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# Floating Car Data Technology

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## ABSTRACT

The limiting conditions of traffic in cities, together with the complex and dynamic traffic flows, require an efficient and systematic management and information provision for the traffic participants, with the goal to achieve better utilisation of traffic resources and preserve sustainable mobility. In that context, it is important to identify the traffic flow location features, which requires data and information. This paper presents the application of mobile vehicles for the collection of real time traffic flow data. Such data have become an important source of traffic data, since they can be collected in a simple and cost-efficient way, enabling higher coverage than the conventional approaches, despite the reliability issues. The term referring to that type of data collection, commonly used in scientific and professional literature is FCD (Floating Car Data) and "Probe vehicle". The efficiency presentation of applying this extensive data source for retrieving necessary parameters and information related to the achievement of sustainable mobility is the final objective of this paper. A description of modern technologies that serve as a basis for probe vehicle data collection has been provided: a geographical information system (GIS), global navigation satellite system (GNSS) and related wireless communication. Within the key technologies review, the development possibilities of data collection by mobile sensors have also been presented.

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## 1 Introduction

The traffic flow data collection is necessary in traffic engineering but also for the efficient management system functioning and for the series of other ITS (Intelligent Transport Systems) applications, setting real time requirements. Real time data are important for achieving sustainable urban mobility since they enable adaptive traffic management i.e. the management system is able to constantly adjust the decisions to the real traffic conditions. This is valid also for other services such as: third generation navigation, dynamic routing on the transport network, incident detection etc.

Today, the traffic flow data are mostly collected by the traffic flow sensors. There are several different sensor technologies and commercial products of various features and prices. Depending on the traffic management system requirements, in order to select the most suitable

traffic flow sensors, a specification of the needed traffic flow parameters has to be defined. The key deficiencies of traffic flow sensors are a low transport network coverage and an impossibility to retrieve O-D (origin – destination) data.

One of the new real time traffic flow and transport system data collection methods is the application of mobile platforms and GNSS (*Global Navigation Satellite Systems*). The terms used in Anglo-Saxon scientific and professional literature referring to this type of data collection are FCD (*Floating Car Data*) and *Probe Vehicle*. This method includes the integration of multiple technologies: satellite positioning systems (GNSS), wireless communication, geographic information systems. The basic principle implies a vehicle moving through the transport network and continuously sending data to the traffic centre. The advantages of this method are a high transport network coverage and a possibility to retrieve O-D (origin – destination) data.

Using additional sensors on the vehicle and/or the data from the vehicle information bus can extend the sent data set, which is a system known as XFCD (*Extended Floating Car Data*).

A significant number of papers related to FCD system development have been published. One group of articles is focused on the FCD vehicle share in the total amount of vehicles and the data delivery frequency. The second group is addressing the issues related to the processing of the extended data collected by the XFCD method. The third group are the articles discussing the wireless communication technologies and the FCD expansion to the so-called FCO (*Floating Car Observer*), by using short range wireless communication technologies. There are also articles describing the computer vision application for the expansion of the XFCD data set.

## 2 Sources of Traffic Flow Information

A traffic flow can be described as an overall flow of traffic entities (vehicles, passengers, packages...) through the service resources of the network. Depending on the perspective, a traffic entity can be a means of transport (road vehicle, train, ship, plane...), passenger or a message, a package or a call (in information transport). In the context of road transport, a traffic flow is a set of traffic participants changing their position in space, in relation to time. Therefore, the traffic flow can in principle be described using the observed time and the spatial coordinates of traffic participants.

Today, the measurement and data collection (on the basis of which the parameters of the traffic flow values are being retrieved or calculated) can be done in several ways,

**Table 1** The parallel overview of the traffic flow data and information

Traffic flow data/information sources		Processing methodologies and information coverage	Basic features
<b>Detectors</b>	Inductive loop	Piezoelectrical	Installation on a fixed position, covering a small traffic surface (point, section or a small polygon). Characterised by a time continuity of data provision. Mostly used for automatic traffic management.
	Magnetic	Ultrasound	
	Infrared	Sound	
	Radar	....	
<b>Video surveillance and Video Image Processing (VIP)</b>	Stationary cameras		Installation on fixed positions, covering a relatively small area of the transport network, but larger than the classical detectors. With a suitable software, it is possible to gain data similar to classical detectors.
	Mobile platform cameras		They cover a large part of the transport network but not simultaneously. It is possible to gather data related to traffic flows, infrastructure and environment.
	(Time sequences; frames)		(A complex process of data/information extraction).
<b>Aerial / satellite photography</b>	Unprocessed and georeferenced photographs		They have a high coverage and can retrieve data about traffic flows and infrastructure. The atmospheric conditions and high costs affect the availability of high-quality imagery. Due to the complexity of the data processing, they cannot provide real-time data.
	(merging multiple photographs; ORTOPHOTO)		
<b>Observers</b>	Traffic participants (calls)		Mostly local calls when incidents occur.
	Special services (calls and reports)		Used as needed.
<b>Probe vehicle (FCD)</b>	Basic FCD model (Floating Car Data)		They cover a large part of the transport network but not simultaneously. The method is suitable for identifying the real time traffic flow conditions on the transport network.
	Expanded models: XFCD ( <i>Extended FCD</i> ) FCO (Floating Car Observer)		They enable additional data e.g. video imagery, data from the vehicle information bus, data related to the local environment of the vehicle etc.

Source: Authors

using different technologies. For example: by traffic flow sensors, video surveillance, mobile platform video imaging, satellite and aerial imagery, using vehicles equipped to enable satellite positioning and FCD communication etc. As the traffic flow parameters describe both the current and the historical traffic flow conditions, their application is wide. They serve as a direct manager parameter in automatic management systems, as the parameters intended to be minimised or maximised through the traffic management, as service quality indicators, as evaluation indicators for the applied betterment measures, as input data for various simulation models or ITS (Intelligent Transport Systems) applications [1].

Besides the traffic flow parameters, other information usable in the ITS can be retrieved from the information source. The examples of such information are: the congestion locations, incident detection, weather and visibility, road and other transport infrastructure conditions, air quality, noise etc. The transport system information sources today include various modern telematic technologies, primarily different sensors, wireless communication, satellite positioning, video application, but also data processing e.g. computer vision [2].

The methodology for an accurate and reliable assessment of traffic flow conditions, especially on urban roads, is the key part of the traffic management and control. In practice, different traffic data and information sources (Table 1) are used (magnetic loops, road counters, radar, Bluetooth, FCD etc.) in order to assess the traffic conditions and provide traffic parameters and information such as road occupancy, average speed (time taken) and corridor density. Finally, these parameters are combined for the purpose of assessing the conditions or traffic flow indicators, on the basis of the key relations between the flow, density and speed. The aforementioned relations enable the identification of various traffic conditions (con-

gestion, free flow etc.) and events (e.g. entrance or exit to/from a bottleneck, shock wave etc.).

The Table 1 gives an overview of the contemporary information sources based on different technologies. Regarding the FCD possibilities, in comparison to other sources, the transport network coverage is higher and there is a possibility of dynamic traffic detection (DTD), which could be highlighted as the key advantages of the concept. The FCD application is a suitable method for the identification of the network traffic flow conditions in real time.

### 3 Floating Car Data, FCD

#### 3.1 Basic Concept of Probe Vehicle Data Collection

The probe vehicle data collection system (FCD) is based on several sub-systems of different technologies. Figure 1 presents the key technologies included in the probe vehicle traffic data collection, together with the possible applications of these data. The basic data, related to the vehicle position and time, are generated by the satellite positioning system terminal. These vehicle coordinates and time data are delivered as “raw” data to the processing centre. Since mobile platforms are included, a wireless communication is required. The most appropriate system for the location-related information processing and presentation is GIS (Geographic Information System).

Despite the reliability issues and mostly because of the lower costs and the higher traffic network coverage, the application of the FCD data collection system is increasing. It most often implies real-time data collection by locating the vehicle in space and time (as shown in Figure 1). The data like the vehicle location, travelling speed and direction, are sent anonymously to the central processing unit and then processed in order to produce applicable data and/or information.

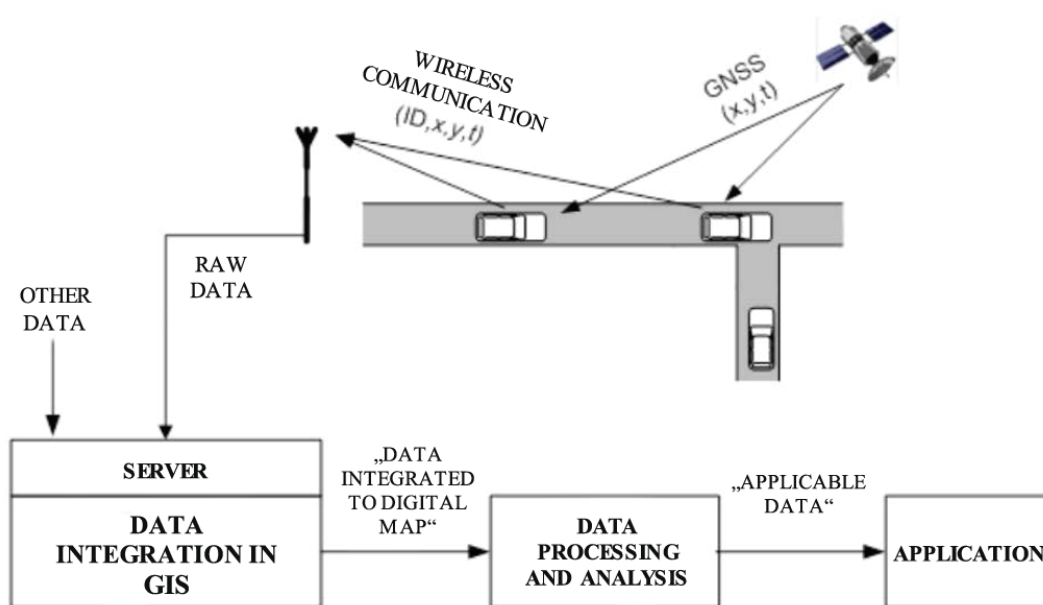


Figure 1 Probe vehicle data collection system [3]

Today, the vehicles used as probes usually belong to a fleet, most often taxi service, since they are already equipped by an OBU device (On – Board – Unit; a device for receiving, sending and processing data; mobile computer). Such mode of data collection, that includes taxi vehicles, is known as the “Taxi – FCD” [4]. A significant number of pilots (Berlin, Vienna, Beijing, Hefei...) and researches was launched globally (e.g. DLR - Das Deutsche Zentrum für Luft- und Raumfahrt e.v.), confirming that this way of data collection and processing, by using algorithms, can generate traffic information with high accuracy even with a small share of FCD in real time [5].

Therefore, one of the most important aspects of the efficient application of probe vehicles is the share of probe vehicles in the total amount of vehicles. The bigger the share, the more reliable the presentation of the transport network conditions is. According to the paper [6], a minimal recommended share of probe vehicles is 2.4% on highways and 10% in the urban network. In other papers related to urban surroundings, e.g. [7], a minimum share of 2% is proposed, in [8] it is 10% while in [9] the minimum is set between 3% and 6%.

More additional data on the probe vehicle share can be found in paper [10].

The next important issue is the frequency of sending messages from the vehicle to the data processing centre. A very high frequency i.e. short time intervals between the messages, put a significant pressure on the communication network and the receiving server of the probe vehicle system. If the frequency is low, and the message does not contain the record of the vehicle, the system becomes unusable for traffic flow conditions assessment. According to [11], the interval of 30 sec generates an acceptable error in traffic conditions calculation, while an interval of 60 sec is not acceptable. Nowadays, as a consequence of using the existing fleet management systems, the frequency is most

often low. The paper [9] defines the level of congestion in Beijing by using taxi vehicles as probes, with an envisaged sending interval between 60 and 90 sec.

In addition to the aforementioned data collection approaches based on probe vehicles, a series of other systems is being developed, such as the ones based on networking (of social network users) or free mobile (smartphone) applications that collect data on traffic flows. For example, the Waze application differs from other classical navigational applications because it focuses on the real-time data exchange among the application users. In Waze and other similar applications, during the traffic related data transfer, other data are also being exchanged. Therefore, different information of interest can be provided e.g. the location of police control or road works. Of course, the accuracy and the update of data depend upon the number of application users within the certain territory. There are also voice information services integrated in the application, so that drivers could concentrate on the driving instead on the mobile device. The benefits of these types of applications come from enabling all users to report on traffic conditions.

### 3.2 Extended Floating Car Data (XFCD)

Besides the basic data, i.e. information retrieved by the probe vehicles, by using additional equipment which is today available in modern vehicles, the data set sent by probe vehicle can be significantly extended. For example, the Driver Assistance System- DAS can significantly expand the basic data set [12].

In order to demonstrate the scope of the information (retrieved by the vehicle) that could be used in the FCD system, the information cycle that includes the driver is illustrated in Figure 2. In terms of the temporal aspect of data collection, the data generation occurs within several

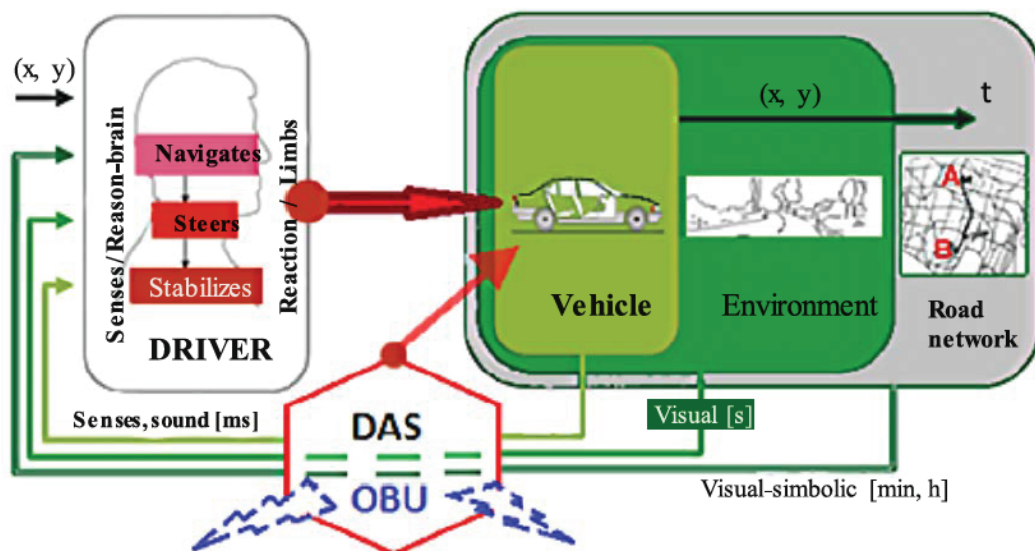


Figure 2 Spatial and temporal aspect of the potential FCD  
Source: Authors

milliseconds to minutes. In spatial terms, data can be collected from the vehicle itself or from its surroundings successively within the transport network.

The various systems that use the data generated in the vehicle are also developed by the vehicle producers (BMW, Audi, Volvo etc.). These are most often development projects i.e. pilots related to traffic safety, which include the application of advanced systems. For example, the NFC (Near Field Communication) is a standardised contactless technology, with a short-range between two electronic devices (communication between the pedestrian with a smartphone and in-vehicle transceiver (Bluetooth or Wi-Fi). In case of danger, these data and other information (distance from the next vehicle, records from the thermal and infrared cameras...) are being projected on the windshield and are also the potential sources of information for the probe vehicle system.

One of the ways to expand the data set collected by the probe vehicles is the video technology and computer vision application. In case of transferring the entire georeferenced video record, a significant amount of information can be acquired, Figure 3. However, the process of extracting the individual data from the video records by using digital image processing is a complex procedure, requiring many software and hardware resources. Additionally, there are other specific problems such as extreme weather conditions, lighting etc. [13].

The expansion of the data set sent by the probe vehicle, which does not include the transfer of the entire video

record, can be achieved by the application of the so-called virtual detectors. In that case, the video record is processed in the vehicle and only the data about the detected vehicles and/or information of interest are being sent [14]. In this paper [15], the authors have used the XFCD in order to assess the transport network level of service (LOS), while applying the stereovision and computer image processing.

### 3.3 Wireless Communication Technologies and a Cooperative System for Probe Vehicle Data Collection

The communication technologies which enable mobility are necessary for the application of FCD. As the FCD implies a data transfer from any point in the transport network to the centre for FCD data receiving and processing, the most commonly used are the cellular mobile networks such as GSM (Global System for Mobile Communications) and similar technologies GPRS (General Packet Radio Service), EDGE (Enhanced Data Rates for Global Evolution), UMTS (Universal Mobile Telecommunication System), HSPA (Evolved High-Speed Packet Access) and LTE (Long Term Evolution), which is the first example of 4G generation of mobile data transfer used from 2009 [16][17]. Figure 4 shows the basic features of mobile data transfer development.

Very suitable for the extended FCD (XFCD) and its application in the cities are the WiMax (Worldwide Interoperability for Microwave Access) networks, characterised by mobility and high data transfer speeds [18][19]. The short range communication technologies can also be applied in the FCD system, e.g. Wi-Fi (Wireless-Fidelity, IEEE 802.11), Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.4), RFID (Radio Frequency Identification) and other NFC (Near Field Communication) technologies.

Their application is primarily related to the extension of data collection possibilities like in the case of intelligent cooperative sensing. For example, in paper [20] the Bluetooth technology is used for the extended data collection from vehicles not being directly connected to the central, but which are in the range of the vehicles who are connected. Figure 5 shows that Wi-Fi networks could be used in the same way.



Figure 3 The system of georeferenced video (developed by the Faculty of Transport and Traffic Sciences) Source: Authors

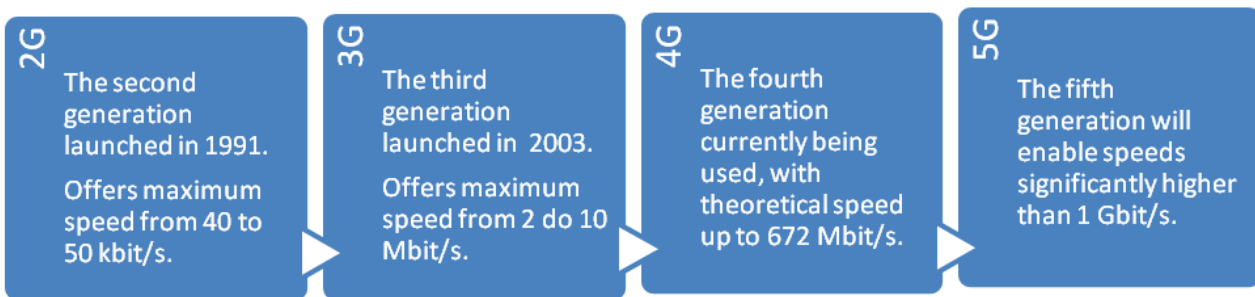


Figure 4 Overview of mobile telecommunication data transfer technology development Source: Authors

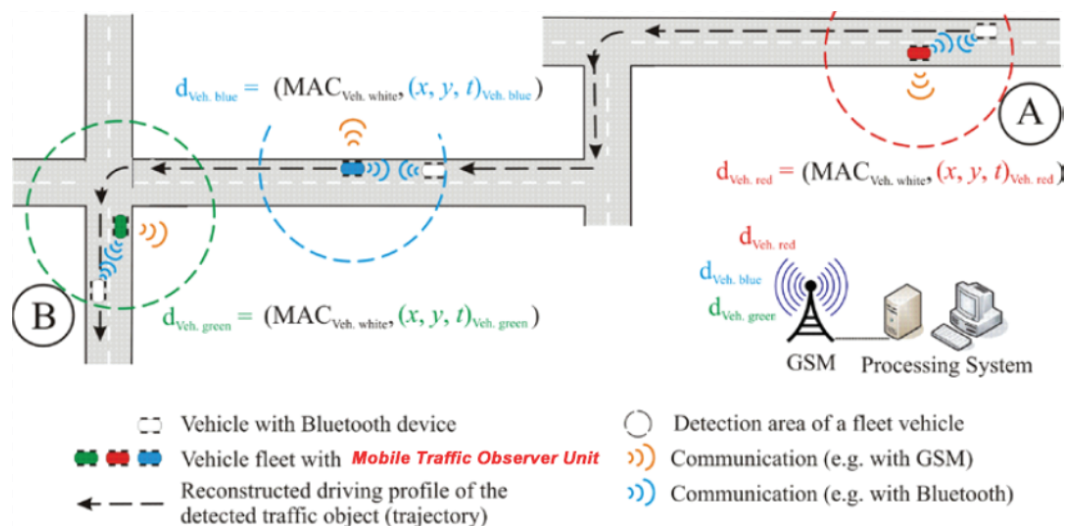


Figure 5 The application of the Bluetooth technology in the probe vehicle system [20]

Bluetooth technology enables a unique identification and re-identification, so that travel times in the transport network could be measured, thus theoretically identifying the O-D (origin – destination) data. The key problem in this approach is the time theoretically needed for establishing the connection between devices.

Within the paper [20] and other research studies, such as [19], the authors have used the term FCO - *Floating Car Observer*, denoting a concept in which the vehicle does not only send data related to its position, but also communicates to other traffic participants in their proximity. In the scientific projects, e.g. FP7 (ICSI), FCO is a part of the intelligent cooperative sensing. In these systems, there is a large amount of input data which makes the information generation from such spatially and temporally distributed data quite complex, particularly because the data are random, inconsistent, time-varying and imprecise or incomplete. For that reason, different approaches are used for data processing – from mathematical methods and fuzzy logic [21] to neural networks [22].

The standardization of the telecommunication technologies for ITS is of great importance for the successful application of the aforementioned communication technologies in the FCD and XFCD. It is the objective of standardization organisations ITU-T (Telecommunication Standardization Sector) through the multiple study groups, primarily the SG16. This group is dealing with the standardization of the wireless communication between vehicles (V2V - Vehicle to vehicle) and between the vehicle and the infrastructure (V2I - Vehicle to infrastructure) i.e. defines the communication platform for the ITS (Vehicle gateway platform for telecommunication / ITS).

Through the series of working groups, the ISO (International Organization for Standardization) is developing an ISO/TC204 standard for the global integration and interoperability of telecommunication technologies in ITS environment. The vision, according to the IEEE

(Institute of Electrical and Electronics Engineers), is a globally standardized network enabling communication between vehicles and access points. The most important is the data exchange between vehicles moving in high speeds within the licensed radiofrequency bands for ITS applications (5,85 GHz - 5,925 GHz).

In Europe, the CEN (European Committee for Standardization), CENELEC (European Committee for Electrotechnical Standardization) and ETSI (European Telecommunications Standards Institute) organizations for standardization are dealing with the standardization of traffic telematics, with Technical Committee TC 278 (TC 278 – Road transport and traffic Telematics) being the most important entity [23].

## 4 Basic Support Technologies to Floating Car Data Collection System

### 4.1 Systems of Satellite Positioning and Navigation

The fast and reliable positioning with satisfactory accuracy and global coverage can be achieved by the application of the Global Navigation Satellite System (GNSS). The most significant representatives of GNSS technology are the American GPS (*Global Positioning System*), the Russian GLONASS, the European Galileo which is in its initial implementation phase and will be operational by 2014, the Chinese Compass planned to be operational by 2015.

All these systems comprise three segments: space (orbital-satellite) segment, control segment (ground-based) and user segment (receivers).

A low-power radio signal is used for measuring distance. The signal contains the encrypted data about the sending time. Based on these data, the receiver calculates the distance to the satellite and then its own position if there are at least three “visible” satellites.

Important for the probe vehicle systems is the development of stationary ground reference stations networks, intended for the correction of the positioning calculation. The availability of these data is significantly increasing the accuracy of the probe vehicle systems. For example, in Croatia, the State Geodetic Administration (SGA) has established a national station network called CROPOS (*CROatian POSitioning System*) which became operational on 9<sup>th</sup> December 2008. The high level of technological and technical quality of all system components, its administration and maintenance, has enabled reliable system operation and availability on 99.9% of the national territory. The CROPOS system consists of 30 reference GNSS stations on a 70 km distance. The network of GNSS stations enables a continuous measurement processed in the controlled system, with the final results delivered to the users by mobile communications. There are three types of services available, differing on the solution method, data transfer modes, accuracy and data format.

The most significant CROPOS service, supporting the probe vehicle systems, is the Differential Positioning System (*in Croatian: "Diferencijalni servis pozicioniranja", DSP*) operating in real time with 0.5 m accuracy. For that reason, it is suitable for utilisation in probe vehicle systems, where, in addition to the data processing algorithms and hardware development (SIRF chip; small dimensions, low price), it enables high accuracy and high positioning speed. It intended application is in geo-informational systems, navigation, traffic management, environmental protection, agriculture and forestry.

The second two services:

- **VPPS** (*in Croatian: "Visokoprecizni pozicijski servis pozicioniranja u stvarnom vremenu"*) – centimetre accuracy; intended for the application in state measurements, cadastre, geodesic engineering, state boarder measurements, aerophotogrammetry and hydrology. This service is referred to as RTK (*Real Time Kinematic*) service.
- **GPSS** (*Geodesic Post-Processing Service*) – it includes a precise geodesic positioning service of subcentimeter

accuracy, intended for the application of basic geodesic networks, scientific and geodynamic research. The service requires a complex hardware and is not of interest for the FCD systems.

### 4.2 Geographical Information System

GIS, *Geographical Information System* is a space-oriented database with a set of tools used by persons and applications for the purpose of problem solving, applied to space in the real world. The GIS integrates spatial and table (non-spatial) data within the "smart" map, enabling the users to create interactive inquiries, carry out research, spatial information analysis and data editing.

The spatial database contains object-based spatial data: points, lines and polygons connected by the topology into logical groups (the relations between objects are defined) for the purpose of creating real-world models. Classical databases can store only numerical and textual data [24], while the GIS enables a digital presentation of the realistic space.

The result of the GIS analysis can vary from the provision of simple answers, responding to questions such as "where" and "how many", but can also reply to the most complex inquiries such as "what" and "if" [25]. GIS enables the transformation of the spatial data to relative information and correlate them to temporal variables.

Additionally, it is possible to integrate different types of data e.g. a georeferenced video [13] that can serve for the upgrading of the probe vehicle system.

It should be highlighted that the data received from the probe vehicles have a value only if observed in the spatial (geographical) context. Therefore, the linear referencing is extremely important for the FCD system, as it integrates all section related data and enables a simple application of algorithms without a need for a complex spatial interpretation. The complex spatial referencing is in fact geocoding, simply presenting length and direction (vector) and mitigating the positioning errors [3].

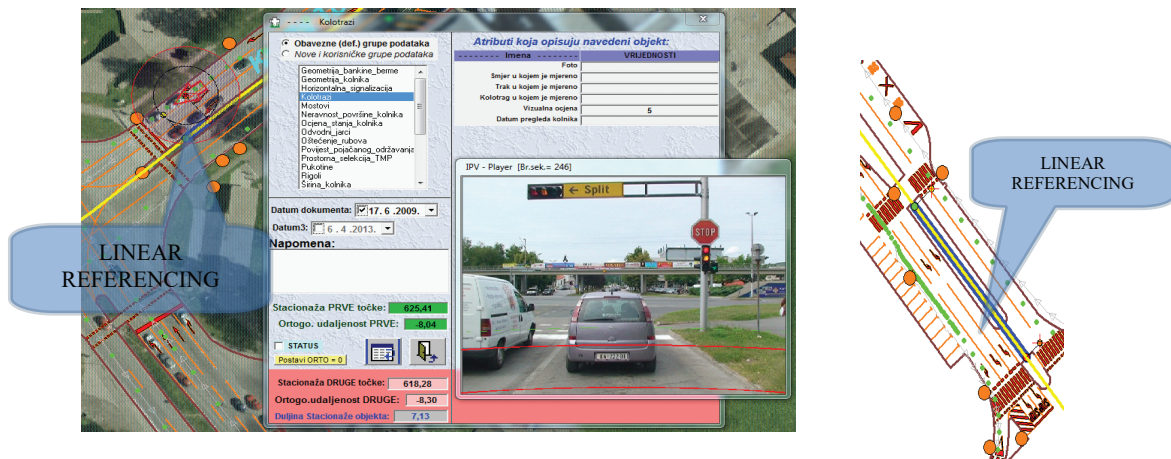


Figure 6 Linear referencing supported by a georeferenced video (OptaGIS, FTTS)  
Source: Authors

Figure 6 shows an example of linear referencing done in the OptaGIS application developed on the Faculty of Transport and Traffic Sciences (FTTS). Within this approach, time can be simply added in the data model, making the analysis easier.

The basic characteristics of the linear referencing applied in the traffic flow data collection, processing and presentation are the following:

- Route defining (simple route identification)
  - Route segmenting into sections (the division of route into multiple segments with the starting and ending point).
- Assigning values along the route (to segments from – to)
  - Establishing relations to the chainage (object localisation along the liner geometry).
  - Unification of the geometric data into a whole.
  - Possibility of harmonization and re-calculation of the chainage coordinates into the geo-coordinates and vice-versa.
  - Grouping multiple features without the need for segmenting.
- Feature referencing by the application of tables
  - Establishing relations between objects which do not possess geometry suitable for segments.
- Simple presentation of events along the route (visualization) [26][27].

For the purpose of traffic analyses, GIS can - with the layer containing the georeferenced video - enable a driver's perspective on the infrastructure, providing conditions that significantly differ from the ones present on-site (the possibility of stopping and repeating the scenes), thus enabling a more detailed analysis and a better perception. By further development of the georeferenced video and similar supporting technologies, new possibilities of data extraction, perception, research methods and real time traffic analysis will arise.

#### 4.3 Methodologies of FCD Processing

An overview of the most frequently used traffic flow forecasting methods has been provided in a significant number of publications [14] [28].

The historical average method estimates the values of specific traffic parameters by calculating the average value of their historic values. A higher accuracy can be achieved by grouping data, which is based on data groups formation and averaging within these groups [29].

The parametric models are based on a final set of parameters and require only the information for determining the values of model parameters. These values are determined from the available traffic system data. The data set is smaller than with the non - parametric models [30]. Most often, these are the traffic simulation models. The traffic simulation is based on the idea of traffic behaviour modelling and rules insertion, usually building on origin - destination (O-D) matrixes for the pairs of origins and destinations [31][32].

The non-parametric models require much more data than the parametric ones, which is also their main deficiency. However, the advantage is their flexibility, reflected in the possibilities of dynamic traffic flow modelling. The non-parametric models for traffic flow characteristics prediction include the methods such as K-Nearest Neighbour, [33][34], Weighted Regression [35], Fuzzy Logic [36], Bayesian Networks [37][38] and Neural Networks [39] [40].

The literature review has shown that most of the papers dealing with travel time forecasting use the regression method. The regression is a method anticipating the value of numerical data. There are parametric and non-parametric regressions. Within the parametric regression, the model parameters are determined on the basis of known data values. Based on the data parameters, the envisaged data variables are determined. Such models are also used for travel time and speed prediction [41][42]. While examples of nonparametric regression models for estimating travel time use complex statistical models [33].

One of the possible approaches to FCD processing is the application of deep analysis. According to [43], a deep data analysis is a process of knowledge retrieval from large amounts of data with the final goal to detect useful, understandable, correct, new and non-trivial patterns.

There are several models describing the deep analysis, with CRISP-DM (CRoss Industry Standard Process for Data Mining) as one of the most known and often cited models. The CRISP-DM model defines the deep analysis as an iterative process with an objective to solve a certain problem [44].

When selecting a method for the FCD processing, one should pay attention to the final objective which is usually related to the speed profiles on the transport network sections, identification of locations with repeating and non-repeating congestion or identification of bottle necks, also discussed by many authors.

#### 5 Application of Information Retrieved by the Probe Vehicle (FCD)

The possibilities of applying the information gained by FCD primarily depend upon the data quality. There are three key impacts to probe vehicle data quality. The first represents the set of emitted probe vehicle data, the second, the frequency of probe vehicle data, and the third, the share of probe vehicles in the total amount of vehicles on the network [15][45].

Although there are globally numerous projects related to the probe vehicle use, their share is mostly small. The current studies have been focused on the traffic flow reconstruction, based on a small share of probe vehicles, with an application of interpolations and probability, like in [46]. Such processing often results in graphical presentations like the one in Figure 7, which clearly shows the predicted maximum travel speeds and times on road sections.



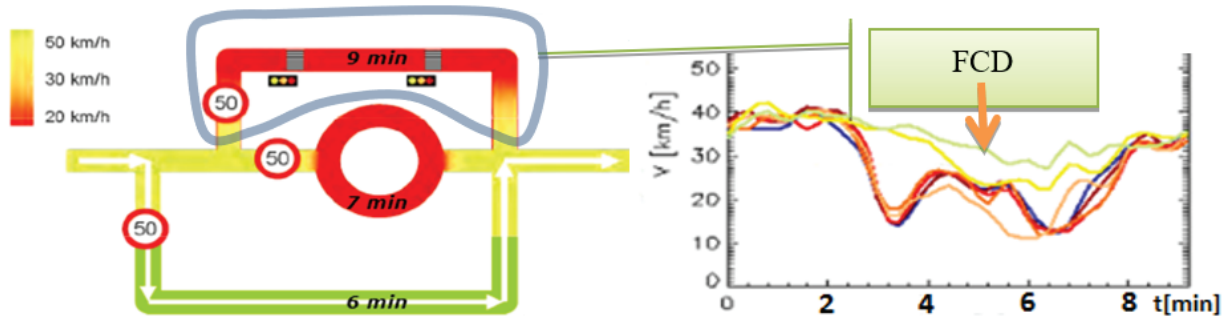


Figure 7 The illustration of the resulting speed profiles retrieved by mobile sensing  
Source: Authors

The calculation and the presentation of quantitative and qualitative parameters for traffic flow description in cities have been a subject of various researches. The quantitative parameters encompass the number of stops on intersections, delays at intersections, O-D data, and the qualitative one refers to the level of service (LOS) [47][48].

The paper [49] has proposed a light signalling management system based on real time data from the transport system, FCD being the main data source.

Since the GPS has become a standard equipment in fleet vehicles (as it is used for the surveillance in fleet management (like taxis and trucks)), the data from taxi vehicles has proved to be especially useful due to the vehicle number and the coverage of all city parts [50].

If time and location related data are taken from multiple test vehicles, the speed profiles can be calculated in time intervals for each road segment [51][52]. To make their usage easier, data from fleet vehicles are usually pre-processed in order to identify just the section speed or travel time as in Figure 7.

The processed probe vehicle data, which also include the processing on the GIS platform, are most commonly used for the following purposes:

- traffic management and/or regulation (traffic accidents, road maintenance...)
- road infrastructure capacity planning
- vehicle information systems
- road design and construction
- emergency interventions planning
- logistic routes planning
- navigation (third generation)
- toll/ parking fees collection
- environmental impacts assessment
- other applications dependent on the trip length and duration.

## 6 Conclusion

Because of the high coverage, when compared to the detector technologies, the most commonly used data collection method today is the FCD. The application of the FCD implies an integration of the satellite positioning, wireless communication technologies, geographical infor-

mation system and computer data processing. Besides the basic data set, including spatial coordinates and temporal positions, the FCD (probe vehicle) can also collect other types of data such as the data from the driver assistance, video records or only information provided by the video record processing.

Today, probe vehicles are usually fleet vehicles owned by the organizations with a surveillance and vehicle tracking system developed, e.g. taxi services, postal services and various transport operators. There is a high probability that all vehicles will become mobile sensors i.e. probe vehicles in the near future, despite of the current data privacy issues. As the share of probe vehicles in the total amount of vehicles increases, the data will become more significant and reliable, enabling their application in traffic management in terms of the increased capacity for adaptive management.

The literature includes a significant number of studies with an objective to locate the traffic flow conditions, which could be divided into three main groups:

- focus on the determination of the average speed (section time taken),
- focus on the identification of congestions (bottlenecks)
- focus on the determination of traffic flow parameters.

The indispensable part of the probe vehicle application is the geographical information system. Only after the integration of probe vehicle data with other spatial data, the information is generated with a potential to be efficiently used. The presence of the topic in the previous research has been relatively low, although the subject is particularly important for urban areas. The integration of spatial data, especially data related to the transport infrastructure, in the process of information generation, is not studied proportionally to its potential role in the transport sector.

The application of GIS with an added layer of georeferenced video record has provided an additional dimension of virtual space visualization. The application of the georeferenced video, although demanding significant resources during the system set up and data extractions, represents a good data and information source, enabling various analyses and monitoring the transport network dynamics. In transport engineering, the georeferenced video has contributed to the simple data collection and

the possibility of subsequent, time unlimited, detailed and replicable analysis, which is the main advantage of this approach.

International and European organizations for standardization have been dealing with the communication standards within the ITS environment, thus having direct effects on the possibilities of FCD system introduction in commercial applications. In the future, the communication base of the probe vehicle system will most probably consist of the combination of the cellular network and some of the short-range telecommunication technologies. A probable candidate for the short-range technology is the Bluetooth, as the application trend of this "cheap" technology in vehicles is growing. The new generation of WiMAX<sup>2</sup> and 5G technologies have enabled the XFCD development in terms of sending a large quantity of data by probe vehicles.

The probe vehicle systems have a significant potential, since every improvement of the global navigational satellite systems, wireless communication technologies and computer technology, can simultaneously improve the probe vehicle systems. Considering the growing application of the wireless communication technologies and positioning devices in the automobile industry, the growth of the aforementioned types of data collection from the transport system and their diverse application is also expected.

## References

- [1] N. Jelušić, "Evaluation of Sensor Technologies in Road Traffic Automatic Management System", 2008.
- [2] N. Jelušić, M. Anžek, i B. Ivanković, "Information Source Quality in Intelligent Transport Systems", *PROMET - Traffic&Transportation*, sv. 22, izd. 2, str. 125-131, ožu. 2010.
- [3] D. Budimir, "Mobile Sensor-Based Estimation Method of Spatio-Temporal Indicators in Public Urban Transportation". 2016.
- [4] T. Wang, T. Fang, J. Han, i J. Wu, "Traffic Monitoring Using Floating Car Data in Hefei", u *2010 International Symposium on Intelligence Information Processing and Trusted Computing*, 2010, str. 122-124.
- [5] J. J. Vinagre Díaz, D. Fernandez Llorca, A. B. Rodríguez González, R. Quintero Minguez, A. Llamazares Llamazares, i M. A. Sotelo, "Extended Floating Car Data System: Experimental Results and Application for a Hybrid Route Level of Service", *IEEE Trans. Intell. Transp. Syst.*, sv. 13, izd. 1, str. 25-35, ožu. 2012.
- [6] S. Breitenberger, B. Grüber, ... M. N.-T. engineering &, i undefined 2004, "Traffic information potential and necessary penetration rates", *trid.trb.org*.
- [7] J. Hong, X. Zhang, Z. Wei, i Y. Ren, "Spatial and Temporal Analysis of Probe Vehicle-based Sampling for Real-time Traffic Information System", u *2007 IEEE Intelligent Vehicles Symposium*, 2007, str. 1234-1239.
- [8] R. Long Cheu, C. Xie, i D.-H. Lee, "Probe Vehicle Population and Sample Size for Arterial Speed Estimation", *Comput. Civ. Infrastruct. Eng.*, sv. 17, izd. 1, str. 53-60, sij. 2002.
- [9] J. Sun, H. Wen, Y. Gao, i Z. Hu, "Metropolitan Congestion Performance Measures Based on Mass Floating Car Data", u *2009 International Joint Conference on Computational Sciences and Optimization*, 2009, sv. 2, str. 109-113.
- [10] E. Vanhauwaert, W. Vandenberghe, P. Demeester, I. Moerman, i S. Verbrugge, "Feasibility of expanding traffic monitoring systems with floating car data technology", *IET Intell. Transp. Syst.*, sv. 6, izd. 4, str. 347-354, pros. 2012.
- [11] C. Nanthawichit, T. Nakatsuji, i H. Suzuki, "Dynamic estimation of traffic states on a freeway using probe vehicle data", *Doboku Gakkai Ronbunshu*, izd. 730, str. 43-54, kol. 2003.
- [12] J. Küçükay, F. Bergholc, "Driver Assistant Systems, Institute of Automotive Engineering", 2010.
- [13] I. Dadić, G. Luburić, i D. Budimir, "Surveying-video transport infrastructure as an alternative and supplement to conventional databases", u *34th International convention on information and communication technology, electronics and microelectronics*, 2011, str. 363-367.
- [14] D. Budimir, D. Brčić, i N. Jelušić, "Analiza operativnih karakteristika javnog gradskog prijevoza temeljem prikupljanja podataka pokretnim osjetilima", u *docs.mipro-proceedings.com*, 2015, str. 1351-1356.
- [15] W. ZHANG, J. XU, H. WANG, "Urban Traffic Situation Calculation Methods Based on Probe Vehicle Data", *J. Transp. Syst. Eng. Inf. Technol.*, sv. 7, izd. 1, str. 43-48, velj. 2007.
- [16] C. Ide, B. Dusza, i C. Wietfeld, "Energy efficient LTE-based Floating Car Data collection for dynamic traffic forecasts", u *2012 IEEE International Conference on Communications (ICC)*, 2012, str. 6303-6307.
- [17] G. Remy, S.-M. Senouci, F. Jan, i Y. Gourhant, "LTE4V2X - impact of high mobility in highway scenarios", u *Global Information Infrastructure Symposium - GIIS 2011*, 2011, str. 1-7.
- [18] C. Ide i ostali, "Efficient Floating Car Data Transmission via LTE for Travel Time Estimation of Vehicles", u *2012 IEEE Vehicular Technology Conference (VTC Fall)*, 2012, str. 1-5.
- [19] M. Markiewicz, "Comparison of travel times estimation using intelligent infrastructure and floating car data", u *2012 12th International Conference on ITS Telecommunications*, 2012, str. 375-379.
- [20] S. Ruppe, M. Junghans, M. Haberjahn, i C. Troppenz, "Augmenting the Floating Car Data Approach by Dynamic Indirect Traffic Detection", *Procedia - Soc. Behav. Sci.*, sv. 48, str. 1525-1534, 2012.
- [21] F. Haußer i Y. Luchko, *Mathematische Modellierung mit MATLAB: Eine praxisorientierte Einführung*. Spektrum, 2010.
- [22] H. Dia i K. Thomas, "Development and evaluation of arterial incident detection models using fusion of simulated probe vehicle and loop detector data", *Inf. Fusion*, sv. 12, izd. 1, str. 20-27, 2011.
- [23] D. Majcen, "Wireless Technologies in Intelligent Transportation Systems", 2012.
- [24] M. F. Goodchild, "Geographic information systems and science: today and tomorrow", *Procedia Earth Planet. Sci.*, sv. 1, izd. 1, str. 1037-1043, 2009.
- [25] M. Batty, M. Dodge, B. Jiang, i A. Hudson-Smith, "GIS and urban design", (*CASA Work. Pap. 3*). UCL (University Coll. London), *Cent. Adv. Spat. Anal. London*. 1998.
- [26] T. Miwa, D. Kiuchi, T. Yamamoto, i T. Morikawa, "Development of map matching algorithm for low frequency probe data", *Transp. Res. Part C Emerg. Technol.*, sv. 22, str. 132-145, lip. 2012.

- [27] B. Mu, J. Hu, T. Zhao, i Y. Zhang, "Evaluating the Performance of Link Travel Time Estimation Based on Floating Car Data", u *2010 International Conference on Optoelectronics and Image Processing*, 2010, sv. 1, str. 504–508.
- [28] J. van Hinsbergen i F. Sanders, "Short Term Traffic Prediction Models", *ITS World Congr. Beijing, China*, str. 18, 2007.
- [29] W. Weijermars i E. van Berkum, "Analyzing highway flow patterns using cluster analysis", u *Proceedings. 2005 IEEE Intelligent Transportation Systems, 2005.*, 2005, str. 831–836.
- [30] M. D. Delis, A. Koutsomanoli-Fillipaki, C. K. Staikouras, i G. Katerina, "Evaluating cost and profit efficiency: a comparison of parametric and nonparametric methodologies", *Appl. Financ. Econ.*, sv. 19, izd. 3, str. 191–202, velj. 2009.
- [31] Y. Kamarianakis i P. Prastacos, "Forecasting Traffic Flow Conditions in an Urban Network: Comparison of Multivariate and Univariate Approaches", *Transp. Res. Rec. J. Transp. Res. Board*, sv. 1857, str. 74–84, sij. 2003.
- [32] D. Boyce, "Forecasting Travel on Congested Urban Transportation Networks: Review and Prospects for Network Equilibrium Models 1 1 Introduction 2 The Origins of Travel Forecasting Models", *Traffic*, sv. 2003, izd. August 2003, str. 1–36, 2004.
- [33] B. L. Smith, B. M. Williams, i R. Keith Oswald, "Comparison of parametric and nonparametric models for traffic flow forecasting", *Transp. Res. Part C Emerg. Technol.*, sv. 10, izd. 4, str. 303–321, kol. 2002.
- [34] R. K. Oswald, W. T. Scherer, i B. L. Smith, *Traffic flow forecasting using approximate nearest neighbor nonparametric regression*. University of Virginia, 2000.
- [35] D. Nikovski, N. Nishiuma, Y. Goto, i H. Kumazawa, "Univariate short-term prediction of road travel times", u *Proceedings. 2005 IEEE Intelligent Transportation Systems, 2005.*, 2005, str. 1074–1079.
- [36] L. Li, W.-H. Lin, i H. Liu, "Type-2 fuzzy logic approach for short-term traffic forecasting", *IEE Proc. – Intell. Transp. Syst.*, sv. 153, izd. 1, str. 33–40, ožu. 2006.
- [37] X. F. S. Shiliang, Z. Changshui, Y. Guoqiang, L. Naijiang, "Bayesian Network Methods for Traffic Flow Forecasting with Incomplete Data in Machine Learning: ECML 2004", *Springer*, sv. 3201, Springer, Berlin Heidelberg, str. 419–428, 2004.
- [38] Z. Changshui, S. Shiliang, i Y. Guoqiang, "A Bayesian network approach to time series forecasting of short-term traffic flows", u *Proceedings. The 7th International IEEE Conference on Intelligent Transportation Systems (IEEE Cat. No.04TH8749)*, 2004, str. 216–221.
- [39] S. H. Huang i B. Ran, "An Application of Neural Network on Traffic Speed Prediction Under Adverse Weather Condition", *researchgate.net*, str. 1–21, 2006.
- [40] B. Çetiner, M. Sari, i O. Borat, "A neural network based traffic-flow prediction model", *Math. ...*, sv. 15, izd. 2, str. 269–278, 2010.
- [41] H. H. Versteegt i C. M. J. Tampere, "PREDICTIME : state of the art and functional architecture", *TNO Intro Rapp. ; 2003-07*, 2003.
- [42] F. Gössel, "Informationsentropische, spektrale und statistische Untersuchungen fahrzeuggenerierter Verkehrsdaten unter besonderer Berücksichtigung der Auswertung und Dimensionierung von FCD-Systemen", Der Fakultät für Verkehrswissenschaften der Technischen Universität Dresden, 2005.
- [43] Jiawei, "Data Mining : Concepts and", sv. 05, str. 703, 2012.
- [44] U. Shafique i H. Qaiser, "A Comparative Study of Data Mining Process Models (KDD, CRISP-DM and SEMMA)", *Int. J. Innov. Sci. Res. ISSN*, sv. 12, izd. 1, str. 2351–8014, 2014.
- [45] Q. Li, Q. Ge, L. Miao, i M. Qi, "Measuring Variability of Arterial Road Traffic Condition Using Archived Probe Data", *J. Transp. Syst. Eng. Inf. Technol.*, sv. 12, izd. 2, str. 41–46, tra. 2012.
- [46] A. Graser, W. Ponweiser, M. Dragaschnig, N. Brändle, i P. Widhalm, "Assessing traffic performance using position density of sparse FCD", u *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, 2012, str. 1001–1005.
- [47] T. Neumann, "Rückstaulängenschätzung an Lichtsignalanlagen mit Floating-Car-Daten", 2011.
- [48] S. Messelodi i ostali, "Intelligent extended floating car data collection", *ELSEVIER*, sv. 36, izd. 3, str. 4213–4227, tra. 2009.
- [49] T. Neumann, "Rückstaulängenschätzung an Lichtsignalanlagen mit Floating-Car-Daten", *Schriftenreihe des Instituts für Verkehrssystemtechnik*. 26-lis-2011.
- [50] G. Leduc, "Road Traffic Data : Collection Methods and Applications", *Tech. Note JRC 47967*, izd. January 2008, str. 1–55, 2008.
- [51] L. Xu, Y. Yue, i Q. Li, "Identifying Urban Traffic Congestion Pattern from Historical Floating Car Data", *Procedia – Soc. Behav. Sci.*, sv. 96, izd. Cictp, str. 2084–2095, 2013.
- [52] O. Altintasi, H. Tuydes-Yaman, i K. Tuncay, "Detection of urban traffic patterns from Floating Car Data (FCD)", *Transp. Res. Procedia*, sv. 22, izd. June, str. 382–391, 2017.