, XFCD works in a similar manner to FCD. It uses a suitably programmed algorithm for event identification which is able within fractions of a second to "sense" the current situation of the car, monitor weather conditions, traffic flow, road conditions, and the vehicle's surroundings. The algorithm's execution is carried out on the vehicle's OBU which can infer from the available measured values and indicate event, traffic situation or road condition messages that are passed to a control centre (Future Transportation – BMW Talking Cars of the Future 2003). It can recognize message contents such as:

- Traffic state
- Entering traffic jam
- Exiting traffic jam
- Jam travel time / classification
- Precipitation, aquaplaning
- Slippery roadway, ice
- Impeded visibility, fog (Breitenberger n.d.)

XFCD can further support subsequent services including:

- Traffic information services
- Dynamic route guidance
- Local hazard warning
- Road weather information (Breitenberger n.d.)

A concrete scenario for a possible indication of black ice and the risk of the car skidding may be given on the basis of ABS and DSC activation at a low road speed with the brake pedal pressed down only slightly, in conjunction with a low outside temperature. Vehicles equipped with the XFCD technology which are in close proximity to each other can warn one another wherever appropriate using wireless LAN (WLAN) transmission technology. For example, if a vehicle starts to swerve out of control in a bend due to oil on the road or black ice, it will send a warning message to other road users in the vicinity currently approaching this location. In a similar way a vehicle can send out warning to other vehicles in foggy conditions before they enter the foggy area themselves. Thus, each vehicle – depending on the situation – can act as a transmitter, receiver, or router. In addition, the messages from the vehicles can also be sent to and processed in control centres which transmit the information to other road users, who do not have XFCD installed, as traffic information or warning messages (Future Transportation – BMW

Talking Cars of the Future 2003). Such a system including this interchange of information between vehicles and control centres was undertaken as part of a German research project known as the Mobility and Transport in Intermodal Traffic and Personal Travel Assistant (MOTIV-PTA) which is described in further details in Chapter 3.2.

As it is expected that the use of (X)FCD technology becomes ubiquitous in the near future, it is also equally important for this technology to be economically viable. Therefore, it is essential to efficiently consolidate the large amount of gathered data, design effective algorithms for their processing and control the transmitting activity in order to limit the reported messages to minimum. XFCD uses also mobile communication interfaces to transmit the traffic-based events via SMS. However, it offers the option of backward channel referencing as well. For example, upon entering congestion, a vehicle that has already been informed via Traffic Message Channel (TMC) can verify whether this information is correct and thus does not need to report entering the traffic jam (Breitenberger n.d.). As can be seen in Figure 2.6 this process has a beneficial effect on XFCD's cost efficiency which even increases as the XFCD's penetration rate increases as well.

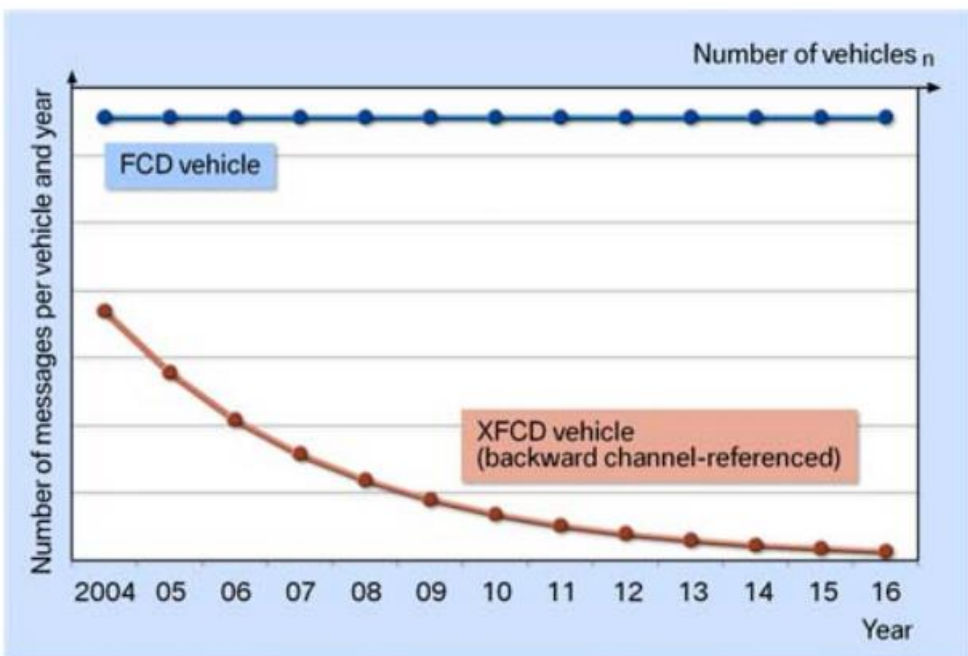


Figure 2.6 Communication costs per XFCD vehicle in comparison with FCD vehicle (Breitenberger n.d.)

A further advantage of the XFCD technology is the fact that it does not require any additional hardware in the vehicle. The event identification algorithms and other data processing procedures can be integrated into the vehicle's existing telematics platform.

2.7 Principle of Floating Car Data Acquisition

The functional principle of the FCD acquisition is depicted in Figure 2.7. The vehicle's OBU records speed values second by second which are then analysed and statistically condensed with the aid of algorithms. Thus, either a route-point or route-section characteristic values can be recognized. The former includes, for example, the vehicle's speed at a given point of the road, whereas the latter offers the mean journey speed and the mean journey time between a route point A and B. In case GATS FCD reference is implemented, mean travel speeds can also be determined. In addition to the mean travel speed value, it also calculates its variation as it provides information on the degree of traffic flow disturbance. All these route-section characteristics are computed using an algorithm in the vehicle's transceiver device (OBU) in accordance with mean travel speed since start of the journey and current travel speed (Huber et al. 1998, 2-4).

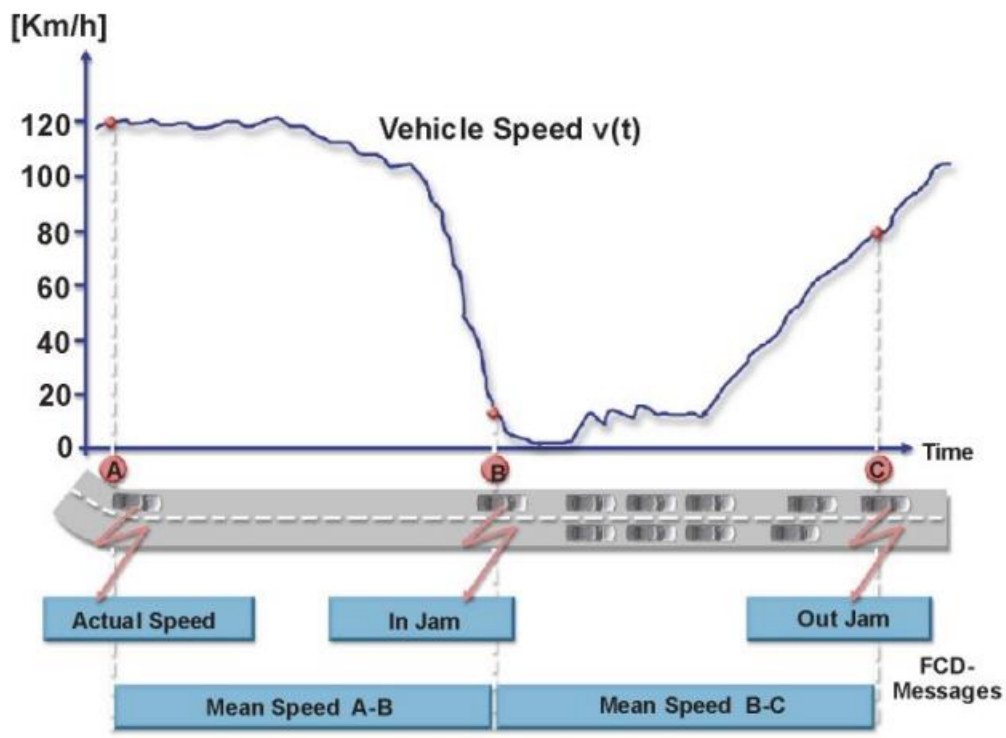


Figure 2.7 Example of a chart depicting a vehicle's speed progress over time (Huber et al. 1998, 3)

The algorithm is able to identify a traffic jam and send a message to the control centre when a special event occurs. The event is associated with the vehicle's position which can be classified either as:

- Approaching the congested stretch

- Present in the congestion zone
- Leaving the congested stretch (Huber et al. 1998, 4)

The event of a vehicle's entry into the congested stretch is identified only if it has been detected by two independent algorithms. Leaving the congestion is also registered as an event in the vehicle's OBU in order to determine the periods of time spent in traffic congestion and the length of the road's congested sections. These data are then compressed and using the cellular network data (GSM/SMS) transmitted from the floating vehicle to the control centre on either a regular basis (periodically) or in case one of the events occurs. The data including the vehicle's position are compressed into so-called "string of pearls" using a further algorithm. In addition to these data strings, each of the FCD message transmitted from the OBU is accompanied by a position stamp which contains the vehicle's last known positions (Huber et al. 1998, 4). This information is useful in the control centre especially for a map matching process which is a technique used as part of Geographic Information Systems (GIS) for associating vehicle's positions with a road network on a digital map.

FCD applications offers the provision of both historical and real-time data which are saved either in the FCD's provider storage or in the users' machines. Characteristics that can be obtained directly from the FCD applications include:

- Historical data (saved on a hard disk and downloaded into the application's interface, for example, once every hour)
    - The journey's origin and destination
    - Travel times
    - Delay (time and place)
    - Chosen route (map matching)
- Real-time data (broadcast at regular intervals, for example, every minute)
    - The vehicle's position
    - The passage through a given point
    - The reach of a given point (Hrubes et al. 2010, 17-18)

These data are then aggregated into systems and applications such as:

- Historical data for traffic statistics and analyses
    - Mean/section speeds on a defined road section
    - Number of vehicles present on a given road section

  - Origin-Destination matrices
- Real-time traffic data
  - Current section speeds
  - Travel times
  - Traffic congestion identification
  - Detour routes (Hrubes et al. 2010, 17-18)

2.8 Floating Car Data Processing

The major difference between the two most utilized FCD technologies – the GFCD and CFCD – is the fact that CFCD-based systems use the GSM standard. This means that the CFCD system is able to collect data from a much larger sample of end users as there is a possibility of monitoring cell phones throughout the whole GSM network in anonymized way. In addition, there is also no need to install any additional equipment in the vehicles. However, the CFCD's localization method is less precise than the GFCD's GPS localization technique, especially in rural areas (Hrubes et al. 2010, 16).

The utilization of the raw FCD data is rather limited as it is necessary to conduct various data analyses and alteration techniques of a large amount of data. In addition, traffic engineers and developers should take into account the specifics and audience of each of the planned traffic applications. For example, a small company with a fleet of 10 vehicles probably would not require an online monitoring tool. Whereas a telematics research project providing data for its whole country or region would like to provide its users with a graphic illustration of the traffic status. In general, there is a 7-step data processing methodology that should be adopted in order to produce ready-to-use outputs for application's final interpretation:

- Data collection
- Validation
- Filtration
- Integration
- Transformation
- Reduction
- Analysis
- Interpretation

The first step, data collection, refers to the collection of raw data from all the traffic detectors including loop detectors, probe vehicles and so forth. It is the simplest one, but takes most of the time as it works with all the data (Hrubes et al. 2010, 16-18; Michek 2013, 3-6).

In order to carry out a detailed analysis of the traffic flow, it is necessary to work with high quality data. However, the raw data consist of several insufficiencies most of the time. Some of the most problematic issues are:

- Damaged, incomplete, missing or redundant information
- Incorrect data caused by an error in measuring devices
- White noise including uncorrelated random variables
- Inhomogeneous domain of variables

Thus it is important to validate the data in advance before using them in consequent calculations. Some of the most known methods for data validation are clustering, regression techniques, and the use of a histogram (Michek 2013, 7-9).

Filtration deals with elimination of either incorrect or extreme values. It refers to the process of defining, detecting and correcting errors in given data samples. In order to minimize the impact of errors, an ideal filtering method presented as a mathematical formula should filter out all unnecessary components without impairing the signal's quality. In general, there are two filtering methods:

- Time domain – a mean is calculated in a sequence of samples of defined length in order to remove the white noise
- Frequency domain – the signal is transformed from a time domain into a frequency domain which filters out irrelevant components such as the high-frequency one

Time domain filtering uses techniques such as simple moving average, exponential moving average, and weighted moving average. Whereas the frequency domain filtering utilizes the Fourier Transform (Michek 2013, 10-16; Wedin 2008, 2-39).

It often happens that two various data sources detect the same information such as consequent loop detectors in a right turn lane, thus one of the data sources can be determined as the major source and the information from the other source can be left out. This integration of traffic data can significantly shorten the processing time (Michek 2013, 17).

Sometimes, the raw data need to be transformed into a more suitable variable for further analysis and calculation. Thus, a defined mathematical function is applied to the input value. For example, transport systems informing drivers about time to destination uses linear function for negative values, but exponential function for positive values as it is better to reach the final destination 5 minutes sooner than get there 5 minutes later. Typical transformation functions include:

- Logarithm, absolute value, square
- Task linearization
- Sampling (discretization)
- Reduction in the number of input variables (Michek 2013, 18-19; Data transformations 2014)

There are around 5 million cars in the Czech Republic (Slozeni vozoveho parku v CR 2013). If all of them were equipped with OBU transmitting traffic data in a 30-second interval, they would generate 14.4 billion records of data per day. Therefore it is essential to reduce the amount of processed data as it can save both memory and transmission capacity and thus lead to an increase in computational performance. A good example of a possible data reduction is an urban junction containing several loop detectors that are connected to the junction's traffic controller. Generally, there are two reduction approaches:

- Quantitative – with the use of clustering methods it is possible to replace a set of detectors by virtual detectors while preserving the information content
- Qualitative – a decrease in the dimension of measured variables such as transformation of intensity and velocity to level of service (Michek 2013, 20-25)

When all of the above actions are taken, the data are prepared for an in-depth analysis from which it is able to draw conclusions. For example, if a control centre detects a decrease in velocity in an unusual place, it might mean emergence of traffic congestion or a road accident. During this type of analysis it is important that a person is present in order to detect any traffic incident. There are, however, also more sophisticated techniques using, for example, neural networks or decision trees that are able to adjust the current traffic situation, including the cycle length of traffic lights, without human intervention (Michek 2013, 26-29).

Finally, as the primary aims of the major telematics projects and systems are to eliminate accidents and increase the availability of traffic information, it is important to provide the main end-users – drivers, pedestrians and cyclists – with the traffic information, if possible, in the form of an online application. Nowadays, it has become a standard of the widely used telematics projects and systems to provide their users with a graphic illustration of the collected traffic data (see Figure 3.2 for an overview of ITS Vienna Region online tool depicting the traffic information including route planning and travel time info) (Michek 2013, 30).

2.9 Comparison between FCD and Stationary Detectors

The (X)FCD technology is a relatively new approach to gathering traffic data, which is why it is still predominantly being used as a complement source to existing conventional stationary technologies. Nowadays, there exists a wide range of the "in situ" sensor and detector technologies for vehicle detection and surveillance which measure traffic data along the roadside. Some of the technologies have been in use for a couple of decades such as inductive loops and have thus become mature and well understood technologies. Table 2.1 shows some of their main advantages and disadvantages.

Table 2.1 Pros and cons with respect to in situ technologies (Leduc 2008, 8)

Conventional Stationary Detectors

Advantages	Disadvantages
Mature and well understood technology	Expensive to install and maintain
Accurate determination of traffic flow and speed	Limited coverage (especially on highways)
No vehicle positioning error due to permanent place of detectors/sensors	Low travel time accuracy
High potential and traffic data quality	Low precision for urban areas (traffic interruptions, etc.)
	Can be affected by bad weather conditions

There are several ways of distinguishing between various types of traffic count technologies. For example, it is quite usual to categorize them according to their physical principal, transportation and technical use, measured and output values, and construction and technical arrangement (Pribyl and Mach 2003, 117). However, in general they are split into two categories: the intrusive and non-intrusive methods. The former consists of a data recorder and a sensor placed either on or in the road. Some of the typical intrusive detectors include:

- Pneumatic road tubes
- Piezoelectric sensors
- Magnetic loops

The non-intrusive technique is based on remote observation and involves following concepts:

- Manual counts
- Passive and active infra-red
- Passive magnetic
- Microwave radar
- Ultrasonic and passive acoustic
- Video image detection (Minge 2010, 1-6)

Table 2.2 shows the different types of variables provided by various detector technologies. A more in-depth analysis of the in situ technologies, including a summary of advantages and disadvantages of each technology, can be found in Traffic Detector Handbook: Third Edition – Volume I.

Table 2.2 Comparison between in situ and (X)FCD technologies (Martin et al. 2003)

Detector type	Count	Speed	Classification	Occupancy	Presence	Travel time	Car and weather info
Inductive loop	X	X[1]	X[2]	X	X	X[5]	
Magnetic	X	X[3]	X[3]	X	X		
Pneumatic road tube	X	X	X				
Active infrared	X	X	X				
Passive infrared	X	X[4]	X	X	X		
Microwave radar Doppler	X	X	X	X			
Microwave radar True Presence	X	X	X	X	X		
Ultrasonic	X				X		
Passive acoustic	X	X	X	X	X		
Video image processing	X	X	X	X	X	X	
FCD		X				X	
XFCD		X				X	X

Notes:

(1) Speed can be measured by dual-loops with a known distance apart, or by algorithms with a single-loop assuming the length of the detection zone and vehicle.
(2) Advanced detector cards can measure classification using „vehicle signature.“
(3) Speed and classification measurement by magnetic detectors requires two units.
(4) Passive infrared detectors with multi-detection-zone capability can measure speed.
(5) Travel time can be measured by dual-loops with a known distance apart.

As can be inferred from Table 2.3 it is obvious that for obtaining high quality traffic data both in situ and (X)FCD technologies have to be utilized. Nonetheless, the fixed technology will still be representing the primary data source. The detectors’ density and placement, however, will be affected by the deployment of (X)FCD which will serve as a complement source (Wang and Wets 2013, 270).

3 Overview of systems using FCD

This chapter focuses on some of the ITS approaches from Europe using data from floating vehicles. It firstly describes ITS Vienna Region, a telematics projects which provided us with FCD data from their fleet of more than 600 taxis. Then it moves to an example of the extended version of probe vehicles – XFCD – that has been employed by BMW's system known as "ConnectedDrive". So that there is also a showcase of an ITS system within the Czech Republic region, a research project called "RODOS" has been described in more detail together with its partnered companies. Finally, the world's leading producer of navigation, mapping and traffic products – TomTom – has been mentioned and introduced as a ground-breaking company providing better traffic services for their users.

3.1 ITS Vienna Region

ITS Vienna Region is a cooperative telematics project founded in 2006 by the three Austria's federal provinces – Vienna, Lower Austria and Burgenland. It as an autonomous transport management project created as part of the framework of public transport association Verkehrsverbund Ost-Region (VOR). The project is financed by contributions mainly from the three federal provinces, contracts and research project and has approximately 18 employees. ITS Vienna Region consists of numerous research projects, but the main one is called AnachB.at which was introduced in summer 2009. AnachB.at is a real-time traffic information service for Vienna, Lower Austria and Burgenland which collects real-time traffic data. These data are being continuously updated with the latest information from construction site, service disruption, accident and service schedule databases, as well as traffic sensors (induction loops, traffic and web cams), FCD and traffic news. The complete overview of data sources can be seen in Figure 3.1 (ITS – ITS Vienna Region 2011-2014).

Most of these data are provided by the AnachB.at's partners including ASFINAG, Wiener Linien, VOR, ÖBB, the police, taxi companies (over 3 500 taxi vehicles) and the Ö3 radio station's traffic news service. The traffic data are then merged into an intermodal data pool which is updated every seven and a half minutes and is used to draw up real-time traffic situation reports which serve as a basis for further calculations of travel time and route planning (ITS VIENNA REGION n.d., 4).

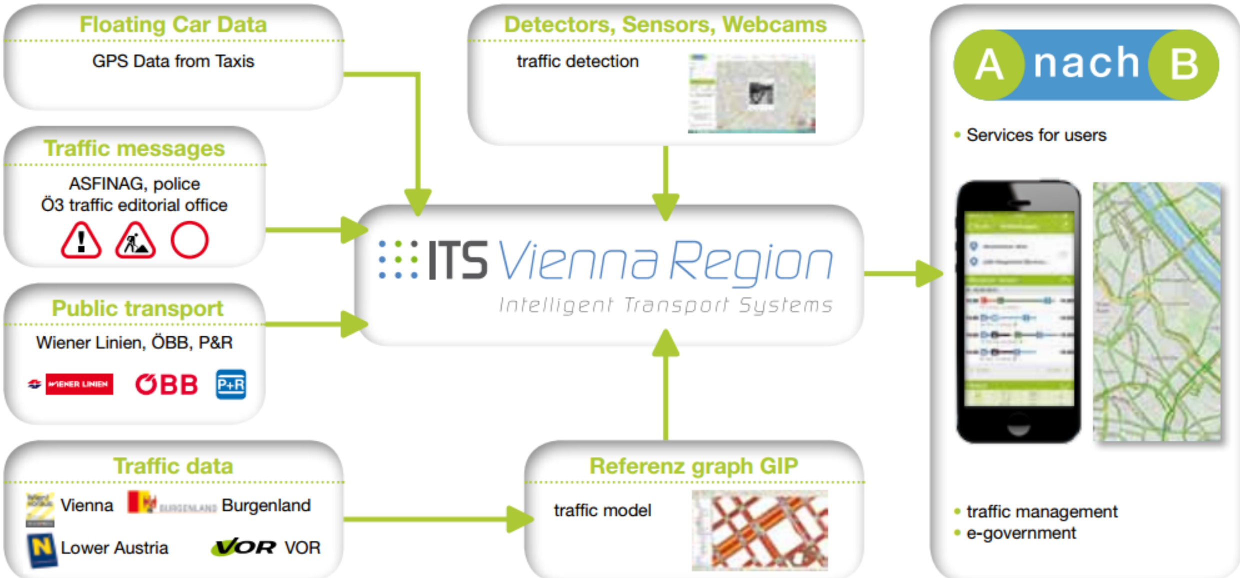


Figure 3.1 Schema depicting the various data sources of AnachB.at (ITS VIENNA REGION n.d., 4)

These calculations and other traffic-related information are displayed through a traffic information service running in the form of a web page AnachB.at (Figure 3.2) which provides its users with the real-time traffic service information. This webpage is accessible also through mobile apps and is free of charge.

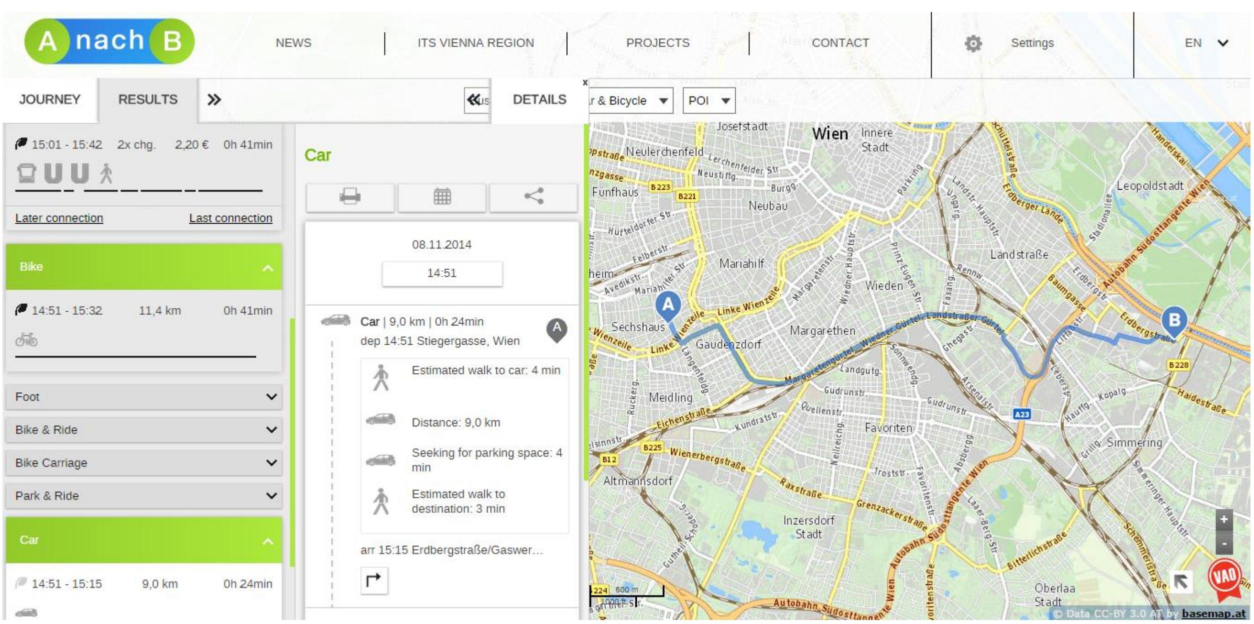


Figure 3.2 Web interface of AnachB.at showing journey details of a random route (AnachB Routenplaner 2015)

On average, AnachB.at generates more than a million of calculations per month and serves as a comprehensive and regularly updated digital transport network. In addition, AnachB.at uses its own digital transport network – Graph Integration Platform (GIP) – to display comprehensive traffic maps for the whole Vienna Region. The GIP method was developed from scratch by ITS Vienna Region and is much more detailed than conventional graphs. Furthermore, due to its high quality images it serves as the reference graph for legally binding administrative procedure, e-Government and other municipalities. There are also several initiatives such as GIP.gv.at underway to extend the GIP coverage to other Austrian regions (ITS VIENNA REGION n.d., 4).

Since 2014 ITS Vienna Region has been relying on Traffic Information Austria (VAO), the Austria's first nationwide traffic information system, and as a result works beyond the Vienna region across the entire nation.

3.2 BMW Group's ConnectedDrive

A German motor-vehicle manufacturer – BMW – was one of the first automotive companies which was part of the German research project MOTIV-PTA that was running from 1996 to 2000. The project's aim was to develop a unified platform integrating travel services, communication networks and end-user devices providing individualized intelligent information and assistance to travellers. Apart from BMW, several other members of the German automotive and IT industrial sector were involved such as Siemens, IBM, DaimlerChrysler, Opel, Bosch, debis and VW. The unified platform was able to produce a multi-agent system which could "wrap a variety of information services, ranging from multimodal route planning, traffic control information, parking space allocation, hotel reservation, ticket booking and purchasing, meeting scheduling, and entertainment" (Ciancarini and Wooldridge 2001, 101).

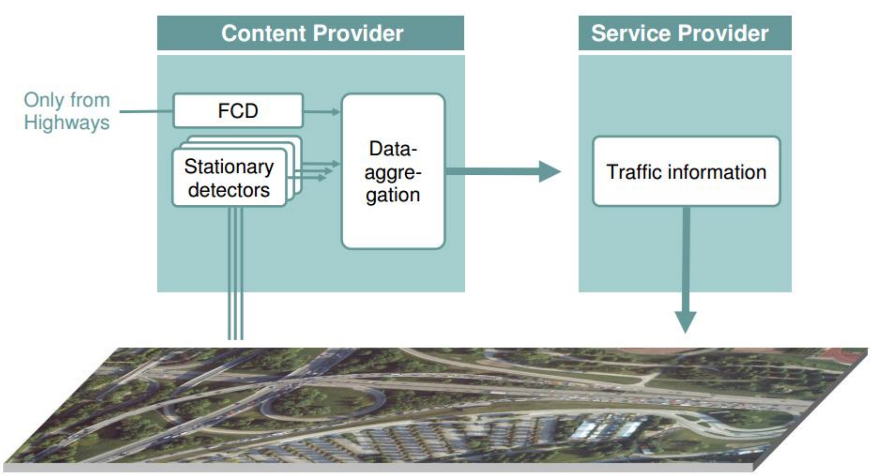


Figure 3.3 BMW's former telematics chain using FCD and stationary detectors data (Lerner 2005, 5)

As part of the MOTIV-PTA project BMW was trying to cover “the entire telematics information chain from mobile traffic data detection to the extraction of information at the control centre and the provision of traffic information in the vehicle” (Huber et al. 1998, 6). However, instead of using the FCD technology they attempted to employ the XFCD one instead. The difference between the telematics chains using FCD and XFCD system is depicted in Figure 3.3 and 3.4.

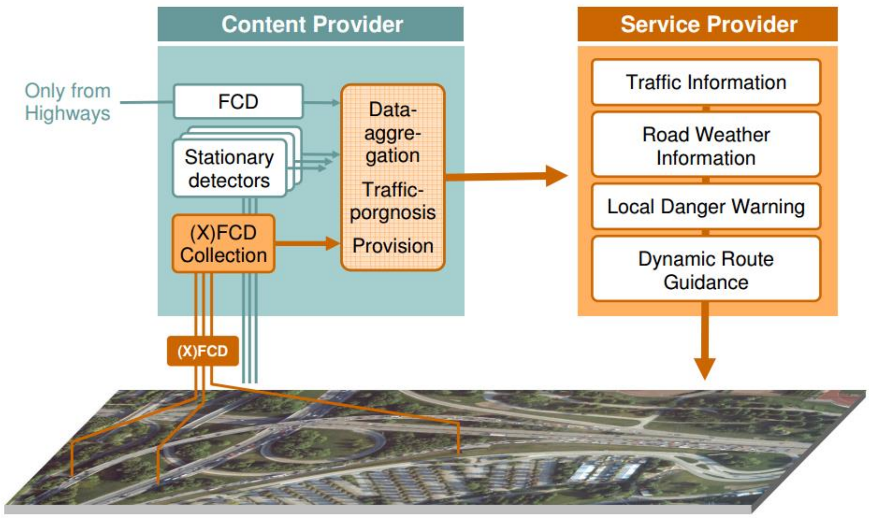


Figure 3.4 BMW’s current telematics chain using additional data sources from XFCD (Lerner 2005, 6)

The MOTIV-PTA’s field trial was divided into three phases. In phase one, the research group chose around a hundred test participants from Munich and its surrounding areas and equipped their vehicles with a commercial FCD transceiver. Consequently, they set up a data control centre dedicated specially for the field test. Apart from the data from FCD, the data control centre was supplied with information from the Traffic Information Centre Bayern (TIC Bavaria). This made it possible to assess the value of mobile traffic data and compare them with the local measurements obtained from the probe vehicles. Finally, an integrated form of information describing the current traffic situation was made available.

Phase 2a put an emphasis on equipping experimental vehicles with XFCD software to collect larger variety of data. One of the experimental vehicles can be seen in Figure 3.5. As the first phase laid out a reliable infrastructure of vehicles covering a vast road network, XFCD software could detect information on compressed traffic, hazard and road conditions which were passed on to the data control centre for further processing. The vehicle PC was equipped with recognition models which were tested within the PC’s two interfaces – telematics terminal and one for the car data bus to obtain raw data from the vehicle’s sensors such switching states of the beam headlights and fog lights, rain sensor, the external thermometer, acceleration, ABS/ASC/DSC, steering angle and so forth. Thus, when a particular event occurred, the terminal encoded and transmitted the message to the data control centre (Huber et al. 1998, 6-8).

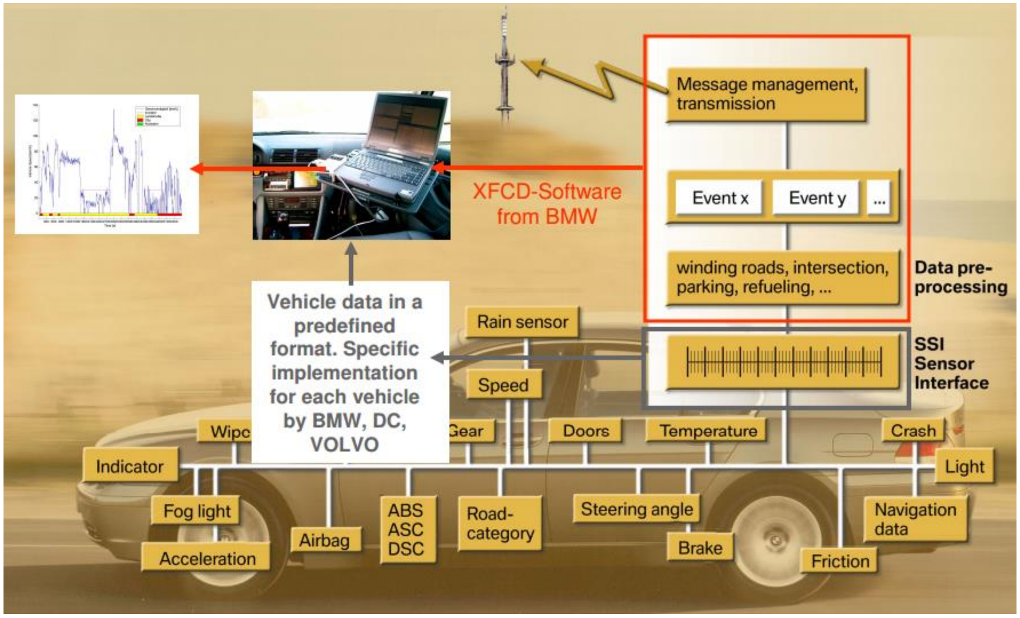


Figure 3.5 BMW's experimental car PC prototype processing XFCD (Lerner 2005, 8)

The whole telematics information chain was closed in Phase 2b, in which the test vehicles were equipped with PC-based telematics platforms specially developed for this data acquisition method. These test vehicles could then receive local hazard messages and passed them on to drivers in the form of a picture displayed in vehicles' OBUs as can be seen in Figure 3.6.

Figure 3.6 A visual warning coming from another vehicle about the end of congestion (Lerner 2005, 12)

BMW recognized the importance of communication and information technologies in the automotive industry whose ever-increasing significance was opening up new perspectives for intelligent mobility. That is why they commenced implementing FCD modules in BMW series-production vehicles since 1999. The MOTIV-PTA trial also allowed them to improve traffic state reconstruction and measure weather conditions, which has led to refining the FCD approach by the XFCD technology. All this resulted in the emergence of ConnectedDrive concept which “networks telematics, online communication and driver assistance systems, in the process enhancing both safety and efficiency in transport” (BMW Group 2002). Nowadays, BMW’s 7-series can use an internet-based service which provides access to a mobile internet portal supplying the driver with information and service tailored to his or her specific needs.

3.3 RODOS

The RODOS Transport Systems Development Centre is currently the largest transport research project with focus on road transport monitoring and control as well as its funding in the Czech Republic. The RODOS centre is composed of three largest technical universities, a public research institution and six commercial companies which are among the first tier businesses in industries such as IT, software, data collection and practical implementation of ITS on the Czech Market.

The project is funded by the Technology Agency of the Czech Republic as part of its “Competence centres” programme for the support of long term cooperation between private and public sector. Additionally, it is co-funded by the centre’s partners as well (RODOS – About the Centre 2013).

There are two main strategic objectives that the RODOS project aims to accomplish – “create complex information superstructure for road transport by means of new transport informatics tools and to integrate it into existing telematics systems” (RODOS – About the Centre 2013). The Czech Republic is perceived to be the heart of Europe and is thus predestined to play a role of a transit country. This is why the RODOS centre focuses also on the Czech Republic’s neighbouring countries.

The core of the RODOS project is the Dynamic Mobility Model (DMM) of the Czech Republic which integrates “dynamic models of passenger, vehicle and goods mobility and related information in the entire area of the Czech Republic” (source). In the next six years the DMM plans to address six fundamental and mutually complement transport research thematic groups.

One of the DMM's specifics is its broad scope of use as it wants its model and operation incorporate also into other network industries, processes of the state and public administration as well as during future implementation of the so-called Smart Cities concepts (RODOS – Strategic objective of research and development 2013).

The RODOS centre offers following traffic information:

- Queueing on roads
- Travel times
- Traffic continuity
- Traffic in Prague, Brno and Ostrava
- Road closure analysis
- Radar image (RODOS – Products and outputs 2013)

One of the RODOS' outputs is the Czech Republic's highway overview which can be seen in Figure 3.7.

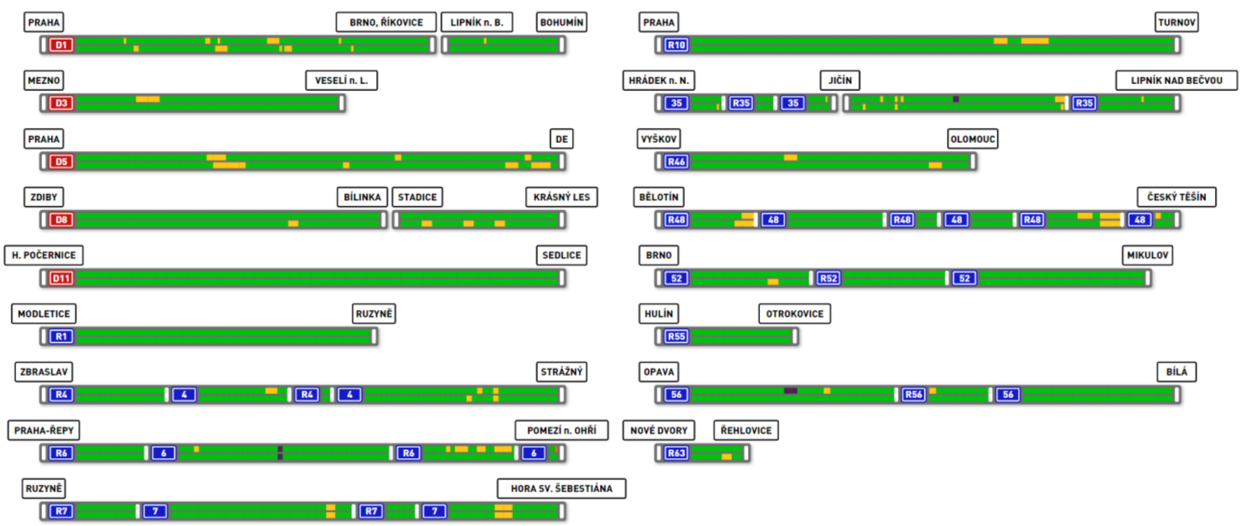


Figure 3.7 Highway Overview of the Czech Republic (RODOS – Celkovy prehled 2015)

Each of the displayed highways shown in Figure 3.7 can be further examined and information on intensity, restriction, current speed, level of service, travel time, free flow speed and delay can be obtained as depicted in Figure 3.8.

The RODOS application gathers data from stationary detectors, 220 tollgates covering 1,170 km of toll roads, and also from an integrated fleet of around 150,000 FCD vehicles within the Czech Republic provided by the project's partners such as O2 Czech Republic and Secar Bohemia.

The FCD vehicles provide approximately 40,000 data samples including position and speed per minute. This gives a traffic flow's penetration rate of 5 % which means that every twentieth vehicle is being monitored (Hajek 2013, 9).

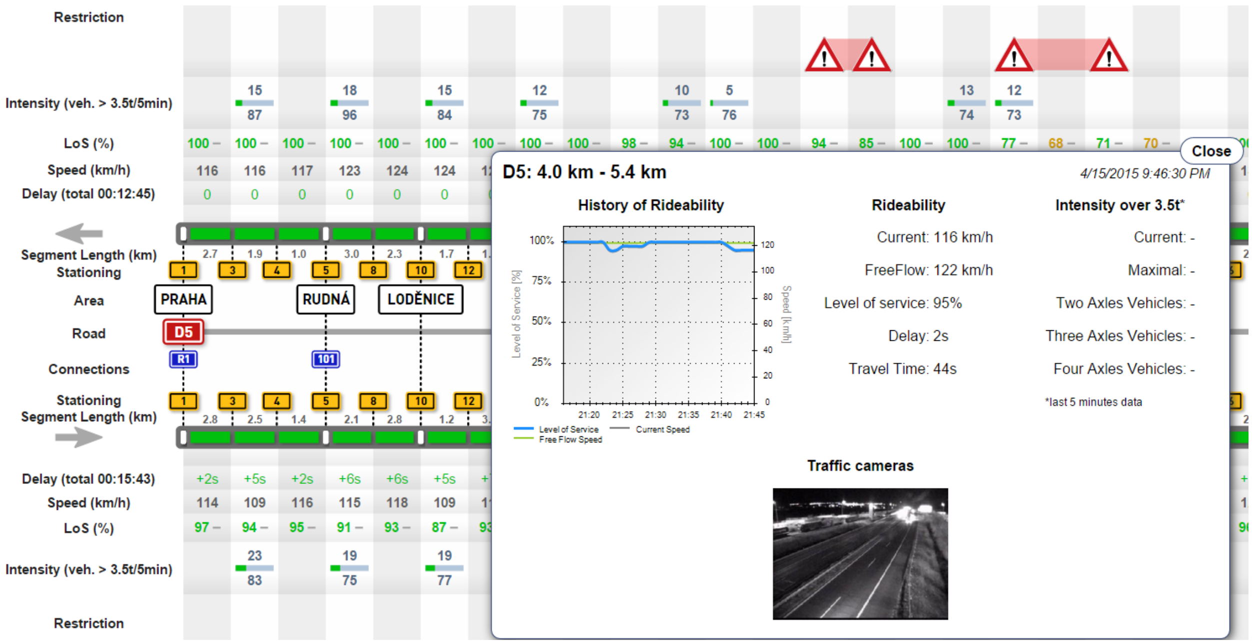


Figure 3.8 Detailed overview of the D1 highway showing traffic information (RODOS – Dalnice D1 2015)

In addition, O2 Czech Republic provides RODOS with residual signalling GSM data of all of their customers which is approximately 5 million data samples. Thus, it is possible to anonymously monitor the distribution and mobility of a huge part of population across time and space. This represents a large enough representative sample which could be used for creation of origin-destination matrices and consequently help with nationwide traffic surveys in the near future (Hajek 2013, 11).

3.4 TomTom

The Netherlands conducted a transport survey in 2006 and found out that the traffic data available within its region did not meet the drivers' criteria in terms of both content quality and availability (Hrubes et al. 2010, 25). That is why TomTom, the world's leading producer of navigation, mapping and traffic products, embarked on embedding better services into their navigation systems for their users. In 2008, TomTom thus announced the launch of the High Definition (HD) Traffic Receiver in the Netherlands which was able to deliver advanced traffic information through the FCD methodology. The HD Traffic Receiver had a built-in Subscriber

Identity Module (SIM) card for GPRS connectivity and could be plugged into the vehicle's cigarette lighter. Some of the added benefits allowed their users to:

- Easily plan the smartest route to their destination due to highly accurate measurements of traffic jams and delays (see Figure 3.9)
- Receive more traffic updates so that they were better informed about traffic situation
- Receive more accurate travel and arrival times (TomTom 2008)

Also, the coverage of roads were extended and therefore offering more alternative route options. However, throughout the years the number of TomTom users has significantly increased as well as the coverage has widened (TomTom – Key facts & dates 2015).

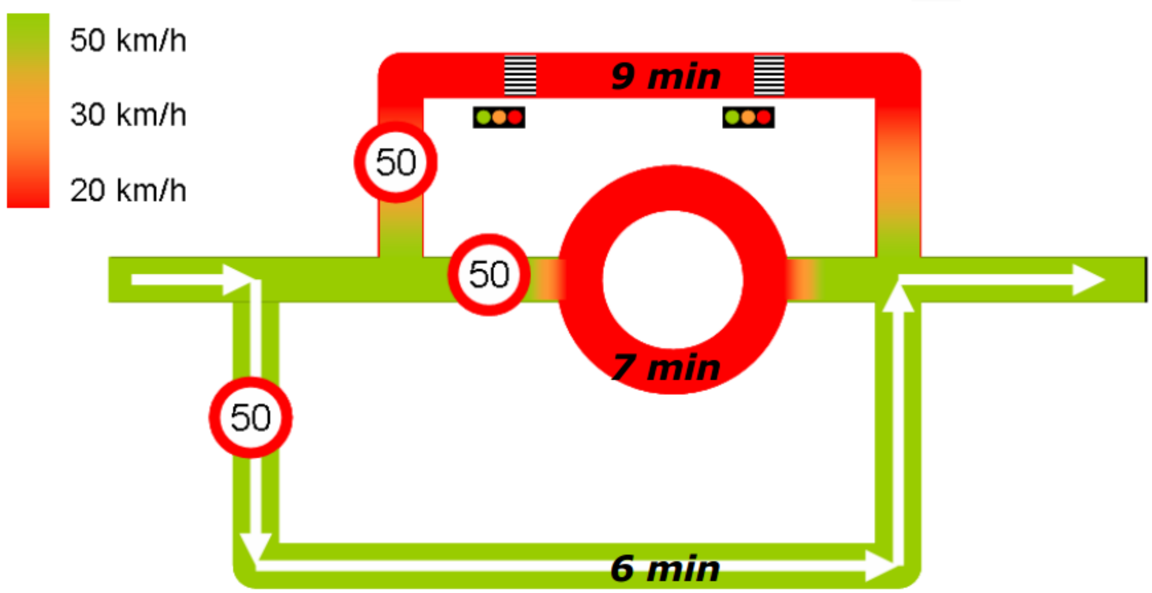


Figure 3.9 TomTom route navigation system using community feedback for better routing (Weijer 2013, 10)

Nowadays, TomTom offers several navigation products and in order to generate precise real-time traffic information and achieve above-average quality and road coverage, it uses a wide range of GPS probe data from fleets, Portable Navigation Devices (PNDs), smartphones, and so forth as can be seen in Figure 3.10 (Annual Report 2014: TomTom Traffic). TomTom states it combines information from major traffic authorities with crowd-sourced real-time data from over 350 million drivers worldwide In addition, there are millions of government loops and thousands of journalists collecting incident data as well (Chen-Pyle 2013, 9-13).

Figure 3.10 TomTom has a broad and significant number of data sources (Chen-Pyle 2013, 13)

Along their real-time traffic products they also store all of the gathered information in a historical database that continues to be a standard source of data in the government sector. Local authorities use this information to improve traffic flow on congested road networks. Since 2007, TomTom has collected over 12 trillion of probe measurements which are being used for congestion level benchmarking and long-term trend analysis of traffic behaviour. The sheer amount of traffic data allows TomTom to create its own Traffic Index, a global benchmark that is published annually and compares congestion levels and their impacts on over 220 cities worldwide (Annual Report 2014: TomTom Traffic).

In terms of the FCD processing TomTom Traffic service provides updates every 30 seconds. Whereas requests for the end-users' navigation devices are typically provided in a 2 minute interval. TomTom's data fusion system combines data from all the available sources and utilizes 4 processing methods – raw data collection, data alignment, data assessment, and data combination – as can be seen in Figure 3.11. For distribution purposes it uses standardised delivery protocols such as TMC, Datex-2 and Transport Protocol Experts Group (TPEG) so that it can be easily used by third-party navigation software as well (Annual Report 2014: TomTom Traffic).

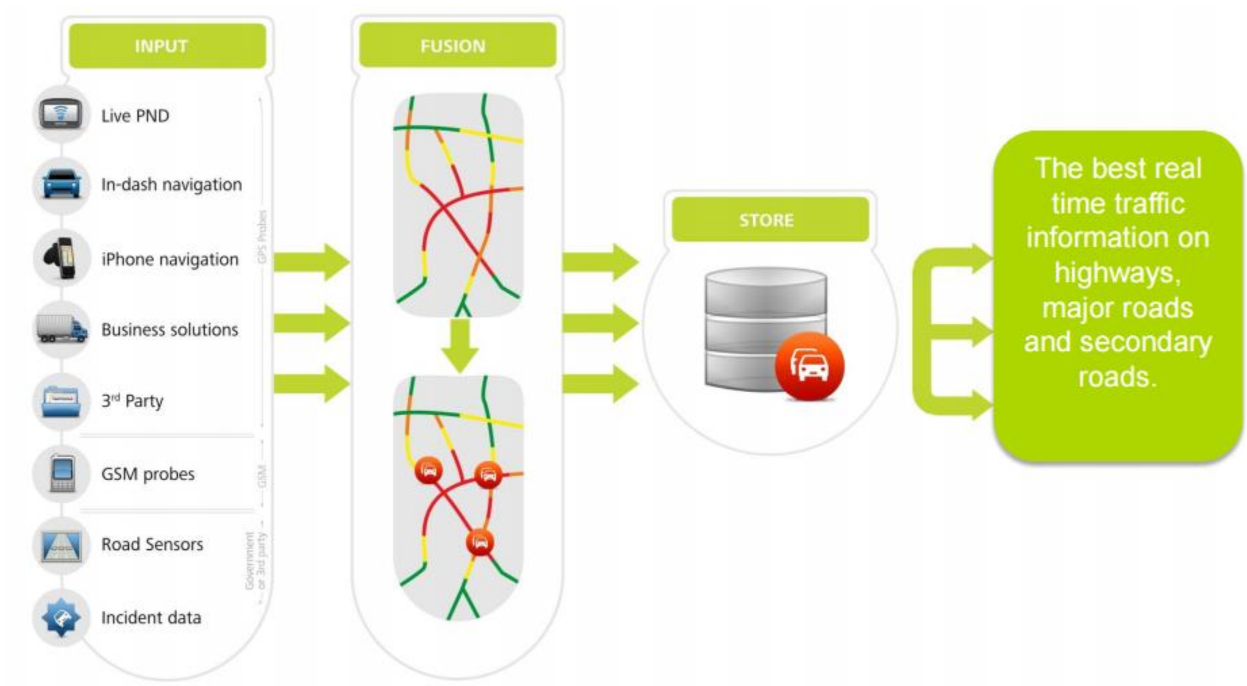


Figure 3.11 TomTom data fusion system processing data from all the sources available (Chen-Pyle 2013, 14)

In 2014 TomTom was the first company to take into account real-time weather information when calculating route and arrival times. Their system is now able to warn drivers about upcoming delays caused by adverse weather conditions such as rain or snow (Annual Report 2014: TomTom Traffic).

TomTom is gradually growing and expanding their business worldwide. Their historic and real-time traffic information is at the moment available in over 40 countries including China, Malaysia, Turkey and the United Arab Emirates. It is therefore slowly becoming a truly global provider of real-time traffic data (Annual Report 2014: TomTom Traffic).

4 Analysis of Floating Car Data

4.1 Data source

The ITS Vienna Region, a cooperative telematics project in Austria described in more detail in Chapter 3.1, provided us with FCD from a fleet of around 600 taxis mainly from Vienna during a week beginning March 24, 2014 and ending on March 31, 2014. However, as the ITS Vienna Region operates across the whole Austria, data from taxis in Linz, Salzburg and several other places were included as part of the sample as well. The taxi-FCD system which supplies the ITS Vienna Region project with traffic data in terms of travel times for a single vehicle is run by one of the project's partners – the Institute of Transportation Systems – which is part of the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt – DLR) based in Berlin. DLR uses taxis as mobile data sources for the automated collection of FCD. The taxis must be equipped with communication devices enabling area-wide collection and transmission of traffic data (Ehmke 2012, 64). The typical architecture of the taxi-FCD system is shown in Figure 4.1.

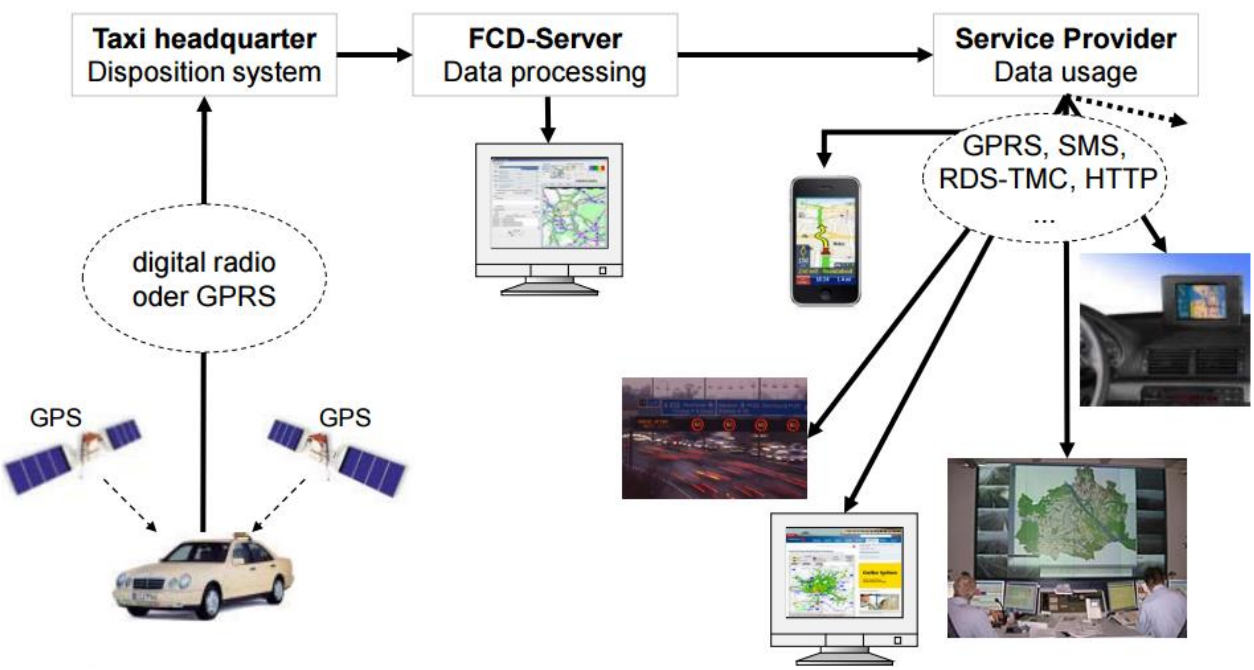


Figure 4.1 Taxi-FCD system architecture (Brockfeld et al. 2010, 2)

The taxi office collects the GPS locations and then send them to the traffic information centre, where vehicles' individual trajectories are derived from their locations. Consequently, a map matching algorithm is used for matching their trajectories to a digital roadmap and assigning travel times. All the traffic data are anonymized and become worthless for the taxi dispatch after the end of the trip. Also, once the data are parsed and transformed into a proprietary and xml-based FCD format (see Appendix A), they are stored in an internal database. DLR collects and analyzes taxi-FCD data in a number of cities worldwide as can be seen in Figure 4.2. An example of a non-European city where the DLR city-router software for FCD collection was established is one of China's oldest city – Ningbo (Ehmke 2012, 65-67).

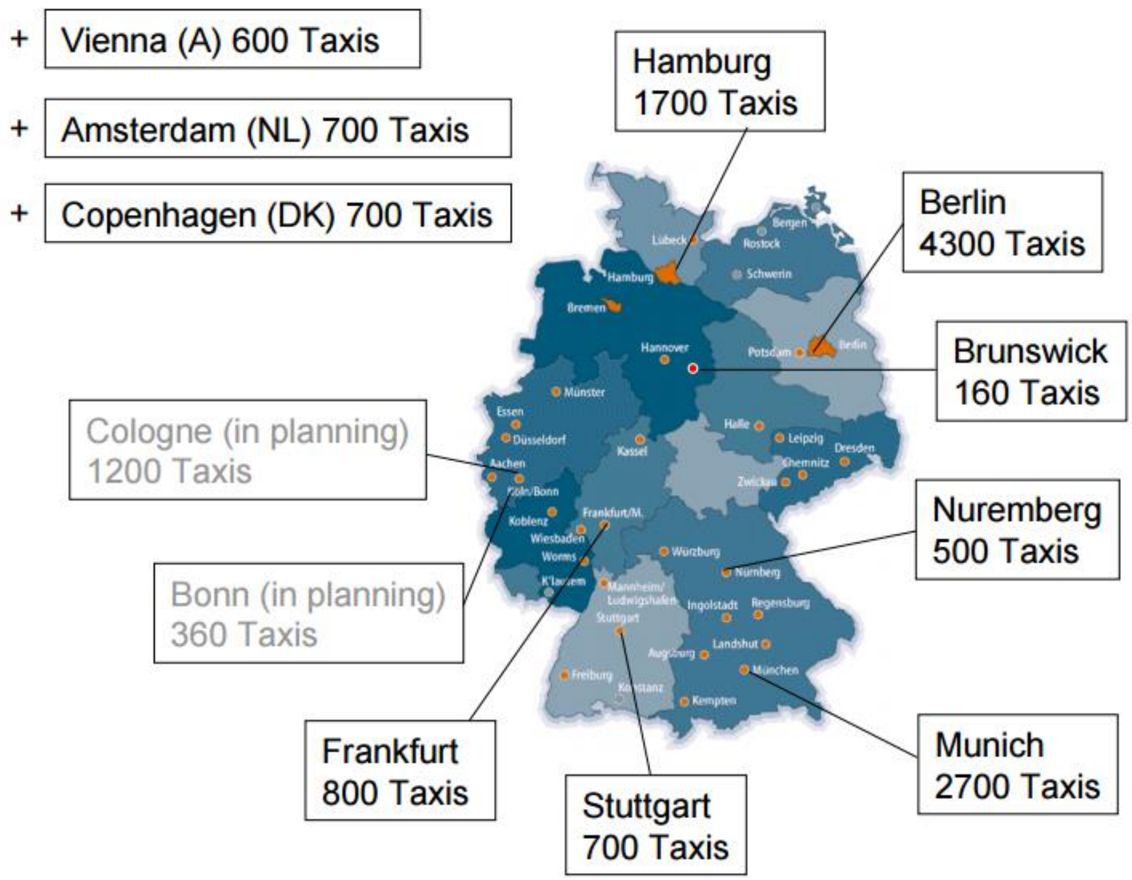


Figure 4.2 FCD database of the German Aerospace Centre (Brockfeld et al. 2010, 3)

4.2 FCD sample description

As it has been mentioned, the FCD records of Vienna taxis are stored in an extensible markup language (XML) format which is further being processed and used by other applications for complex traffic computing models. Each of the FCD samples, which is generated by an individual taxi, is transmitted approximately every minute to the taxi dispatch centre. For example, for Berlin it is every 30 seconds. DLR then connects every five minutes using File Transfer Protocol (FTP) to the taxi companies to get the data packages and process them further. A detailed overview of the sample rate of the provided data set for Vienna is described in

Chapter 4.3.3. The whole XML sample can be seen in Appendix A and its individual pieces, depicted in Figure 4.3 and 4.4, are described in more detail below.


```
<FAHRT>
	<ID>155182586</ID>
	<STATUS>66</STATUS>
	<ZEITPUNKT>24.03.2014 00:00:00</ZEITPUNKT>
	<SEKUNDEN>83</SEKUNDEN>
	<SOLLZEIT>135</SOLLZEIT>
	<METER>547</METER>
	<KMH>23</KMH>
	<WINKEL>83</WINKEL>
	<RICHTUNG>O</RICHTUNG>
	<ABFAHRT>
		<X>16.3649495443</X>
		<Y>48.1990641276</Y>
		<ZBZ>10669</ZBZ>
		<ZBZ_X>16.3650007769</ZBZ_X>
		<ZBZ_Y>48.1990731914</ZBZ_Y>
		<SEKTOR>604</SEKTOR>
		<GEBIET>4</GEBIET>
		<SATELLITEN>5</SATELLITEN>
		<PDOP>1</PDOP>
		<ABFRAGEDAUER>1</ABFRAGEDAUER>
	</ABFAHRT>
```


Figure 4.3 The first part of DLR FCD sample (German tag names)

The sample's main root element is called “FAHRT” which represents a taxi's individual trip. As part of the trip each vehicle is assigned its own unique identifier in the form of an ID number. Thus, it is possible to track each vehicle's route. Furthermore, there is a status number, which is a distinctive feature of the taxi-FCD format as it is connected with the vehicle's occupancy. The ITS Vienna Region distinguishes following statuses:

- 65 – registered
- 66 – occupied with customer
- 70 – free
- 75 – drives to customer
- 79 – occupied with follow-up order
- 83 – at the home place
- 87 – waits at the customer
- 90 – occupied with destination goal
- 107 – drives to a customer, knows destination
- 119 – waits by customer, knows destination

However, the traffic engineers at ITS Vienna Region work only with statuses 66, 75, 79, 90, and 107 as it significantly reduces the processing time and provides more useful information in terms of describing the actual traffic conditions.

So that each of the samples could be linked with a given time frame, the “ZEITPUNKT” node represents a time stamp of sample acquisition. Then, there is a number in seconds showing the sample rate – how much time has passed since the last record was obtained. “SOLLZEIT” node gives a notion of how much time is left to the destination. Similarly, the node “METER” tells how many meters have been driven from the last position. The “KMH” element inform about the vehicle’s actual velocity. In addition, the sample contains information about an azimuth, which is an angular measurement in a spherical coordinate system, and the direction of travel consisting of either N (north), O (east), S (south), W (west), or any of these combinations.

The other part is composed of information on the vehicle’s current position in the form of GPS coordinates – longitude (node “X”) and latitude (node “Y”). Moreover, the “ZBZ” nodes encompasses corrective measures for the GPS values. “SEKTOR” and “GEBIET” divide a given area into sectors and regions which, however, do not correspond with Vienna districts as the software is used by vehicles across whole Austria. Then, a number of visible satellites at the time of data acquisition is given in the “SATELLITEN” node. PDOP stands for position dilution of precision and specifies the additional multiplicative effect of navigation satellite geometry on positional measurement precision. There exist, in addition to PDOP, other separate DOP measurements such as horizontal (HDOP), vertical (VDOP), and time (TDOP) (Langley 1999). The final element gives information about the query time of the GPS-based device in the vehicle.

Figure 4.4 depicts the other part of the FCD sample which commences with trip’s goal. It contains precisely the same node elements as in the vehicle’s source position. Again, it provides information about location, correction, area, visible satellites, PDOP, and query time. Furthermore, there is a section “FAHRZIEL”, meaning final destination, which consists of longitude and latitude coordinates, corrective factor, sector, and region. However, the section only contains information when the cab driver entered the final destination in the GPS device. This happens in rare cases as the cab drivers usually know the area very well and thus do not need to follow the directions given by the satellite navigation.

Finally, there is information about the route direction “FAHRTRICHTUNG” including data on speed, azimuth and travel direction including again one of the combinations of N (north), O (east), S (south), and W (west).

```
        <ZIEL>
              <X>16.3721842448</X>
              <Y>48.2</Y>
              <ZBZ>63658</ZBZ>
              <ZBZ_X>16.3728542897</ZBZ_X>
              <ZBZ_Y>48.1998134301</ZBZ_Y>
              <SEKTOR>129</SEKTOR>
              <GEBIET>1</GEBIET>
              <SATELLITEN>6</SATELLITEN>
              <PDOP>1</PDOP>
              <ABFRAGEDAUER>3</ABFRAGEDAUER>
        </ZIEL>
        <FAHRZIEL>
              <X>0</X>
              <Y>0</Y>
              <ZBZ>0</ZBZ>
              <SEKTOR>0</SEKTOR>
              <GEBIET>0</GEBIET>
        </FAHRZIEL>
        <FAHRTRICHTUNG>
              <KMH>44</KMH>
              <WINKEL>90</WINKEL>
              <RICHTUNG>O</RICHTUNG>
        </FAHRTRICHTUNG>
  </FAHRT>
```


Figure 4.4 The second part of DLR FCD sample (German tag names)

4.3 FCD pre-processing

In the pre-processing step, incomplete or apparently erroneous data records were identified and subsequently either removed completely or validated and replaced with a more suitable value. The data were revised (data cleaning) and investigated in terms of range (speed limits and GPS coordinates), completeness, and denomination.

In order to analyse the enormous data set and clearly identify some of the most problematic spots in terms of traffic congestion and bottlenecks within the area of Vienna, it was necessary to choose appropriate software for their processing. As all of the 7 files were large in size – each of the file representing data set for the whole given day had on average around 840 MB – it was impossible to use Microsoft Excel for it took too much time to load and process as well. In addition, some of the files, such as Friday's file had over a million of records which was beyond the size of an Excel worksheet. Therefore, MATLAB (Matrix Laboratory) software, a multi-paradigm numerical computing environment, was chosen for the data processing. The complete overview of all the files in terms of number of samples and file size is summarized in Table 4.1. The table also illustrates the sheer size of data that has been collected, processed and analysed as part of this paper.

Table 4.1 Overview of provided FCD from taxis in Austria during a week in March 2014

Date	Day	Number of samples	File size (MB)
24.3.2014	Monday	866 329	743
26.3.2014	Wednesday	981 938	843
27.3.2014	Thursday	1 039 158	892
28.3.2014	Friday	1 105 809	949
29.3.2014	Saturday	1 104 877	949
30.3.2014	Sunday	892 962	767
31.3.2014	Monday	847 928	728
	Total	6 839 001	5 871

As the main aim of the analysis of historical FCD was to show how it could serve as a decision-support tool for traffic engineers in case of identifying traffic congestion and similar bottlenecks, data mining approach as described in Chapter 2.8 was adopted.

4.3.1 Data Transformation

Before the data processing could begin, it was firstly necessary to extract the data from the XML format. Even though MATLAB is capable of working with the XML structure, it took an enormous amount of time to process such a huge quantity of data that we had available. Thus, a MATLAB script, enclosed in Appendix B, was written in order to transform some of the node elements into MATLAB variables. As it was not necessary to work with all the characteristics available throughout the analysis, the script transformed only the following ones:

- Vehicle's ID (ID node)
- Occupancy status (STATUS)
- Time stamp (ZEITPUNKT)
- Sample rate (SEKUNDEN)
- Time to destination (SOLLZEIT)
- Distance in meters from last sample (METER)
- Velocity (KMH)
- Longitude (X)
- Latitude (Y)
- Sector (SEKTOR)
- Region (GEBIET)
- Number of visible satellites (SATELLITEN)
- Position dilution of precision (PDOP)

In addition, the script checked whether each of the records during the given day was complete, as it was discovered throughout the analysis that some of the records were missing information, predominantly about the number of visible satellites, PDOP, and query time. A complete summary of both complete and incomplete records is given in Table 4.2. As it can be seen, the number of incomplete lines is relatively small and corresponds with the statistical deviation of the given sample. The total number of incomplete samples for the whole data set was circa 150 000.

Table 4.2 Overview of samples with missing information

Date	Day	Number of samples	Number of complete samples	Incomplete samples		
				Absolute	Relative (%)	
24.3.2014	Monday	866 329	846 905	19 424		2,24
26.3.2014	Wednesday	981 938	959 746	22 192		2,26
27.3.2014	Thursday	1 039 158	1 016 015	23 143		2,23
28.3.2014	Friday	1 105 809	1 080 572	25 237		2,28
29.3.2014	Saturday	1 104 877	1 082 639	22 238		2,01
30.3.2014	Sunday	892 962	874 412	18 550		2,08
31.3.2014	Monday	847 928	828 795	19 133		2,26
	Total	6 839 001	6 689 084	149 917	Average	2,19

It took around 21 hours to complete the whole transition for all 7 files from the XML structure to MATLAB variables. For example, the script execution time for the Friday's file took around 3 and a half hours. By contrast, once MATLAB accessed the information through its defined variables, the execution time of a script that looped through the whole data set took from 1 to 60 seconds, depending on the complexity of operations that were performed inside the loop.

4.3.2 GPS Error Analysis and Elimination

As the data were readily available after the transformation, the GPS coordinates were analysed in further detail. Ideally, FCD from taxis should be continuous in terms of time intervals between each pair of continuous GPS points and the coordinates of each GPS point should be accurate compared with the actual position of the taxi. Nonetheless, there exist GPS errors caused by either blockage of the GPS signal or hardware/software malfunctions and bugs during the data collection process (Liu and Ban 2013). The correctness of GPS coordinates is of significant importance especially during a map matching process which matches the vehicles' positions with road segments in the digital map using complex algorithms.

The GPS points were first filtered according to the boundaries of the selected study area in Vienna as depicted in Figure 4.5. The area formed a rectangle whose latitude and longitude coordinates were 48.292079905275806 and 16.56538598632801 for the north-east corner, and

48.09216946074534 and 16.195977050781266 for the west-south corner. It was necessary to perform this task as the data set contained samples from other places in Austria such as Linz and Salzburg.

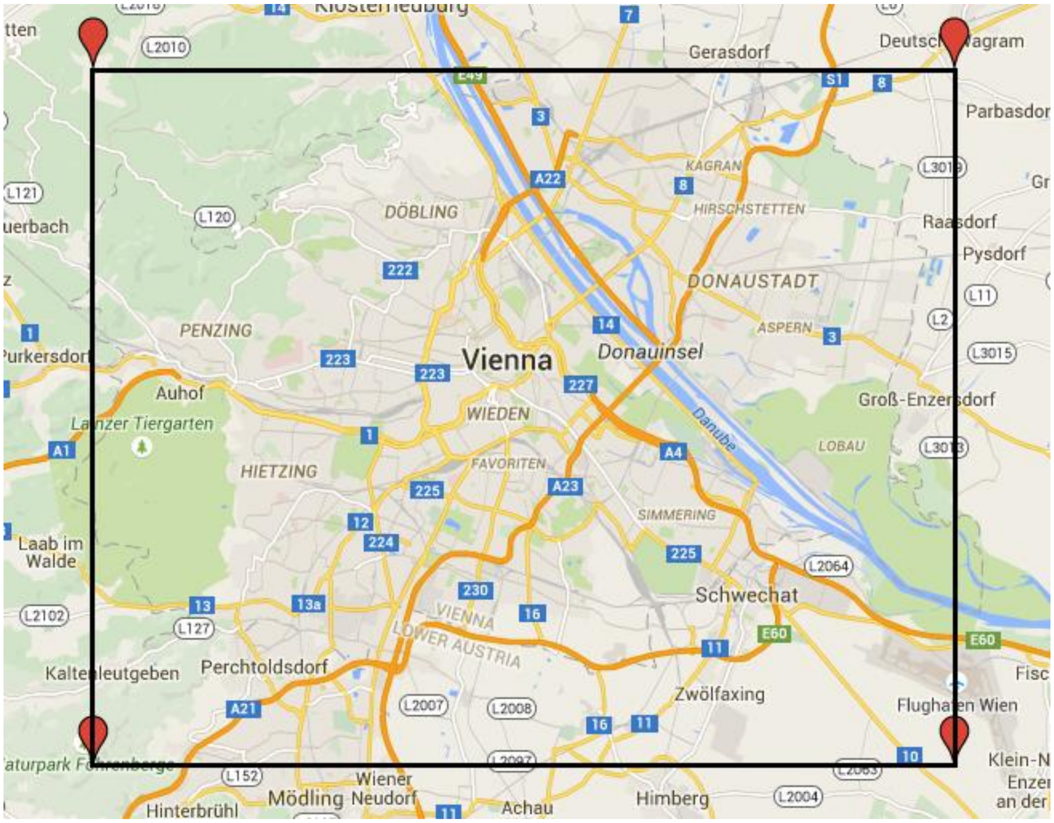


Figure 4.5 Bounding box of the study area in Vienna (Google 2015)

In total, there were 642,063 (9.6 % of all) of such points that were identified as outliers. The reason why there were so many samples deviating far away from the bounding box was because of the fact that the taxi-FCD fleets in Linz, Salzburg and other places were quite large as well. A detailed overview of the outlying GPS points per given day is provided in Table 4.3.

Table 4.3 Overview of identified outliers during the given week

Date	Day	Number of samples	Outside Vienna			Inside Vienna
			Absolute	Relative (%)		
24.3.2014	Monday	846 905	73 944		8,73	772 961
26.3.2014	Wednesday	959 746	84 286		8,78	875 460
27.3.2014	Thursday	1 016 015	87 842		8,65	928 173
28.3.2014	Friday	1 080 572	107 303		9,93	973 269
29.3.2014	Saturday	1 082 639	116 537		10,76	966 102
30.3.2014	Sunday	874 412	98 099		11,22	776 313
31.3.2014	Monday	828 795	74 052		8,93	754 743
	Total	6 689 084	642 063	Average	9,57	6 047 021

4.3.3 Sample and Distance Rate

The sampling interval stated by ITS Vienna Region for the taxi-FCD system in Vienna is one minute. Table 4.4 provides a detailed overview of the sampling rate which has been calculated for each of the given day in our data set. It can be seen that it is highly accurate and corresponds with the stated value.

Table 4.4 Time interval and distance between previous and current sample per given day

Date	Day	Sample rate (seconds)	Distance rate (meters)
24.3.2014	Monday	61.98	273.82
26.3.2014	Wednesday	61.01	277.37
27.3.2014	Thursday	60.70	279.73
28.3.2014	Friday	59.78	277.21
29.3.2014	Saturday	53.57	278.13
30.3.2014	Sunday	51.43	294.33
31.3.2014	Monday	61.41	279.06
	Average	58.55	279.95

If the time interval between two consecutive GPS points is greater than 60 seconds, then it could be due to either the loss or delay of a GPS signal, or the driver turning off its GPS device. In the case of too long time interval (for example greater than a set time threshold) between two consecutive GPS points, it is very hard and in most scenarios almost impossible to track the movement of a given taxicab. Even if we were able to at least identify the route a given vehicle took, such as while driving on a section of a highway from which there were no exits, it would not provide us with a lot of information about the current traffic status. Therefore the trajectory should be split into different parts at such GPS points. In order to decide on the values for such time thresholds which would eliminate the long intervals, we looked at the time intervals and travelled distances between all pairs of two consecutive GPS points in the trajectories of taxicabs on Monday, 24 March 2014. It was found that the percentages of the time intervals that were less than 60, 120, 180, 240, and 300 seconds (1, 2, 3, 4, and 5 minutes) were 71.67 %, 96.16 %, 97.65 %, 98.05 %, and 98.29 % respectively. Therefore, we could set a time threshold of 240 seconds (4 minutes) without losing any valuable data and deteriorating the sample as the threshold indicated a relatively small error representing 1.95 % of the total samples. We also identified a maximum value of 490,703 seconds (approximately 136 hours) which was obviously an error. The distribution of the time intervals of all pairs of consecutive GPS points can be seen in Figure 4.6.

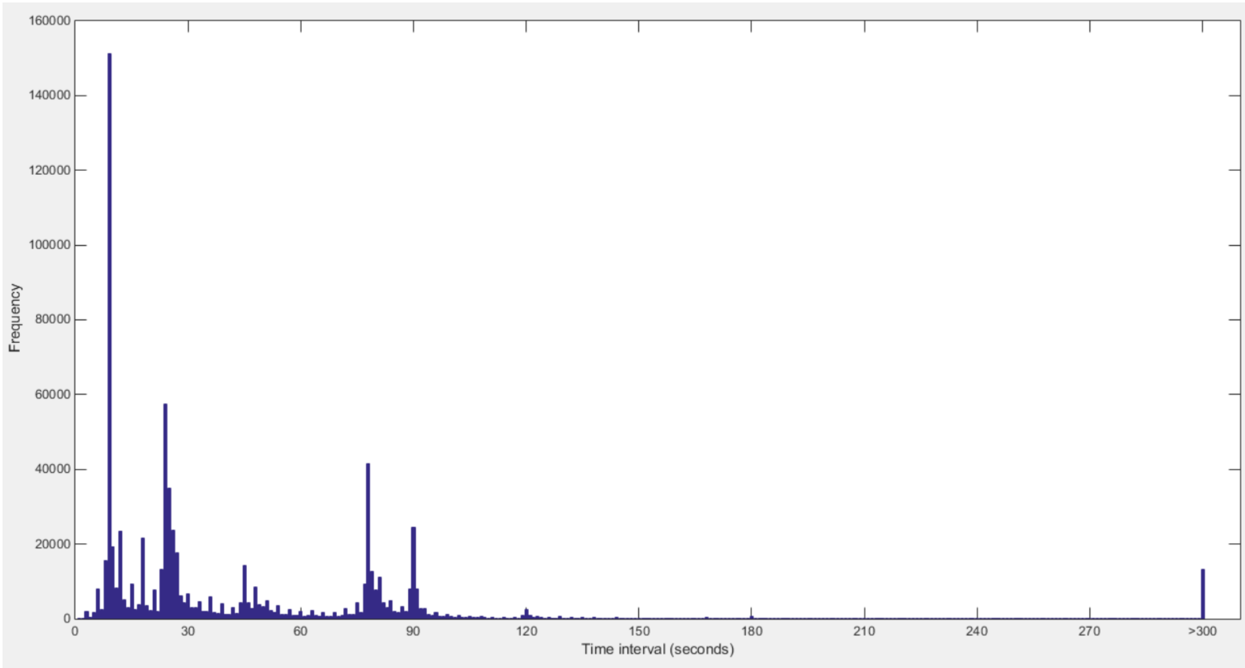


Figure 4.6 Histogram of time intervals of all pairs of consecutive GPS points on Monday, 24 March 2014

The threshold setting for the distance rate was analogous to the method for the threshold setting for the time interval. The percentages of travelled distances that were less than 300, 500, 800, 1000, 1200, and 1500 meters were 75.49 %, 88.11 %, 94.51 %, 95.67 %, 97.14 %, and 98.07 % respectively. Thus, a distance threshold of 1500 meters were set, eliminating 1.93 % of samples.

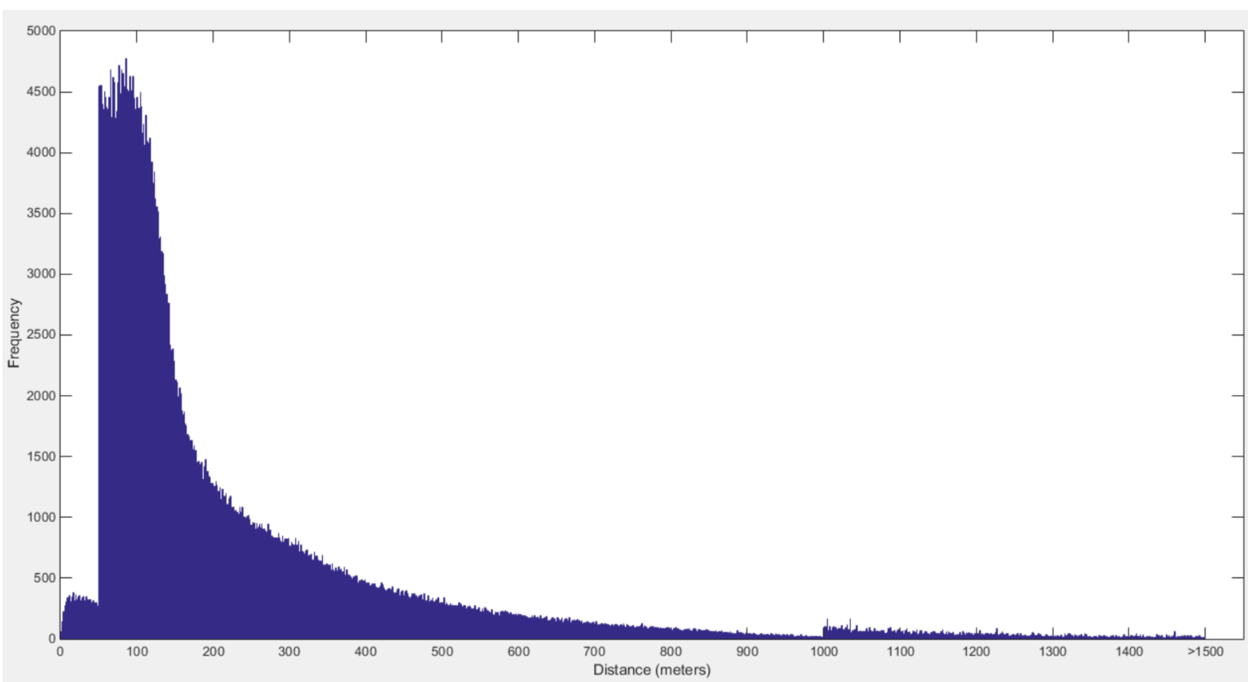


Figure 4.7 Histogram of distances of all pairs of consecutive GPS points

A complete overview of average distance rates per given day can be found in Table 4.4. There were also identified some obviously erroneous distances of more than a hundred of kilometres, the maximal being 189,230 metres.

According to the above analysis, the following scripts took into account the set thresholds and eliminated such GPS errors. For example, if the time interval and travelled distance between two consecutive points were greater than 4 minutes and 1500 meters, it indicated that the GPS signal was discontinuous during the given time period. Vice versa, if both the time interval and the travelled distance were less than the given threshold, they were considered continuous over time and space. This way the FCD errors could be efficiently and effectively reduced.

4.3.4 GPS precision

The GPS is a space-based satellite navigation system that has currently 31 active satellites in orbit inclined 55 degrees to the equator that provide location and time information in all weather conditions, anywhere on or near the Earth. The precision of the location varies and depends on the number of satellites that are in line of sight. In order to get one's position in 3-dimensions, the GPS receiver has to receive signals from at least 4 satellites. If there are only 3 satellites available, an approximate position can be determined by making the assumption that one is at sea level. Thus, in case of being close to the sea level, the position will be reasonably accurate. However, places at higher altitudes of thousands of meters such as mountains will show measurements hundreds of meters off (How GPS Works 2014).

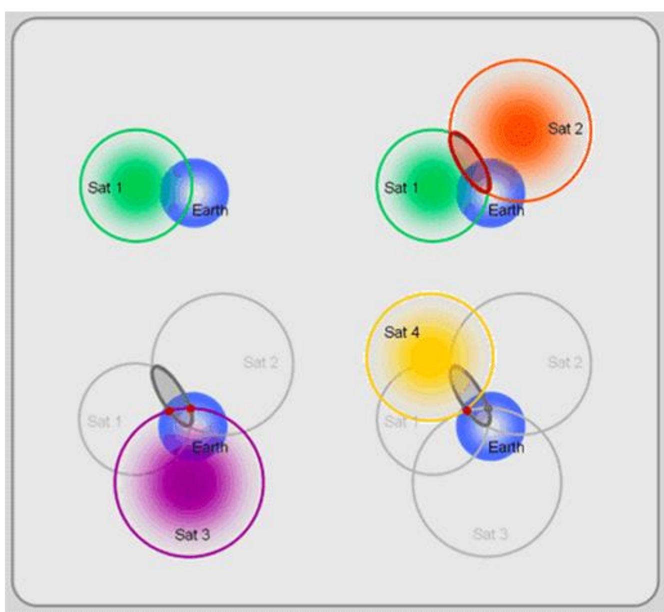


Figure 4.8 GPS satellites determining one's location (Geographic Information Systems 2015)

The process of determining the exact location is known as trilateration and is shown in Figure 4.8. The first satellite locates a device's position somewhere on a sphere. The second satellite narrows its location to a circle created by the intersection of the two satellite spheres. The third satellite reduces the choice to two possible points. Finally, the fourth satellite helps calculate a timing and location correction and selects one of the remaining two points as its position (Geographic Information Systems 2015).

Additionally, the position's accuracy relies heavily either on the obstructions in close proximity of the given place such as trees near the road or tall buildings, or the obstructions that stand in device's line of sight and block its view such as buildings, dense foliage or tunnels. These solid objects, either natural or man-made obstructions, prevent the GPS signal from passing through and therefore making it impossible to determine device's global positioning (Fink 2010).

Thus, we looked at the sample in terms of the number of visible satellites at the moment of receiving the GPS signal. As can be seen in Figure 4.9, the number of samples that received signals from less than 4 satellites is almost negligible – 1.83 % of the Monday's data sample. Samples that received signal from 0 (did not receive any signal), 1, 2, and 3 satellites were 0.29 %, 0 %, 0.00026 %, and 1.53 % respectively. The sample's average fluctuated between 7 and 8 satellites, giving exactly an average of 7.41 satellites. The data set of the remaining days followed a very similar pattern and showed almost identical values.

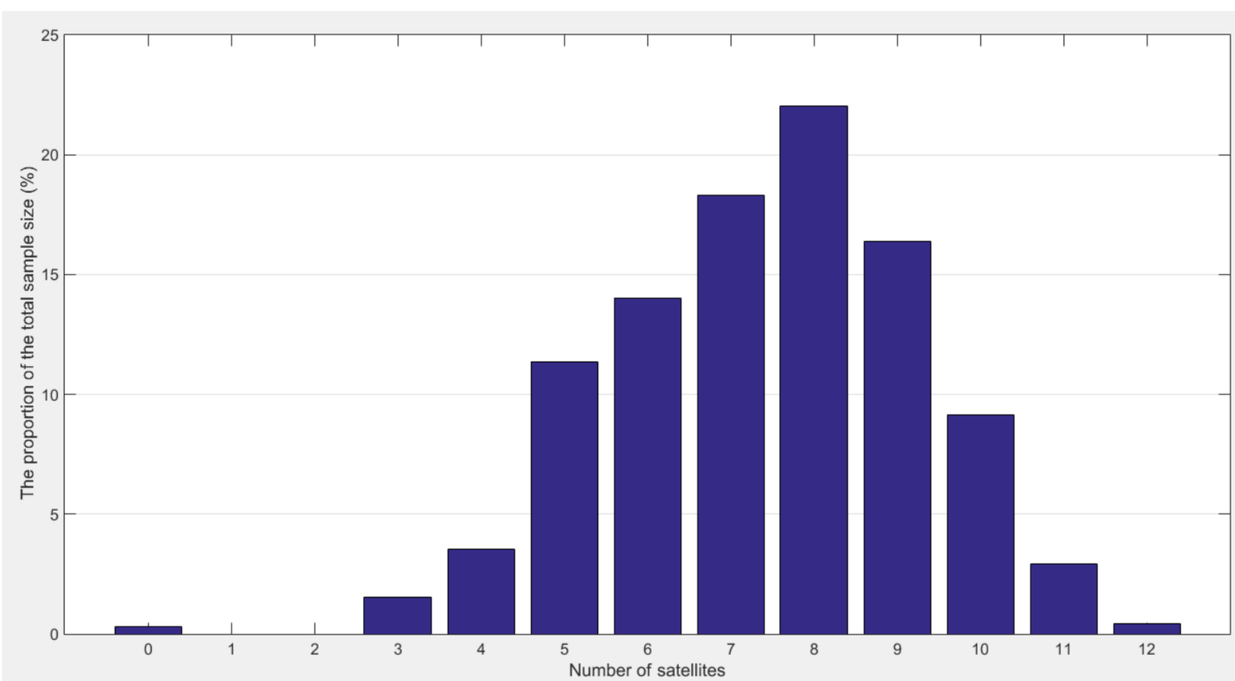


Figure 4.9 Histogram of number of satellites while receiving the GPS signal on Monday, 24 March 2014

Even after a further examination of the samples that did not receive the GPS signal from a large enough number of satellites, we found out that their GPS coordinates were very precise, especially of those which received signals from exactly 3 satellites. However, they were spaced further apart in time which is why it made sense to eliminate them.

Additionally, we plotted all of the taxicabs' locations within a centre part of Vienna during Monday, 24 March 2015 to illustrate the effect that some of the obstructions had on the quality and preciseness of the GPS localization. Figure 4.10 depicts a satellite image of a town square in Vienna – Karlsplatz – whose latitude and longitude coordinates were 48.201608985143 and 16.3749062309264 for the north-east corner, and 48.198583253861365 and 16.364376861572282 for the west-south corner. In total, there were 9,264 recorded positions during the whole day. The figure provides a fine example of both good and poor line of sight as there are relatively tall buildings and open spaces. Therefore, it is clearly visible how some of the points lying among the buildings were less accurate, some of them even being displayed on the buildings' roofs, than those within open spaces.

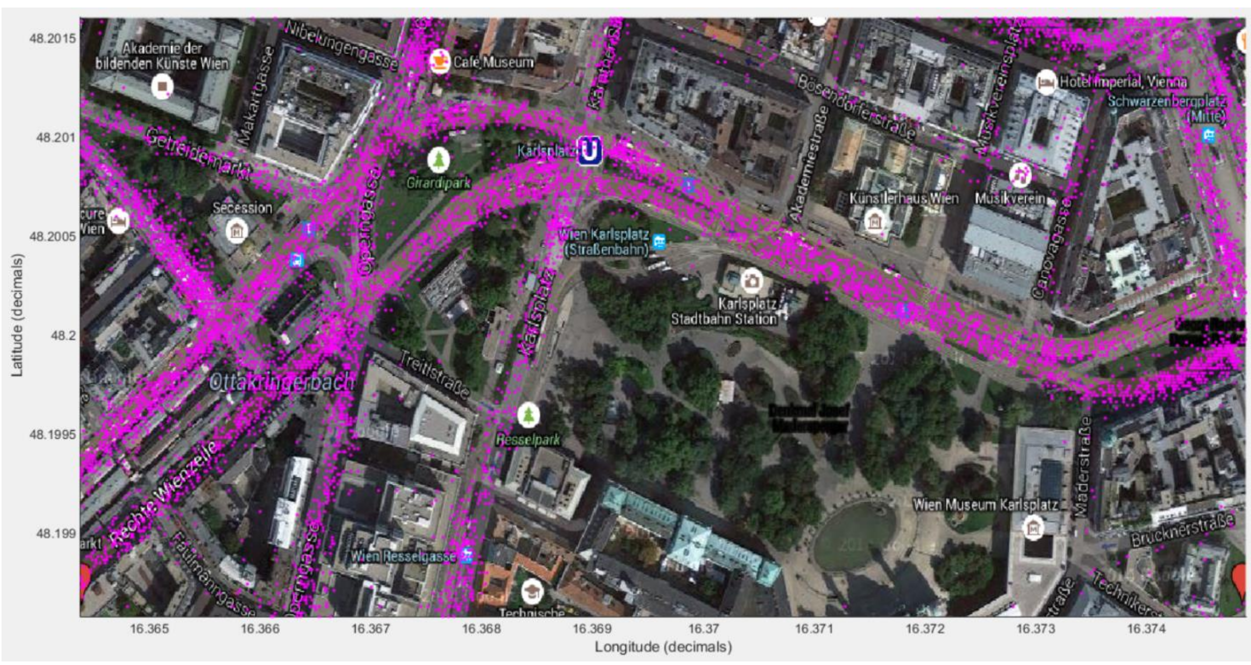


Figure 4.10 Recorded points on Monday, 24 March 2014 in Karlsplatz in Vienna

A better example of the GPS accuracy for open spaces is given in Figure 4.11 which shows a section of the Ost Autobahn (highway) A4 that is in close proximity of Vienna. The section's latitude and longitude coordinates were 48.158776950201855 and 16.47856922817232 for the north-east corner, and 48.15735109999047 and 16.47730760669708 for the west-south corner.

Again, we looked at positions during Monday, 24 March 2015 and recorded 1,053 points in total within the given section. Clearly, the positions seemed to be very accurate as all of them were within the boundaries of the highway's lanes.

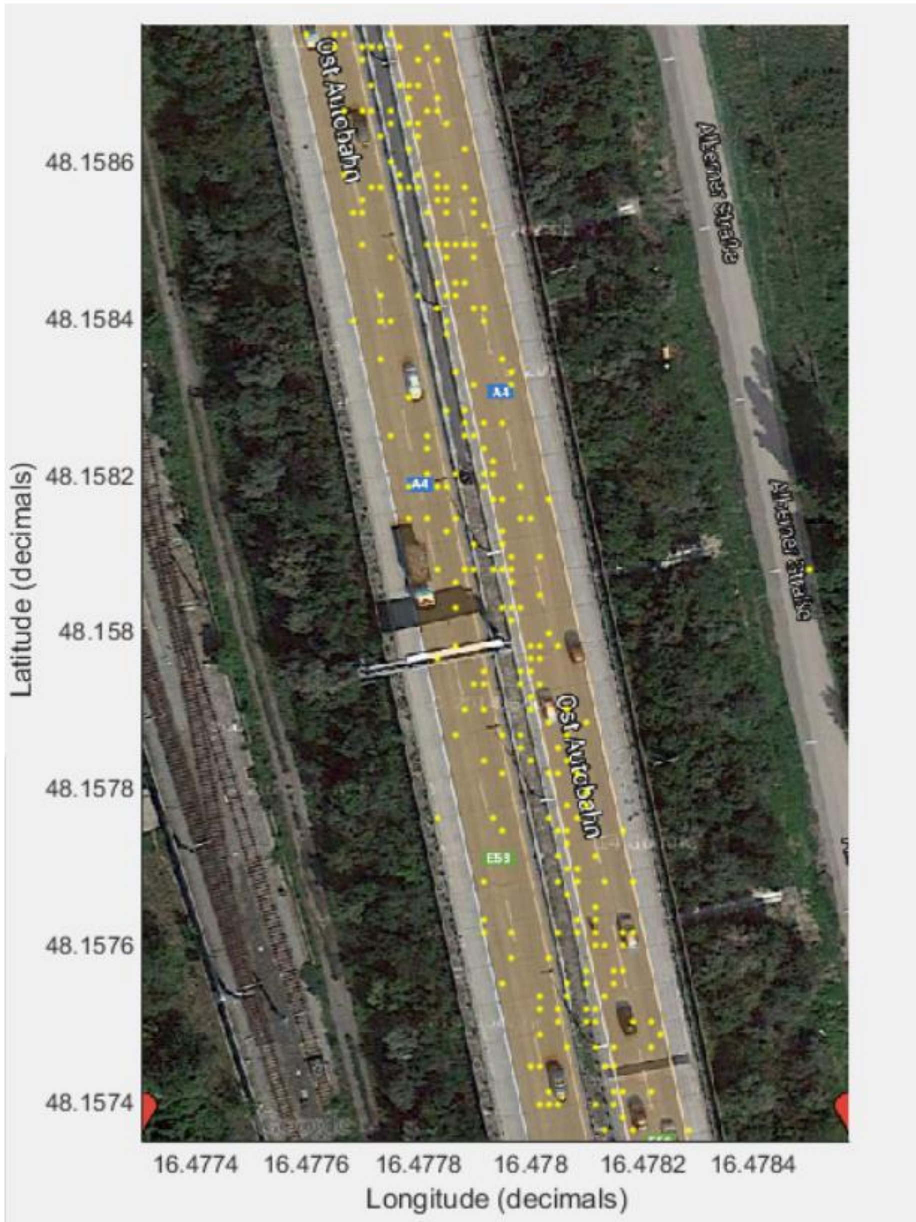


Figure 4.11 A section of the Ost Autobahn A4 going from Vienna to Nickelsdorf

On the other hand, Figure 4.12 depicts a densely inhabited area, close to the city centre of Vienna, showing how the points' vast majority lies outside the roads' boundaries due to the signal blockage caused by the buildings. The image's latitude and longitude coordinates were 48.1909012 and 16.3537392 for the north-east corner, and 48.1884606 and 16.3488191 for the west-south corner. The figure shows 4,365 recorded points on Monday, 24 March 2014 again.

Figure 4.12 An example of signal blockage among many buildings

4.3.5 Distribution of Measurements and Velocity Analysis

Although the collection of taxi-FCD results in a voluminous database of historical data, FCD covering varies spatially and temporally, depending on the utilization rate of taxi services. Figure 4.13 gives an impression of the temporal distribution of FCD measurements during the whole data set distinguishing measurements within 24 hours of the given day. Clearly, two apparent trends could be identified – one during weekdays and the other one at the weekends. Throughout the weekdays' night hours, a relatively small number of data was collected, contrasted by a high number of measurements at the weekends. This is particularly because of the fact that people mostly do not work at weekends and go out and party on Friday and Saturday night and then take a cab home during late night hours as public transport does not operate very frequently at this time. The difference in the amount of FCD collected was very significant, for example on Sunday night it was 3 times more than on a Monday night. Furthermore, the amount of information provided on weekdays between 6 am and 4 pm was very similar, almost identical. During the remaining time period of the day the number of samples varied significantly. Similar characteristics applied to the weekends. However, the temporal distribution analysis revealed that there was a missing segment of information on Sunday between 2 am and 3 am. In addition, this analysis establishes hints for subsequent data analysis, for example variation of the number of measurements at certain times of the day at different places in the city road network as well as an insufficient number of data records in the outskirts.

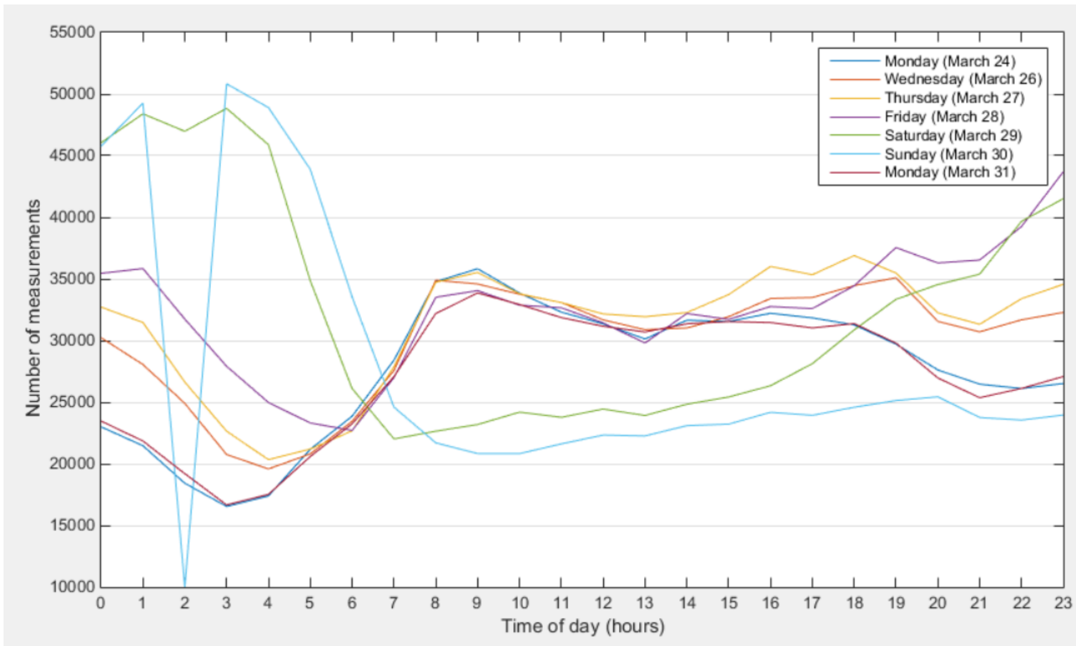


Figure 4.13 Temporal distributions of FCD measurements

Consequently, we looked at the general properties of the Vienna traffic and plotted the mean velocities against the time of day as shown in Figure 4.14. The velocities were calculated from data samples of all taxicabs averaged over sample ranges of 30 minutes. Totally, about 6 million records were taken into consideration for this plot. The working day profiles were very similar for all days from Monday up to Thursday, Friday differed slightly between 3 and 5 pm. A pattern with two valleys was discovered. The speed continuously decreased in the morning hours until it reached the first rush hours between 7 and 9 am. Later in the morning, around noon, and in the early afternoon the average speed was relatively low and nearly constant as it fluctuated between 25 and 29 km per hour. After a speed minimum during the second rush hours between 3 and 5 pm, the speed increased again. During weekends, the plots indicated rush hours between 6 and 9 pm. However, there were also another valleys discovered between 1 and 3 pm that could possibly be classified as rush hours. The decrease in speed was happening from 6 am until 3 pm, however, there were some moments during which the speed slightly increased again. After the speed minimum which occurred around 7 pm it commenced increasing again.

Overall, it can be seen that weekdays and weekends presented two typical representative velocity patterns.

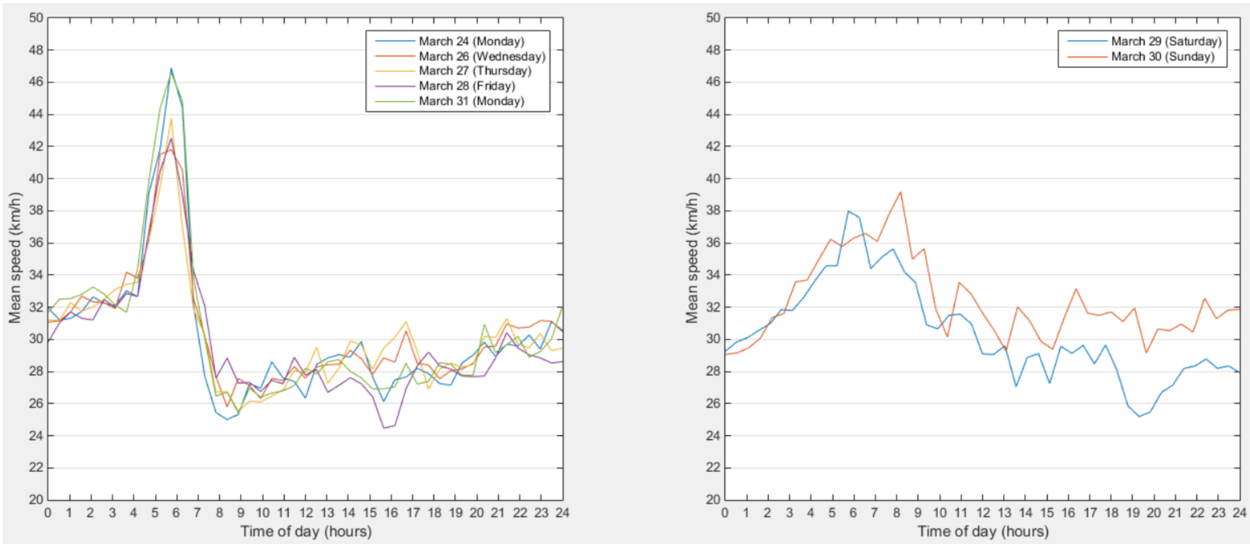


Figure 4.14 Mean speed of taxis during workdays (left panel) and weekends (right panel)

Figure 4.15 shows the mean speeds for the whole data set. The mean speed represents the average value of all GPS speed points in each day, where the green ones at weekends were higher than the blue ones during workdays. This is the reflection of how traffic is generally less congested at weekends than on working days. It also indicates that traffic congestion on Friday is typically heavier than that on other weekdays.

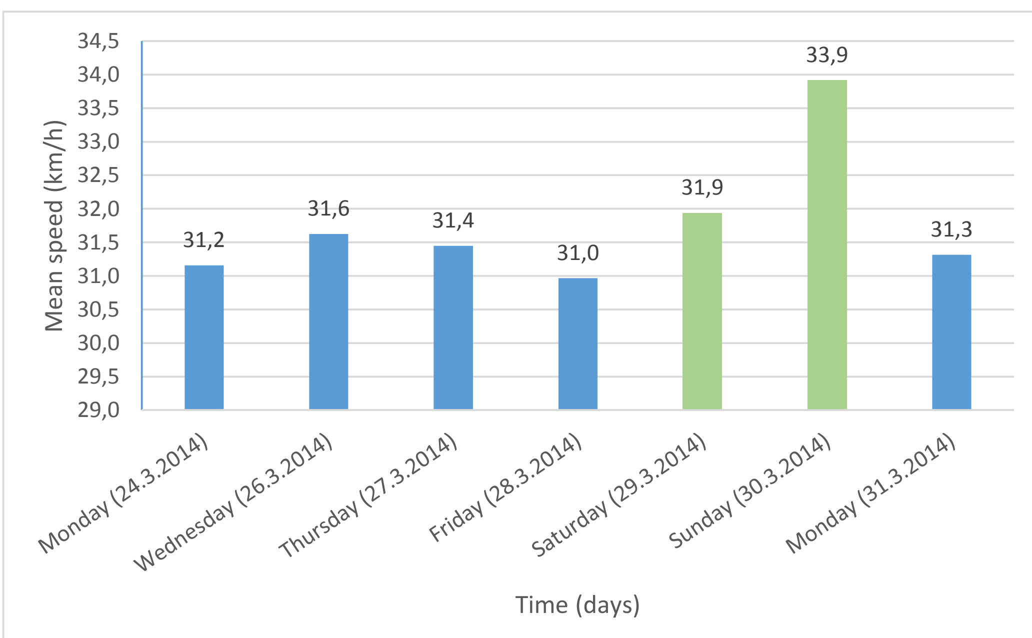


Figure 4.15 Mean speeds of taxicabs during weekdays (blue) and weekends (green)

A more detailed analysis of speeds is shown in Figure 4.16. Working days are coloured blue, whereas weekends are depicted in green. Again, two representative velocity patterns can be seen as the working days are very similar to each other, in contrast to weekends which shows higher velocities especially between 20 and 70 km per hour.

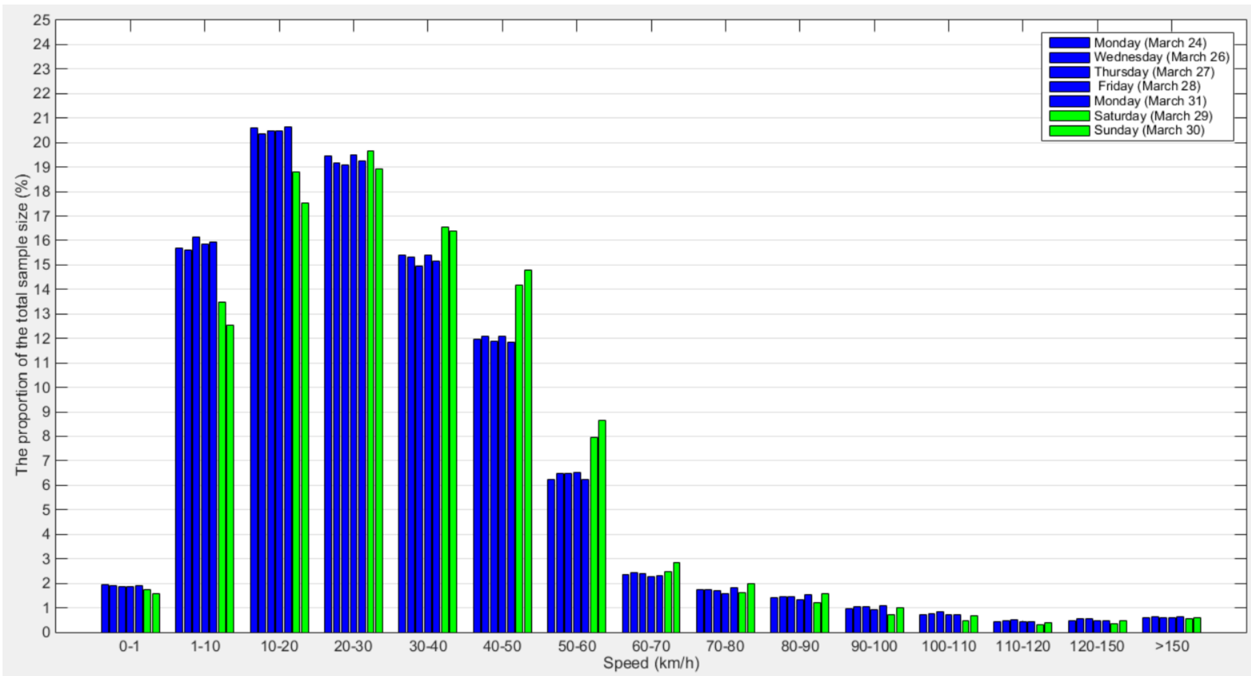


Figure 4.16 Relative frequencies of speed measurements for the whole data set

An even better example of how the speed differs during the day is given in Figure 4.17, where two exemplary distributions distinguishing the relative frequencies of measurements are depicted.

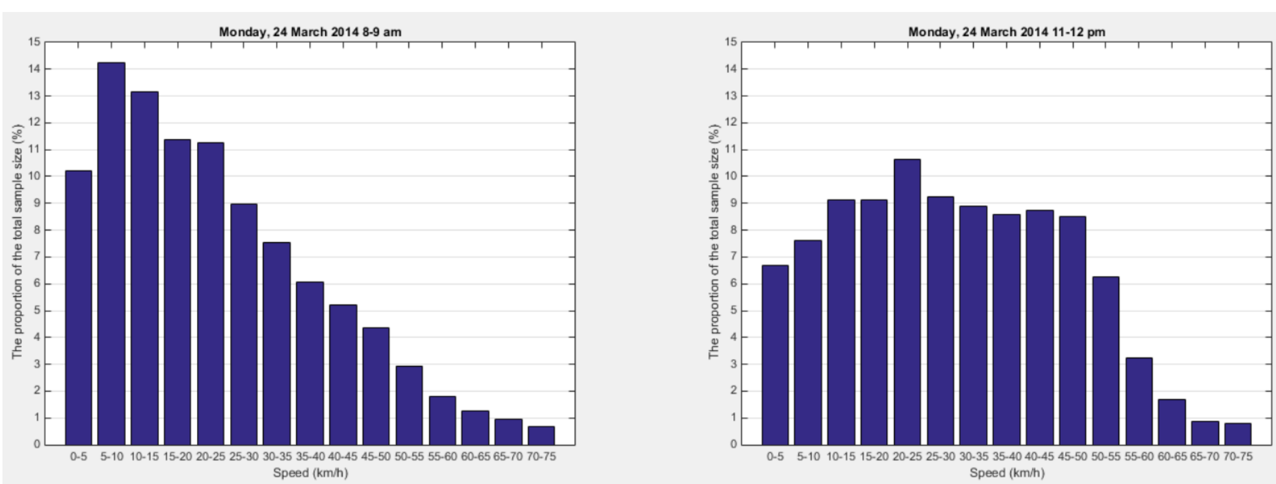


Figure 4.17 Relative frequencies of speed measurements for different time bins on Monday

The left panel shows velocities during the morning rush hour between 8 and 9 am with a propensity of frequencies in the direction of lower speed classes. In contrast, the right panel shows more or less free traffic flow between 11 and 12 pm in the evening. This underlines the necessity of time-dependent travel times for routing in city logistics.

Figure 4.16 also shows relatively high frequency of velocities over 150 km per hour. Similarly to the sample rates and distance rates, there were some erroneous speeds as well. We identified values reaching more than 800 km per hour, which were obviously incorrect ones. Therefore, we set a speed threshold of 150 km per for the urban area and eliminated around 1 per cent of the samples within a given day. It is also important to note that not only the obviously high values of speed were the only inaccurate ones as even the lower speeds could have been affected by the positioning error from the GPS unit. If the GPS unit logs a point far backward and then too far forward for the next point, the distance covered in that segment is calculated as much higher than it actually was, and therefore so is its speed. For example, a speed value of 75 km per hour could have been originally a speed value of 15 km per hour due to a wrong distance calculation.

4.3.6 Congestion Detection

Once the FCD samples were thoroughly analysed, validated and the incorrect and incomplete values eliminated, it was possible to use them for our main purpose – congestion detection. Similar matching procedure was used for plotting the taxicabs' locations as has been done in Figures 4.10-4.12. Only this time, we were more interested in the taxis' velocities within given road segments and city sectors which is why we divided them into different speed clusters and assigned them various colours. The matching procedure for the congestion detection used a satellite image whose latitude and longitude coordinates were 48.292079905275806 and 16.56538598632801 for the north-east corner, and 48.09216946074534 and 16.195977050781266 for the west-south corner, and thus corresponded to the rectangle area bounding Vienna in Figure 4.5.

As we attempted to eliminate most of the erroneous data samples before performing the congestion analysis, we did not use any of the more complex map matching algorithms that use a digital road map and neglect positions where the distance to the nearest edge is larger than a certain threshold (see Figure 4.18). Figure 4.19 shows positions and derived velocities from FCD on Friday, 28 March 2014. Of course, the GPS positions could have been plotted for any other day, but Friday seemed to be the most heavily congested day during the whole week and thus the best option for identifying problematic traffic variation. As can be seen in Figure 4.14 on

Friday was recorded the lowest 30-minute mean speed of around 24 km per hour during the afternoon rush hour (between 3 and 5 pm). Similarly, Friday proved to have the lowest daily mean speed of 31 km per hour (Figure 4.15).

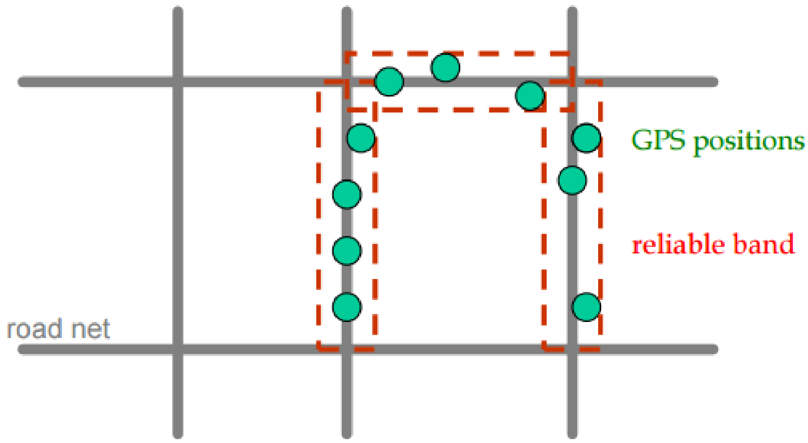


Figure 4.18 Matching principle of GPS position data to a digital road map (Schäfer et al. 2002, 7)

Figure 4.19 represents one of the more sophisticated interpretation of such a high quantity of FCD samples in comparison to the charts and graphs that have been presented up until now. It provides a broad overview of the historical traffic status in Vienna on Friday, 24 March 2014 during the afternoon rush hour – 16:00-16:15 – and offers the possibility of identifying problematic places on Vienna's road network as well. Totally, the plot shows 8,205 positions.

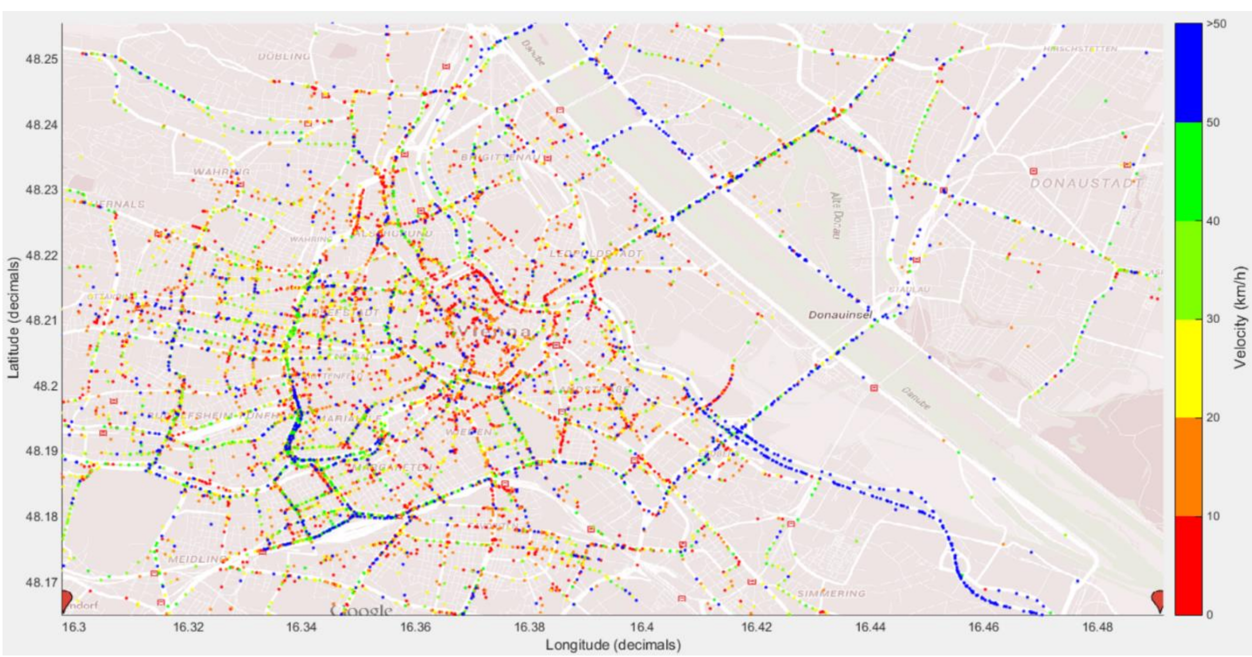


Figure 4.19 Road velocities in central part of Vienna on Friday between 16:00-16:15

By contrast to the congested areas in rush hours, Figure 4.20 shows traffic conditions during the early morning, between 6:00-6:15. Clearly, the difference in the derived velocities is obvious. There were only a few road segments in rush hours that indicated a speed higher than 50 km per hour, such as the highway A4 going from the right bottom of the picture and the north bank of the River Danube. On the other hand, the morning period shows predominantly green and blue points indicating speeds of more than 40 km per hour. However, as can be easily observed there were much fewer recorded positions (4,587) in the morning than there were during the rush hour (8,205). This was caused primarily by the fact that there were fewer measurements in the morning (22,500) than there were during the afternoon (see Figure 4.13). Generally, the decreased demand for taxis in the morning is a common phenomenon.

Figure 4.20 Road velocities in central part of Vienna on Friday between 6:00-6:15

Figure 4.21 shows a smaller part of Vienna city centre that we identified, based on the derived velocities in Figure 4.19, as problematic and congestion-prone. Again, we looked at recorded positions and derived velocities in the afternoon rush hour, but we widened the time interval to the whole hour during which we got 9,020 positions in total. This has provided us with a slightly larger amount of samples and gave us a clear indication of heavily congested roads – those with speeds of 20 km per hour and fewer – which were marked with black circles. All of these bottlenecks are located in the city centre and three of them are on the Vienna's ring road.

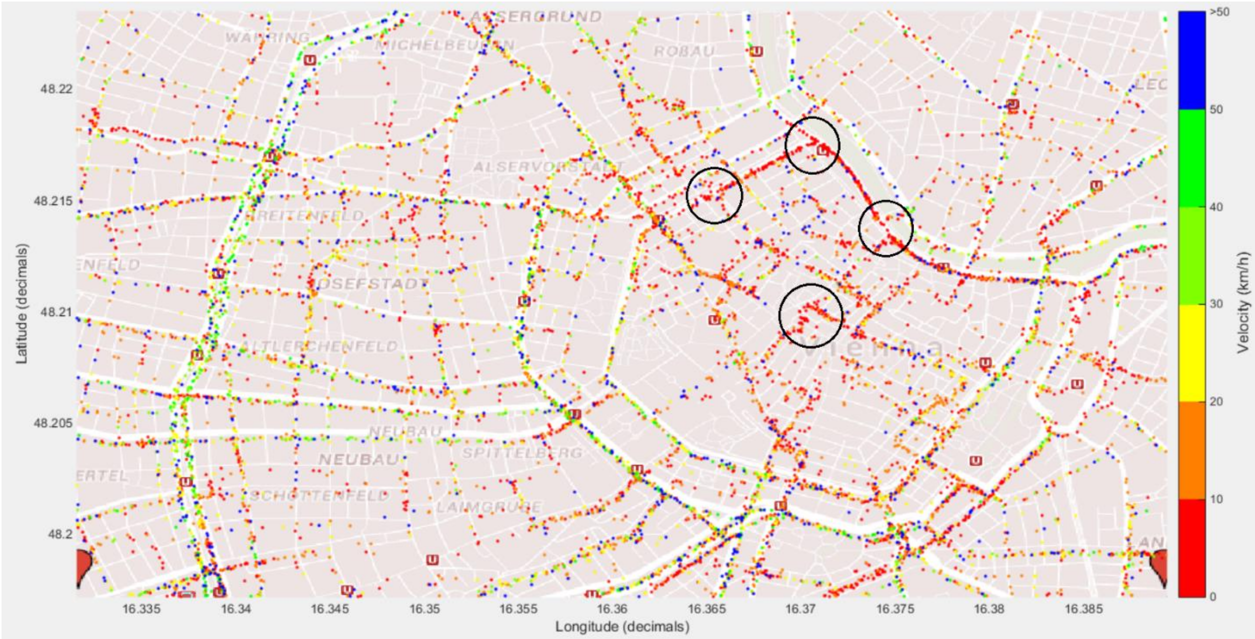


Figure 4.21 Road velocities between 16 and 17 rush hours on Friday with marked congested areas

Even though Friday proved to be a day with the lowest daily mean speed as well as 30-minute mean speed, we also looked at another days in order to see whether there were problems in the same areas as in Figure 4.21. Therefore, we plotted taxicabs' positions and derived velocities on Monday which showed the second lowest mean speed during the afternoon rush hour. As can be seen in Figure 4.22, Vienna's ring road is much less congested than on Friday afternoon.

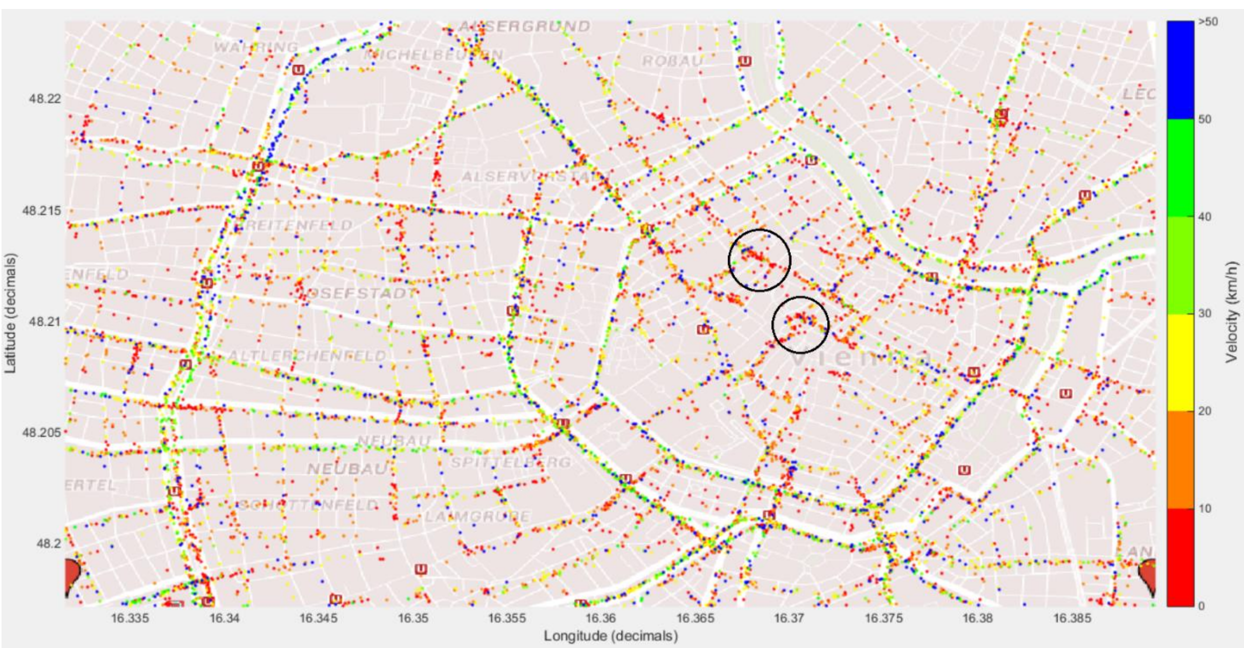


Figure 4.22 Road velocities between 16 and 17 rush hours on Monday with marked congested areas

Figures 4.21 and 4.22 provide good comparison also in terms of the recorded positions as there were 9,020 positions on Friday afternoon and 9,548 on Monday afternoon. Clearly, there exist two different weekday patterns of Vienna traffic, as the south bank of the river Danube showed no congestion at all on Monday afternoon in comparison with Friday afternoon when it was heavily congested. However, one of the central parts of Vienna seemed to be congested on both days. In order to prove or disprove that the area in the city centre was really a congestion-prone spot we also looked at traffic patterns during Wednesday. Figure 4.23 shows an overview of traffic conditions during rush hour on Wednesday afternoon (8,565 positions). Wednesday afternoon shows similar traffic behaviour to Monday, however, with more congested south bank of the River Danube as in Friday afternoon. Most importantly, the central part of Vienna showed signs of traffic congestion again and thus proved to be a congestion-prone spot.

Figure 4.23 Road velocities between 16 and 17 rush hours on Wednesday with marked congested areas

In Figure 4.24 a satellite image of the congestion-prone is depicted, showing predominantly velocities of 10 km per hour and lower. The figure shows a total of 538 positions that were recorded during a time interval between 14 and 18 hour on Wednesday. With this image and derived velocities at hand, traffic engineers are able to design corrective measures and thus eliminate such congested areas. In general, there several options that can be considered for improving the area’s traffic situation. Firstly, the road’s structural arrangement can be changed. This includes mainly either extending or narrowing the lanes’ widths as well as construction of new lanes. Secondly, the area’s transport arrangement can be altered. For example, this means introduction of one-way road system, traffic zones limiting speeds within a given area, and also adjustment of a green cycle at traffic signals. Given the situation in Figure 4.24 and the fact that it is in historical part of Vienna, it is almost impossible to alter the road's properties. The area is rather similar to Wenceslas Square in Prague. Thus, it also possible that due to its location and high intensity of pedestrians, the area is not congestion-prone and that the vehicles passing through this location slow down because of road signs that limit the speed to 20 km per hour. However, as Figure 4.24 shows, quite many velocities of more than 50 km per hour were recorded which suggests evidence of no speed limitations at all. Therefore, one of the possible measures that could be designed is to eliminate traffic within this area by introducing pedestrian zones. A similar action was taken in Wenceslas Square in Prague, where its bottom part was completely closed to cars, with exception of buses, taxicabs, and supply trucks. Nonetheless, the fact that the FCD samples were provided by a fleet of taxicabs imposes another limitation – a possibility of vehicle limitations being in place and thus only the taxicabs could pass through this area. It is of crucial importance for traffic engineers to be perfectly familiar with the city's road network. We did not have such detailed information about pedestrian zones, traffic lights, traffic arrangement of each part in Vienna.

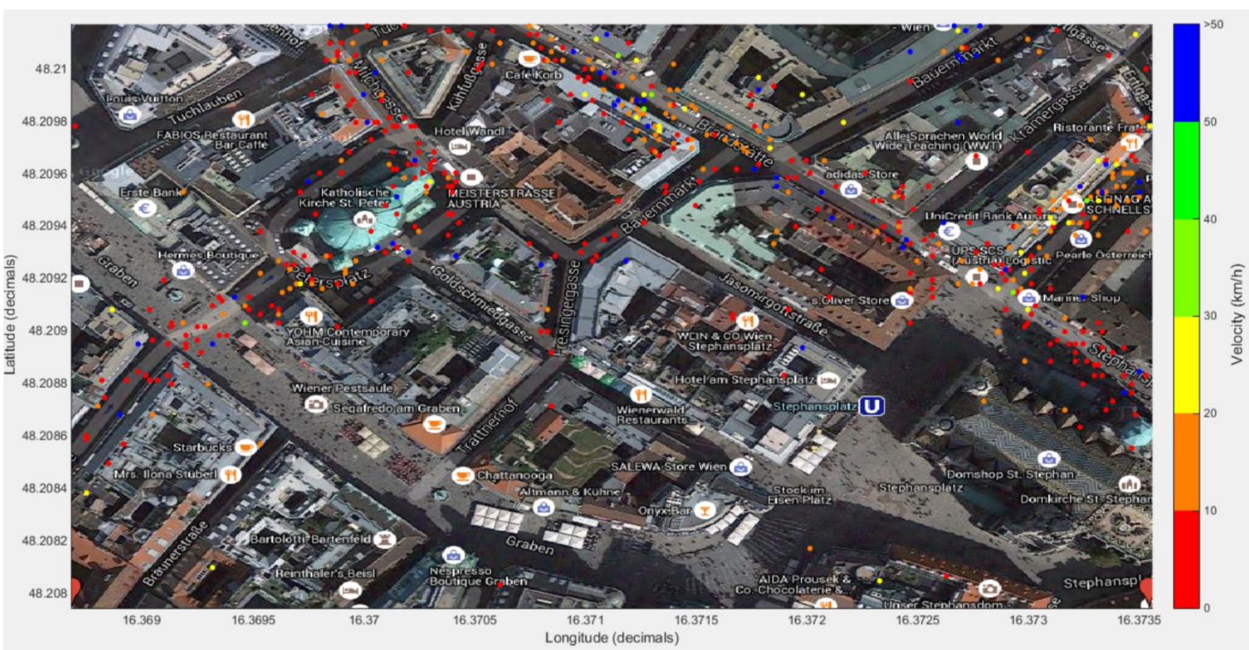


Figure 4.24 Satellite image of identified area with low velocities on Wednesday between 14 and 18 hour

Following the above procedure, a time-dynamic road map of historic and real-time link-based velocities becomes available, which is usually the input for several service applications as well as for traffic monitoring purposes. Furthermore, this can also be used as a powerful tool for identifying and separate processing of special traffic variation in case of events like demonstrations, soccer games, unusual weather conditions or vacations. It provides traffic engineers with the possibility to easily identify problematic areas as well as offers an overview of current traffic situation in the whole city.

5 The Future of Mobility and ITS

Chapters 2.3 to 2.5 described some of the current technologies for real-time traffic monitoring, including congestion detection and management, route planning, travel time calculation, information about road accidents and so forth. All this traffic information is now readily available mainly due to the use of floating vehicles that act as traffic probes. However, the penetration rate of such vehicles is still very low and thus the knowledge about traffic status is not adequate enough. Therefore, in order to decrease the amount of time spent in congestion, minimise the fuel consumption, and reduce the number of accidents, many more roads and vehicles have to be monitored. The rapidly advancing technology during the past few decades has changed how we work, entertain ourselves, and most importantly how we communicate with each other. This why it is of crucial importance that the future intelligent transport systems integrate existing transport infrastructure with communication networks. Paul Mascarenas (Cooperativity in motion 2013), CTO and Vice President of Ford Research and Innovation, believes that "for maximum benefit we need to invest not only in vehicles, but also in infrastructure. Making the vehicles communicate with each other brings considerable benefits, but the maximum benefits arise where intelligent intersections and intelligent motorways are able to monitor the vehicles' movement and control traffic flows – for a safer traffic landscape."

Several studies on the future of mobility and ITS have been conducted recently and they all have focused on three main pillars – people, community, and vehicles. While the vehicle itself will still assume its original role of a mobile machine that transports people or cargo, it will also take on a role of a companion, trusted partner, through close communication with the driver to whom it will be fully accustomed. Possibly, the vehicle will be even more aware of the driver's preferences and dislikes than he or she. In addition, the vehicles will be fully autonomous – intelligent enough to fully take over the driving tasks. Elon Musk (Lowensohn 2015), Tesla Motor co-founder and CEO, says that "you can't have a person driving car a two-ton death machine," and even believes that driving cars will be eventually outlawed. Furthermore, people's different travelling needs at specific moments will likely result in transportation on demand. Therefore, there will be available vehicles for any particular need – a small, compact vehicle for work commuting; a vehicle with extra storage space for shopping trips; a large vehicle with extra legroom and a big trunk for family holiday. The Tomorrow's Transport Start Today report even coined a new term with the transport terminology – super intelligence – which describes the intelligence of the total transport system that is bigger than the sum of the individual intelligent parts. Similarly to synergy effect, the added value is created by the connection and the reciprocal interaction of the different parts as can be seen in Figure 5.1 (The Future of Mobility 2014; Tomorrow's Transport Start Today 2014).

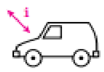
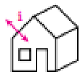
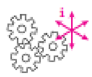
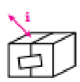
	An intelligent *vehicle* fully takes over the driving tasks from a person.
 	Intelligent *surroundings* consist of buildings, spaces and objects that can communicate about local conditions or situations. A specific aspect of the surroundings is the infrastructure. Intelligent *infrastructure* informs other parts of the transport system about its local status. It also self-repairs small faults, thus increasing its availability and security.
	An intelligent *control system* has the right information to be able to proactively meet a certain goal in real time and to act accordingly.
	An intelligent *traveller* is for the purposes of this foresight study defined as a person who consciously or unwittingly uses the relevant information about possible travel options and corresponding time schedules to optimise his journey and who then takes action accordingly – both before and during travel.
	Intelligent *freight* communicates independently about its destination. When packaging is seen as a part of freight, intelligent freight also guarantees the conditions for delivering the goods in their proper state to their destination.
	The enabler for all these intelligent parts is information.

Figure 5.1 Parts in a super intelligent transport system (Tomorrow's Transport Start Today 2014)

While it is obvious that the FCD technology and its successor – extended FCD – are concepts that follow the right direction, the V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) communications, also known as cooperative technologies, will most likely assume a central role in ITS planning. This especially applies to large cities as the hyper-urbanised life of the 21st century will rely heavily on urban transportation than ever before. The increasing need to supply the city inhabitants with food and drinks together with people's individual lifestyles, flexible work rhythms and unconstrained leisure time activities will actively encourage transportation. The cooperative technologies or cooperative transport systems, the labels sometimes differ but the idea of connecting vehicles with the infrastructure remains the same, uses a two-way wireless communication, precisely a dedicated short-range communications (DSRC). It is similar to Wi-Fi but operating over a different portion of the radio spectrum: a 75-MHz band around 5.9 GHz. In addition, DSRC has been designed to prioritize data associated with safety applications and to handle outdoor networking between vehicles moving up to 120 miles per hour. Whereas Wi-Fi was designed for indoor usage at walking speeds (Future Cars Will Talk To Each Other 2014). Unlike the technology behind fully autonomous vehicles, V2V and V2I communication does not intend to replace human drivers with automated systems that take care of braking, steering, or accelerating. Rather, the connection between the infrastructure and the vehicles via roadside units such as road operators, sensors and actors will help to augment situational awareness and allow travellers to:

- Access real-time local traffic conditions
- Routing information
- Receive warnings about imminent roadside hazard
- Conduct commercial transactions within their vehicles

Additionally, transportation agencies will have access to road condition and traffic situation data which will allow them better managing of traffic operations, support planning, and more efficient maintenance services. Also, once the V2V and V2I technologies are fully developed and ubiquitous, they will allow for advanced applications related to environmental friendly driving, safety, and mobility. Due to the real-time collection of traffic data from vehicles it will be possible to define low emission zones, operate traffic signal corridors for minimum pollution as well as enable various payment services for fuelling, battery charging and electronic toll collection (Kapsch.net – V2X Cooperative Systems 2014).

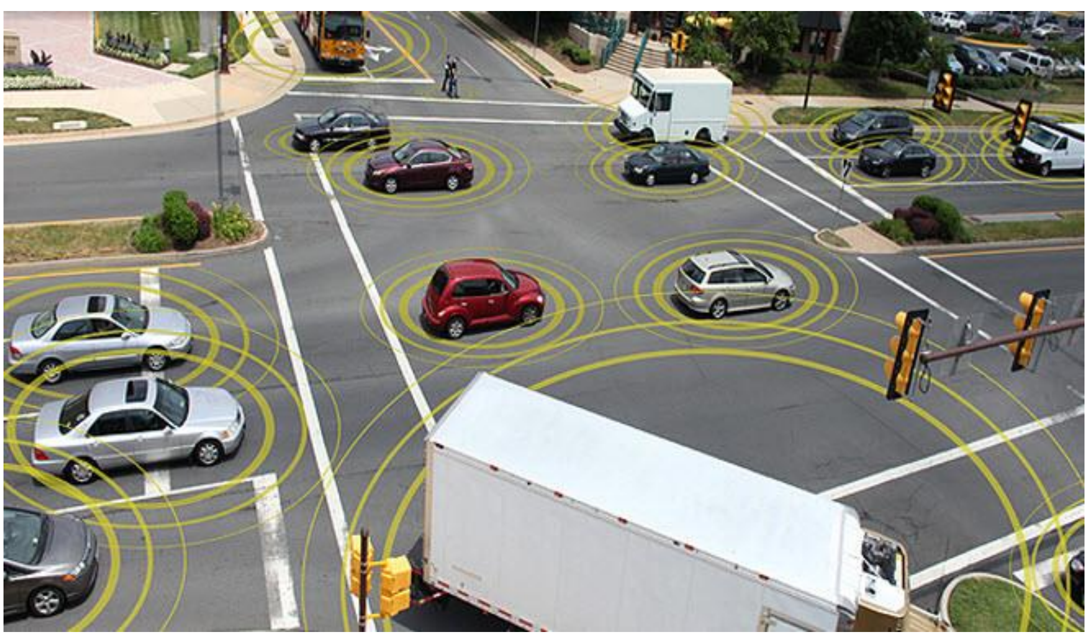


Figure 5.2 V2V communication systems that let cars converse (Future Cars Will Talk To Each Other 2014)

Nowadays, there are several pilots and prototype systems of V2V and V2I technologies in place. One of the examples is a system currently operated in Berlin which collects traffic data registered by 1,200 measuring stations (800 being installed on urban freeways and 400 on inner-city streets). It offers more than the customary blanket statements such as “congested road”, “obstruction ahead”, as the data allow calculation of precise traffic density figures. This data are then used as the basis for deriving an exact picture of the prevailing traffic status (Cooperativity in motion 2013).

An even more sophisticated example of presently used cooperative technologies is under development on Tokyo Metropolitan public roads. The system was introduced as part of ITS Japan initiative known as ITS Green Safety Showcase and provided experiences of the five cutting-edge cooperative technologies shown in Figure 5.3. In addition to V2V and V2I, it also incorporates a new concept called vehicle-to-pedestrian (V2P) communication (ITS GREEN SAFETY SHOWCASE 2010).

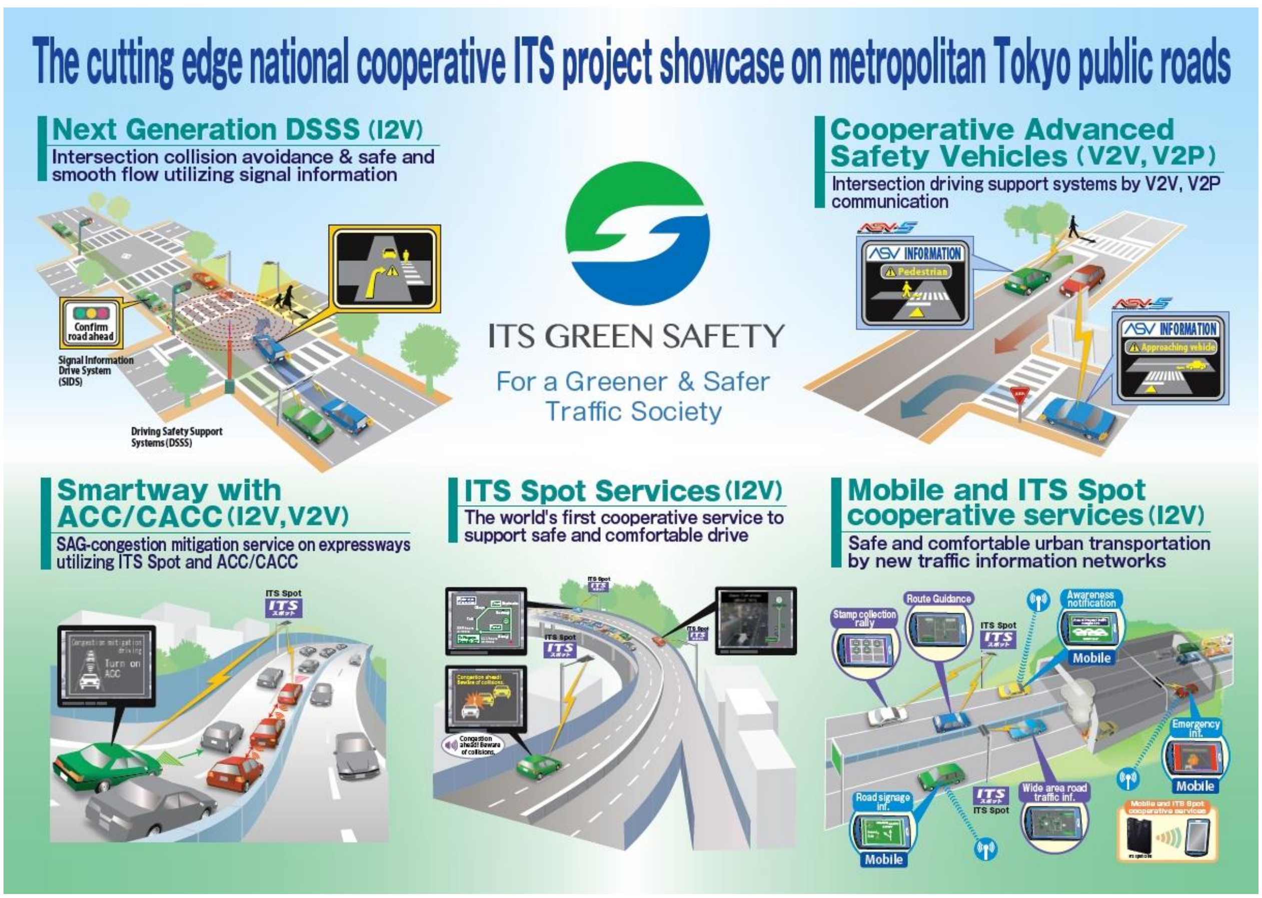


Figure 5.3 Showcase of ITS Japan on Tokyo public roads (ITS GREEN SAFETY SHOWCASE 2010)

This technology is able to detect a pedestrian with a DSRC enabled smartphone and take it into consideration. Honda's Research and Development Centre was one of the first pioneers to test this technology and managed to successfully demonstrate the ability of a car equipped with DSRC technology to detect a pedestrian whose phone sounded a warning and showed an alert, while a head-up display warned the driver that a pedestrian was about to cross the road. The system could even show the driver if the pedestrian was texting, on a call, or listening to music and thus being less aware of the car (Honda 2015).

Figure 5.4 depicts another example of ITS Japan that links ITS Spot and Smartphones. This interconnection lets participants who make a round trip by bus from Odaiba to Umihotaru receive ITS Spot information (wide-area traffic jams, dangerous areas) provided by cellular network (traffic signs, landmarks). The information is displayed on participants' smartphones allowing them to experience a safer and more comfortable highway drive. Furthermore, new services such as emergency evacuation information in the undersea Aqua Tunnel and a stamp collection rally at ITS Spot will be demonstrated (ITS GREEN SAFETY SHOWCASE 2010).

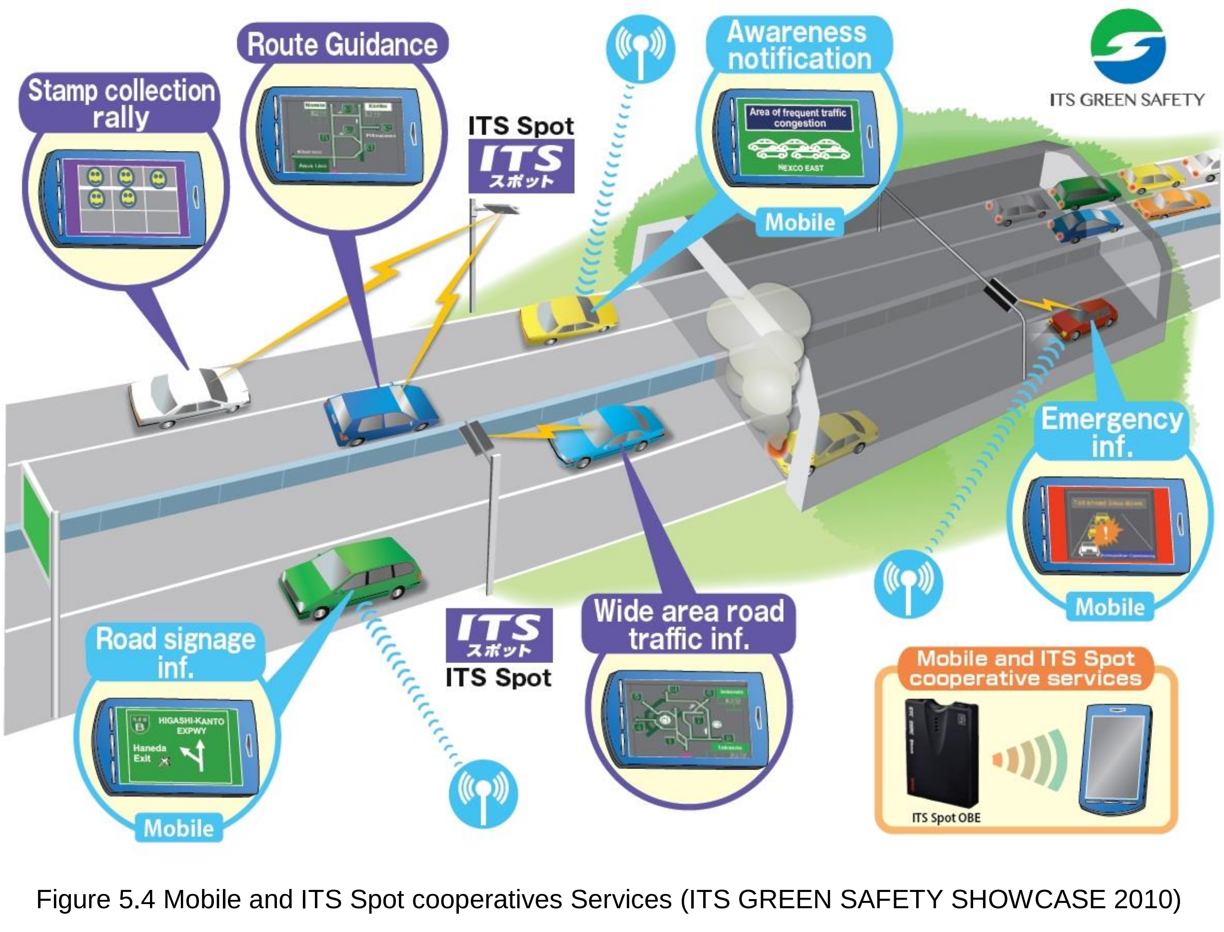


Figure 5.4 Mobile and ITS Spot cooperatives Services (ITS GREEN SAFETY SHOWCASE 2010)

ITS Japan and its showcases above are only a few examples of ITS deployment around the world, however it is important to see that ITS systems are arriving and offering fundamental breakthroughs in safety, congestion reduction, driving comfort, and environmental friendliness, bringing them to levels far higher than those provided by current road transportation systems. It is predicted that future ITS technology will be capable of the following:

- Calculation of current velocity and traffic intensity of given road segments
- Calculation of travel time between arbitrary points of interest
- Accurate identification of real-time congestion on the whole road network
- Calculation of time losses caused by traffic congestion
- Monitor congestion movement, including its creation and dispersion time
- Creation of traffic controlling and managing scenarios
- Prediction of traffic behaviour based on actual weather conditions
- Monitoring of risk areas in terms of the decomposition of the population within those areas (Hajek 2013, 16).

6 Conclusion

Floating car data is a method to determine the average traffic speed on road networks based upon the collection of localization data, velocity, direction of travel, and time information from moving vehicles. This data serve as an important source for traffic information and for most intelligent transportation systems. In this paper, we looked at the different technologies behind FCD as the key to FCD is in gathering the source data. Presently, this is conducted using either the GPS or cellular networks. The former uses a system of satellites (GNSS) providing autonomous geo-spatial positioning whereas the latter utilizes cellular network data (GSM). The difference in the technologies reflects differences in data acquisition. In order to use FCD using the GPS localization it is necessary to equip vehicles with an on-board unit (OBU) which means additional costs. Vehicles equipped with OBUs are usually fleets of taxis, company car vehicles, and trucks. Even though the number of vehicles carrying OBUs has been increasing lately, the penetration rate of these vehicles is still low. This represents one of the major drawbacks of this technology. Also, careful consideration must be given to which vehicle fleets to equip. For instance, taxis provide a major source of inner city traffic information which can sometimes be misleading as they may be using reserved taxi lanes or the drivers, due to a detailed knowledge of the area, take steps to avoid congested roads. Thus, the perception of the current traffic status can be different than actually is.

On the other hand, FCD using GSM localization works on the premise that a high proportion of vehicles contain one or more mobile phones which periodically transmit their presence to the mobile phone network, even when they are not being used for communication. Therefore, every driver with a mobile phone can be used as a data source with no effort or direct involvement in the monitoring needed on his or her part. The fact that this method does not need any additional infrastructure, nor hardware in vehicles, is fast to set up in new locations, needs less maintenance, and offers great coverage of road networks makes it a very good alternative to the GPS concept. However, one of its disadvantages is low accuracy of localizing vehicles. The GSM’s degree of impression can be as high as 300 meters which is in comparison with the GPS accuracy of approximately 10 meters really bad. Additionally, it requires special care in instances of a high speed railway track near the road as it could misinterpret a train as an incredibly fast moving vehicle. Generally, complex algorithms have to be used in order to transform the source data from the GSM method into high-quality traffic information. Nonetheless, both FCD technologies are a very good supplement to conventional stationary traffic sensors as they represent a low-cost traffic sensor for inner city applications. In contrast to the stationary detectors, the travel time and route of vehicles can be detected more reliably.

Recently, there has been introduced the so-called second generation of FCD system known as extended floating car data (XFCD) which works in a similar manner to FCD. However, it offers additional data coming from various vehicle sensors. For example, this includes information on vehicle’s driver assistance systems (for example ABS, ASC, DSC), brakes, friction, crash/airbag, doors, rain sensors, temperature, steering angle and so forth. Therefore, it can provide a possible indication of black ice and risk of the car skidding on the basis of ABS and DSC activation at a low road speed with the brake pedal pressed down only slightly, and in conjunction with a low outside temperature. This type of information adds another dimension to traffic monitoring, especially the combination of vehicle sensors and weather conditions.

Part of this thesis was also focused on providing a general overview of the current Intelligent Transportation Systems incorporating data from floating vehicles from the Czech Republic and abroad using data from FCD. In total, four projects were described including Czech Republic’s “RODOS”, ITS Vienna Region, BMW’s “ConnectedDrive” and TomTom’s traffic services. The importance of integration of FCD into transportation systems is also underlined by the fact that also leading car manufacturing companies such as BMW as well as companies producing navigation systems such as TomTom are investing heavily in developing their own FCD-based applications and services.

This chapter focuses on some of the ITS approaches from Europe using data from floating vehicles. It firstly describes ITS Vienna Region, a telematics projects which provided us with FCD data from their fleet of more than 600 taxis. Then it moves to an example of the extended version of probe vehicles – XFCD – that has been employed by BMW’s system known as “ConnectedDrive”. So that there is also a showcase of an ITS system within the Czech Republic region, a research project called “RODOS” has been described in more detail together with its partnered companies. Finally, the world’s leading producer of navigation, mapping and traffic products – TomTom – has been mentioned and introduced as a ground-breaking company providing better traffic services for their users.

The crucial element of this paper focused on an analysis and interpretation of FCD in the form of a powerful tool for traffic engineers to support them in identifying traffic congestion. Due to close cooperation with ITS Vienna Region we were able to obtain data from a fleet of 600 vehicles. We examined over 6 and a half million records of FCD samples from taxicabs in Vienna during a week beginning March 24 and ending March 31, 2014. For the data processing we used MATLAB, which is a high-level language and interactive environment for engineers and scientists, as Microsoft Excel proved to be incapable of working with such a large amount of data.

We used a processing methodology that included techniques such as data validation, filtration, integration, transformation and reduction as it was necessary to eliminate incomplete, incorrect, extreme, missing or redundant information. We set a certain threshold for maximum time and distance values between two consecutive GPS points in order to eliminate values that were too further apart and could provide misleading information about traffic status. Therefore, if the time interval and travelled distance between two consecutive points were greater than 4 minutes and 1500 meters we eliminated them. There were around 4 % of such samples from the whole data set.

Subsequently, we looked at the GPS precision and the number of visible satellites that were in line of sight during the signal transmission. In general, it is necessary to see at least 3, ideally 4, satellites in order to accurately determine the vehicle’s position. Therefore, we disregarded those with 4 and less visible satellites which represented around 2 % of the total. In addition, we plotted some of the recorded positions and using satellite images showed the level of precision that the GPS method achieved. The localization seemed to be much more accurate on highway sections with fewer obstacles in the signal’s way as opposed to city centre locations with tall buildings making it harder for the GPS signal to pass through.

We then looked at mean velocities during individual days within the given week and found that weekdays and weekends presented two typical representative speed patterns. Also, the mean speed on weekends (33.9 km per hour on Sunday) proved to be much higher than during weekdays (31 km per hour on Friday). We also looked at relative frequencies of different speed clusters (such as 1-10, 20-30, 30-40 km per hour) that showed even greater differences between velocities on weekdays and weekends.

Finally, as an example of the congestion identification process we chose Friday as a suitable day due to its lowest daily mean speed as well as the lowest mean speed during afternoon rush hours. We plotted recorded positions and derived velocities between 16 and 17 hour on a satellite image in order to see low speed areas. Several areas, mainly in the city centre and near the south bank of the River Danube were identified. So that we could tell for sure that these areas were congestion-prone spots, we looked at different days as well, particularly Monday and

Wednesday. Only one of the identified areas seemed to be heavily congested on all of these days. After detailed examination of the area, we found out that it was similar to Wenceslas Square in Prague in terms of high frequency of pedestrians. Therefore, we proposed to introduce pedestrian zones in order to eliminate traffic within this area and make it less congestion-prone. Following this procedure traffic engineers could easily identify special traffic variation in case of events like demonstrations, soccer games, unusual weather condition or vacations. However, it is also a useful tool for everyday traffic monitoring that can identify problematic areas. Additionally, it can serve as a time-dynamic map of both historic and real-time link-based velocities as well as the input for other traffic service applications.

Nonetheless, we identified several limitations of this methodology. Firstly, it is necessary to examine the identified locations in more detail before labelling it congestion-prone as it is possible that there were road signs limiting the road speed within the given area. Thus, traffic engineers have to be familiar with the area that is being monitored. Secondly, taxi-FCD samples always need special care in terms of drawing conclusions on traffic status as it is possible that the taxicabs have their own designated lanes and could thus provide misleading information about traffic conditions.

All in all, we have demonstrated the potential of FCD to identify congestion-prone locations and to use these data for traffic management purposes. However, it is important to note that the full strength of FCD approach will be gained by the data fusion in progress with data from other sources such as stationary or remote sensing technologies.

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