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Mobile Systems applied to Traffic Management and Safety: a state of the art

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Abstract

Mobile systems applied to traffic management and control and traffic safety have the potential to shape the future of road transportation. The following innovations, that will be deployed on a large scale, could reshape road traffic management practices:
- the implementation of connected vehicles with global navigation satellite (GNSS) system receivers;
- the autonomous car revolution;
- the spreading of smartphone-based systems and the development of Mobile Cooperative Web 2.0 which is laying the base for future development of systems that will also incorporate connected and autonomous vehicles;
- an increasing need for sustainability of transportation in terms of energy efficiency, traffic safety and environmental issues.

This paper intends to provide a state of the art on current systems and an anticipation of how mobile systems applied to traffic management and safety could lead to a completely new transportation system in which safety and congestion issues are finally properly addressed.

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Keywords: Traffic management and safety; Mobile systems, Smartphone; Traffic control

1. Introduction

This paper intends to provide a general short state of the art on mobile systems applied to traffic management and safety and an introduction to the First International MOBIT Workshop. The cited references are just a small subset of the whole research and innovation works that have been carried out around the world.

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Mobile systems applied to traffic management and control have already been applied around the world with the use of smartphones. An interesting state of the art on smartphone-based vehicle telematics has been presented in [1], the authors of the paper explain how smartphone use that has changed everyday life is starting to also change the driving experience and the connected systems. The systems that are considered are the internet of things and smartphone-based systems useful for many applications such as vehicle and driver classification, "vehicular ad hoc networks and road condition monitoring". The authors also expect future advances to be driven by "improvements in technology, evidence of the societal benefits of current implementations, and the establishment of industry standards for sensor fusion and driver assessment".

In this paper we will develop and review similar concepts, though in the framework of transportation and traffic engineering, thus adding also, shortly, some state of the art on concepts of traffic control and management that have not been discussed in [1] such as traffic control measures (including adaptive traffic signals) and the introduction of blockchain based systems.

This paper follows, 17 years later, a preceding paper [2] which was the start of many research activities on smartphones applications to traffic management and control at the University of Calabria.

2. The Internet of things, the connected vehicle, new sensors that originate a new flow of information and cloud computing

The definition of the Internet of things as a network of smart devices has changed with time. It all started from when for the first time in early 1982 a drink supplier machine at Carnegie Mellon University became the first connected device raising the first discussions on the concept of a network of devices connected by the internet. The paper of 1991 [3] defined "ubiquitous computing" this paper originated the contemporary vision of IoT that Bill Joy presented at the World Economic Forum at Davos (Device to Device communication) in 1999. In the same year Kevin Ashton at Massachusetts Institute of Technology (MIT) forged the term "Internet of things" [4].

The car is often cited among the 13 billion objects that will be connected to the internet in the Internet Of Things (IOT) in the year 2020 [1]. A revolution in traffic management and control will come from the "connected vehicle". Though it is opinion of the authors and also others [5] that smartphones in transportation systems will have a primary role in the experimentation of IOT concepts and systems before actual implementation on vehicles. Smartphones combine the potential of full computers with mobility and with a set of sensors that can originate a new flow of information. Among the set of available new information the simplest and most important at the moment is the location information coming from GPS-equipped smartphones. Most mobile phones include an embedded GNSS receiver which (when connected) can deliver vehicle locations to a server. Smartphones thus today are a low-cost means to determine travel time [6], obtain vehicle speeds [7, 8], evaluate safety performance on the road [9] and calibrate route choice models [10].

3. Mobile internet systems: the cloud and industrial implementations

The idea to connect vehicles to the cloud (VCC) has been explored in many projects conducted by the automotive industries and universities. The focus of the automotive industries has been on providing navigation add-on and new vehicle features such as voice control, Wi-Fi connections [11] and semi-automatic driving assistance systems. Some of the new systems, but not all of them, are based on smartphones. The automotive industries are oriented toward the development of connected and autonomous vehicles bypassing the use of the smartphone for obvious commercial reasons. In any case, it is very likely that the future connected vehicles will be connected through the already existing wireless mobile phone data infrastructure, which after many years of development has reached a world-wide diffusion. Ad hoc wireless networks might be implemented locally, yet they face a considerable departure delay in implementation that may affect world-wide diffusion.

Traffic control can take advantage in many ways of information obtained from road user mobile phones that can act as traffic probes (Floating Car Data: FCD). At the actual state of the art, a large scale deployment of FCD is happening by using both wireless internet and GNSS (Global Navigation Satellite System) technologies. Since these two technologies are already present in mobile phones in almost every vehicle.

Real time information has been used to give back user traffic information and give road guidance in systems such as Tom Tom, Google Maps, Here Maps, iGO, Ovi Maps and Waze.

Insurance companies have used the same system with dedicated devices applied to vehicles to obtain information useful to assess driving risks associated with distance traveled and other dynamic parameters. In the described systems, information is obtained from the GNSS system and is transferred via wireless mobile phone network directly to a central database using Cloud Computing.

Mobile Cloud Computing (MCC) is the use of remote computation resources on mobile devices. By taking advantage of “the cloud”, mobile devices can find a solution to computationally complicated problems which would not be solvable on mobile devices. As observed in [1], lately, MCC applications have been introduced in the context of VANETs, giving birth to the term vehicular cloud computing (VCC).

4. Notable academic research projects and papers on general Floating car data applications (FCD) based on smartphone localization

The first applications of floating car data dates back to the beginning of 1990 some examples of simple FCD usage and/or mobile system applications are in [12, 13, 14, 15, 16, 17, 18, 19, 20, 21].

Some academic works have preceded commercial implementations in gathering data from smartphones on vehicles (FCD projects). Among early academic works that have been collecting data are projects such as: CarTel in 2006 [22, 23]; Nericell in 2007 [24]; ClearFlow [25]; the Mobile Millennium project started around 2008 [26, 27, 28]. More recent projects have been focused also on developing specific mobile applications based on the cloud: the Movelo Campaign started around 2010 centered on insurance applications; M2M in Italy started in 2010 and focused on traffic safety [29]; the Future Cities project started in 2012 which has been gathering data also from the transit system and has produced the SenseMyCity app to estimate fuel consumption and promote car sharing [30]. Many papers have been focusing on FCD applications, where the objective is to gather traffic data from connected vehicles that can be used as traffic probes. Radio-frequency identification (RFID) transponders have been used in some cases such as in [31, 32]. RFID based systems and vehicular ad hoc networks (VANET) have to bear the cost of new infrastructures and devices. For this reason, mobile phones have been used to evaluate traffic conditions in many works.

A whole sector of research generated from the idea of sampling traffic by detecting mobile phone radio signals among traffic vehicles. The idea of using mobile phone radio receivers to count passing by traffic was envisioned in the patent [33] and has produced real implementations in the field in 2008 using Bluetooth protocol to detect the Bluetooth mobile phone radio signals with an external active Bluetooth device. Results of early works in this field were presented starting in 2008 [34, 35]. Other interesting papers on the subject are [36, 37, 38].

Other works have been taking into consideration the possibility of using just mobile phone data without GNSS system data: [39, 40, 41, 42, 43, 44, 45, 46, 47].

In more recent works, given the great diffusion of GNSS systems on common smartphones, satellite localization and wireless internet data transmission has been considered. The penetration rate for FCD systems that is sufficient to obtain useful traffic information has been studied in many papers. In [39] it was recognized that just 5% of the vehicles with GPS sensors would be enough to guess travel times on a freeway network with an accuracy of 95%. Ferman [48] demonstrated that a real-time traffic information system based on FCD data can be achieved for freeways at a 3% penetration rate and for other roads at 5%. Subsequent researches have started to make real implementations in the field of combined GNSS and data transmission, such as [8, 26, 49, 50]. Dailey [51] proposed the use of data coming from transit vehicles to estimate traffic speeds. Axer [52] investigated the use of low frequency FCD to estimate the level of service on traffic networks.

5. Beyond vehicle localization: a list of potential mobile applications based on the new flow of information coming from smartphones

There are many possibilities offered in traffic control and management that go beyond simple vehicle localization when data coming from on board sensors can be gathered and utilized. Moreover, research has been conducted also on mobile commerce applications cooperative systems and business innovations.

Some works on the following topics are presented in the next sections of this paper: navigation, fuel consumption and fuel savings strategies, Cooperative Intelligent Transportation Systems and automated parking operations are discussed in section 6; vehicle classification and mode use in section 7; traffic safety and driving styles are presented in section 8; road condition monitoring in section 9; toll collection, congestion road pricing, floating car data adaptive traffic lights (FCDATL or FCDATS floating car data adaptive traffic signals) and real time control strategies implementation in section 10; finally blockchain based systems and other business innovation are presented in section 11.

6. Navigation fuel consumption and cooperative Intelligent Transportation Systems

Navigation based on a real traffic situation (travel times and link speeds on the network established from FCD data) is a commercial reality that has established a form of cooperative transportation system in which users exchange localization and speed information with other drivers through a cloud-based system. Research has been also conducted to reduce fuel consumption [53, 54, 55, 56, 57, 58], facilitate parking operations [59, 60, 61], on safety issues and special event information and to reduce congestion (congestion can be reduced for example by shifting modal and time of departure choice). Some of the published works constitute a framework for new cooperative Intelligent Transportation Systems. Salin [62] introduced a cooperative system for vulnerable road users based on mobile devices.

7. Vehicle classification and mode use

Smartphones have been used also for vehicle classification and to establish travelers modal choice [63, 64].

8. Traffic safety and driving styles

Availability of smartphone FCD data has allowed researchers to establish unsafe driving behavior and plan ways to promote better driving styles. Among many works: [9, 65, 66, 67, 68, 69,70,71]. Kerner [72] showed that 1.5% of FCD penetration rate can be enough to detect an incident in a traffic center with a probability of 65%. Safe driving competitions to reward users who adopt the best driving behavior have been proposed in [73] (Co-operative ITS: Smartphone-based Measurement Systems for Road Safety Assessment) with the aim to promote, by creating a competitive safety contest between drivers, an educational process towards better and safer driving styles. Warning systems have been proposed for both drivers and vulnerable road users [29,74].

9. Road condition monitoring

Extreme bad road conditions can also be established by smartphone accelerometers information. Potholes and traffic bumps can be located just by a common smartphone on board of a vehicle. Many works have been proposed on obtaining road pavement conditions from mobile phones: [23, 24, 75, 76, 77, 78].

10. Traffic control, adaptive traffic signals and toll collection

As stated above traffic control can take advantage of FCD localization information in many ways. Some subsequent and yet to be fully explored control strategies are based on:

-congestion road pricing [2, 79] and smartphone-based parking and toll collection systems.

-floating car data adaptive traffic lights (FCDATL or FCDATS) as defined in [80]: a promising topic with many present ongoing research activities. GNSS data have been used to evaluate adaptive traffic signal systems in [81]. Smartphones have also been used to obtain information on signal timings [82, 83] with the final scope of offering driving assistance. The use of FCD data to regulate traffic signals is studied in [84] where a cooperative system is presented in which both the infrastructure and the driver behavior is adjusted so that a double optimization is reached. Also in the Colombo project [85, 86], traffic signal regulation is envisioned from Vehicle to Infrastructure communication. Gradinescu [87] proposes to use vehicle-to-vehicle communication and use microscopic simulation to evaluate the proposed sophisticated adaptive control system.

11. Blockchain based systems and business innovation

Many business innovations in the field of mobile commerce are possible. New forms of insurance which take into account real driving paths have been introduced with dedicated devices. Smartphones can also play a role [88, 89], in [90] a framework is presented to deploy a smartphone-based measurement system for road vehicle traffic monitoring and usage-based insurances. A blockchain-based system has been attempted in the Zero traffic project [91] which can raise new ideas such as the idea of a blockchain with proof of work based on miles traveled [92].

12. Conclusions

The authors excuse themselves for having, eventually for lack of space, omitted reference to some relevant works and/or ideas and welcome scientists and experts to participate in the next editions of the workshop.

References

[1] Wahlström, Johan, Isaac Skog and Peter Händel. (2017) "Smartphone-Based Vehicle Telematics: A Ten-Year Anniversary." *IEEE Transactions on Intelligent Transportation Systems,* **18.10**, pp. 2802-2825.

[2] Astarita, Vittorio, and Michael Florian. (2001). "The use of mobile phones in traffic management and control" In *Intelligent Transportation Systems,* 2001. Proceedings. 2001 IEEE (pp. 10-15). IEEE.

[3] Weiser, Mark. (1991) "The Computer for the 21 st Century." *Scientific american*, **265**(**3**), 94-105.

[4] Madakam, Somayya, R. Ramaswamy, and Siddharth Tripathi. (2015) "Internet of Things (IoT): A literature review" *Journal of Computer and Communications*, **3**(**05**), 164.

[5] McLeod, J. (2013) "How the smart phone is driving the internet-of-things" *Kilopass Technol. Inc*., San Jose, CA, USA, Tech. Rep.

[6] Bar-Gera, Hillel. (2007) "Evaluation of a cellular phone-based system for measurements of traffic speeds and travel times: A case study from Israel" *Transportation Research Part C*: Emerging Technologies, **15**(**6**), 380-391.

[7] Guido, Giuseppe, Frank F. Saccomanno, Alessandro Vitale, Vincenzo Gallelli, Demetrio C. Festa, Vittorio Astarita, Daniele Rogano and Davide Carvelli. (2013) "Extracting vehicle tracking data from smartphone sensors" *92nd Annual Meeting Transportation Research Board*, January 13-17, Washington, DC.

[8] Guido, Giuseppe, Alessandro Vitale, Frank F. Saccomanno, Demetrio C. Festa, Vittorio Astarita, Daniele Rogano, and Vincenzo Gallelli (2013) "Using smartphones as a tool to capture road traffic attributes" In *Applied Mechanics and Materials*, Trans Tech Publications, Vol. **432**, pp. 513-519.

[9] Guido, Giuseppe, Alessandro Vitale, Vittorio Astarita, Frank Fedel Saccomanno, Vincenzo Pasquale Giofré, and Vincenzo Gallelli. (2012) "Estimation of safety performance measures from smartphone sensors" *Procedia-Social and Behavioral Sciences*, **54**, 1095-1103.

[10] Bierlaire, Michel, Jingmin Chen, and Jeffrey Newman. (2010) "Modeling route choice behavior from smartphone GPS data" No. *EPFL-REPORT*-158255.

[11] Whaiduzzaman, Md, Mehdi Sookhak, Abdullah Gani, and Rajkumar Buyya. (2014) "A survey on vehicular cloud computing" *Journal of Network and Computer Applications,* **40**, 325-344.

[12] Boyce, David E., James Hicks, and A. Sen. (1991). "In-vehicle navigation requirements for monitoring link travel times in a dynamic route guidance system." *Operations Review*, **8**(**1**).

[13] Van Aerde, Michel, G. MacKinnon, and Bruce Hellinga. (1991) "The generation of synthetic od demands from real-time vehicle probe data: potential and limitations." In *Vehicle Navigation and Information Systems Conference*, IEEE, Vol. 2, pp. 891-900.

[14] Van Aerde, Michel, Bruce Hellinga, Lei Yu, and Hesham Rakha. (1993) "Vehicle probes as real-time ATMS sources of dynamic OD and travel time data." In *Large Urban Systems-Proc. of the Advanced Traffic Management Conference*, pp. 207-230.

[15] Asakura, Yasuo, Jun Tanabe, and Yong Hwan Lee. (2000) "Characteristics of positioning data for monitoring travel behaviour." In proceedings of *The 7th World Congress On Intelligent Systems*.

[16] Ishida, Haruo, Hiroshi Miura, and Naohisa Okamoto. (2000). "Sampling rates for travel speed survey with car navigation system." In *The 7th World Congress on Intelligent Transportation Systems*.

[17] Kurokawa, Seiichi. (2000). "ITS services by public mobile telecommunications networks." In proceedings of T*he 7th World Congress on Intelligent Systems*.

[18] Natsuno, Takeshi, David Macdonald, and Junji Asatsuma. (2000). "Traffic and traveller information on the mobile phone terminal." In proceedings of *The 7th World Congress On Intelligent Systems*.

[19] Makimura, Kazuhiko, Yasuhiro Nakajima, and Haruo Ishida. (2000). “Study on the effectiveness of performance monitoring using phs and gps.” in proceedings of *The 7th World Congress On Intelligent Systems*.

[20] Lovell, David J. (2001). “Accuracy of speed measurements from cellular phone vehicle location systems.” *Journal of Intelligent Transportation System*, **6**(**4**), 303-325.

[21] Smith, Brian Lee, Michael L. Pack, David J. Lovell, and M. William Sermons. (2001). “Transportation management applications of anonymous mobile call sampling.” In *ITS America 11th Annual Meeting and Exposition, ITS*: Connecting the AmericasIntelligent Transportation Society of America (ITS America).

[22] Hull, Bret, Vladimir Bychkovsky, Yang Zhang, Kevin Chen, Michel Goraczko, Allen Miu, Eugene Shih, Hari Balakrishnan and Samuel Madden, (2006) "CarTel: a distributed mobile sensor computing system." In proceedings of *the 4th international conference on Embedded networked sensor system*s, pp. 125-138. ACM.

[23] Eriksson, Jakob, Lewis Girod, Bret Hull, Ryan Newton, Samuel Madden, and Hari Balakrishnan. (2008) "The pothole patrol: using a mobile sensor network for road surface monitoring." In Proceedings of *the 6th international conference on Mobile systems, applications, and services,* pp. 29-39. ACM.

[24] Mohan, Prashanth, Venkata N. Padmanabhan, and Ramachandran Ramjee. (2008) "Nericell: rich monitoring of road and traffic conditions using mobile smartphones." In Proceedings of *the 6th ACM conference on Embedded network sensor systems*, pp. 323-336. ACM.

[25] Horvitz, Eric J., Johnson Apacible, Raman Sarin and Lin Liao. (2012) "Prediction, expectation, and surprise: Methods, designs, and study of a deployed traffic forecasting service." *arXiv* preprint arXiv, 1207.1352.

[26] Herrera, Juan C., Daniel B. Work, Ryan Herring, Xuegang (Jeff) Ban, Quinn Jacobson, and Alexandre M. Bayen. (2010) "Evaluation of traffic data obtained via GPS-enabled mobile phones: The Mobile Century field experiment." *Transportation Research Part C*: Emerging Technologies, **18**(**4**), 568-583.

[27] Work, Daniel B., Sébastien Blandin, Olli-Pekka Tossavainen, Benedetto Piccoli, Alexandre M. and Bayen. (2010) "A traffic model for velocity data assimilation." *Applied Mathematics Research eXpress*, **2010**(**1**), 1-35.

[28] Herrera, Juan C. and Alexandre M. Bayen. (2010). "Incorporation of Lagrangian measurements in freeway traffic state estimation." *Transportation Research Part B*: Methodological, **44**(**4**), 460-481.

[29] Astarita, Vittorio, Demetrio C. Festa, Raimondo Polidoro. (2013) "M2M system (Mobile to Mobility): The use of Smartphones in the Implementation of a Cooperative Road Traffic Safety Information System" IFKAD 2013: *8th international forum on knowledge asset dynamics: smart growth: organizations, cities and communities* Edited by:Schiuma, G; Spender, JC; Pulic, A Pages: 253-263.

[30] Rodrigues, João GP, Ana Aguiar, and João Barros. (2014) "Sensemycity: Crowdsourcing an urban sensor." *arXiv* preprint arXiv, 1412.2070.

[31] Ban, Xuegang, Yuwei Li, Alexander Skabardonis and Jean-Davi Margulici. (2007) "Performance evaluation of travel time methods for real time traffic applications." In *11th World Conference on Transport Research*.

[32] John, Wright, and Joy Dahlgren. (2001) "Using vehicles equipped with toll tags as probes for providing travel times." *California PATH Program*, Institute of Transportation Studies, University of California at Berkeley.

[33] Astarita, Vittorio, Guido Danieli, and Sergio d' Elia. (2000) "Sistema di rilievo del deflusso veicolare per il monitoraggio e controllo del traffico basato sulla registrazione della localizzazione dei terminali di telefonia mobile." *Italian patent* pending from 26/1/2000 and issued on 15/6/2004. Ref. 0001322707. https://doi.org/10.13140/RG.2.1.5118.5043 .

[34] Wasson, Jason S., James R. Sturdevant, and Darcy M. Bullock. (2008) "Real-Time Travel Time Estimates Using Media Access Control Address Matching*." ITE Journal*, **78**(**6**), pp. 20-23.

[35] Young, Stan. (2008) "Bluetooth traffic monitoring technology: Concept of operation & deployment guidelines." *Center for Advanced Transportation Technology*, University of Maryland, College Park.

[36] Barceló, Jaume, Lidin Montero, Laura Marqués, and Carlos Carmona. (2010) "Travel time forecasting and dynamic origin-destination estimation for freeways based on bluetooth traffic monitoring." *Transportation Research Record*: Journal of the Transportation Research Board, **2175**, 19-27.

[37] Barceló Bugeda, Jaume, Lidin Montero Mercadé, Manuel Bullejos, Oriol Serch, and Carlos Carmona. (2012) "A kalman filter approach for the estimation of time dependent od matrices exploiting bluetooth traffic data collection." In *TRB 91st Annual Meeting Compendium of Papers DVD*, pp. 1-16.

[38] Bachmann, Chris, M. J. Roorda, B. Abdulhai, and B. Moshiri. (2013) "Fusing a bluetooth traffic monitoring system with loop detector data for improved freeway traffic speed estimation." *Journal of Intelligent Transportation Systems*, **17**(**2**), 152-164.

[39] Ygnace, Jean-Luc, Chris Drane, Y. B. Yim, and Renaud De Lacvivier. (2000) "Travel time estimation on the San Francisco bay area network using cellular phones as probes." *California Partners for Advanced Transit and Highways*.

[40] Bolla, Raffaele, and Franco Davoli. (2000) "Road traffic estimation from location tracking data in the mobile cellular network." In *Wireless Communications and Networking Confernce*, 2000. WCNC. 2000 IEEE, Vol. **3**, pp. 1107-1112.

[41] Bolla, Raffaele, Franco Davoli, and A. Giordano. (2000) "Estimating road traffic parameters from mobile communications." In *Proceedings 7th World Congress on ITS*, Turin, Italy.

[42] Rose, Geoff. (2006) "Mobile phones as traffic probes: practices, prospects and issues." *Transport Reviews*, **26**(**3**), 275-291.

[43] Astarita, Vittorio, R. L. Bertini, Sergio d’Elia, and Giuseppe Guido. (2006) "Motorway traffic parameter estimation from mobile phone counts." *European Journal of Operational Research*, **175**(**3**), 1435-1446.

[44] Sohn, Keemin, and Keeyeon Hwang. (2008) "Space-based passing time estimation on a freeway using cell phones as traffic probes." *IEEE Transactions on Intelligent Transportation Systems*, **9**(**3**), 559-568.

[45] Calabrese, Francesco, Massimo Colonna, Piero Lovisolo, Dario Parata, and Carlo Ratti. (2011) "Real-time urban monitoring using cell phones: A case study in Rome." *IEEE Transactions on Intelligent Transportation Systems*, **12**(**1**), 141-151.

[46] Valerio, Danilo, Alessandro D'Alconzo, Fabio Ricciato, and Werner Wiedermann. (2009). “Exploiting cellular networks for road traffic estimation: a survey and a research roadmap.” In *Vehicular Technology Conference*, VTC Spring 2009. IEEE 69th, pp. 1-5.

[47] Janecek, Andreas, Danilo Valerio, Karin Anna Hummel, Fabio Ricciato, and Helmut Hlavacs. (2015). “The cellular network as a sensor: From mobile phone data to real-time road traffic monitoring.” *IEEE Transactions on Intelligent Transportation Systems*, **16**(**5**), 2551-2572.

[48] Ferman, Martin A., Dennis E. Blumenfeld, and Xiaowen Dai. (2003) "A simple analytical model of a probe-based traffic information system." Proceedings of *IEEEIntelligent Transportation Systems*, **1**, pp. 263-268.

[49] Guido, Giuseppe, Vincenzo Gallelli, Frank F. Saccomanno, Alessandro Vitale, Daniele Rogano, and Demetrio C. Festa. (2014) "Treating uncertainty in the estimation of speed from smartphone traffic probes." *Transportation Research Part C*: Emerging Technologies, **47**, 100-112.

[50] Chaturvedi, Manish, and Sanjay Srivastava. (2017) "Multi-modal design of an intelligent transportation system." *IEEE Transactions on Intelligent Transportation Systems*, **18.8**.

[51] Dailey, D. J., and F. W. Cathey. (2002) "Virtual speed sensors using transit vehicles as traffic probes." Proceedings of the *IEEE 5th International Conference on Intelligent Transportation Systems*, pp. 560-565.

[52] Axer, Steffen, and Bernhard Friedrich. (2014) "Level of service estimation based on low-frequency floating car data." *Transportation Research Procedia*, **3**, pp. 1051-1058.

[53] Skog, Isaac, and Peter Händel. (2014) "Indirect instantaneous car-fuel consumption measurements" *IEEE Trans. Instrum. Meas*, vol. **63**, no. 12, pp. 3190–3198.

[54] Tulusan, Johannes, Thorsten Staake, and Elgar Fleisch. (2012) "Providing eco-driving feedback to corporate car drivers: what impact does a smartphone application have on their fuel efficiency?" Proceedings of *the 2012 ACM conference on ubiquitous computing. ACM*.

[55] Araújo, Rui, Ângela Igreja, Ricardo de Castro, and Rui Esteves Araújo. (2012). "Driving coach: A smartphone application to evaluate driving efficient patterns." In *Intelligent Vehicles Symposium* (IV), IEEE, pp. 1005-1010.

[56] Wollaeger, James, Sri Adarsh Kumar, Simona Onori, Dimitar Filev, Ümit Özgüner, Giorgio Rizzoni and Stefano Di Cairano. (2012) "Cloud-computing based velocity profile generation for minimum fuel consumption: A dynamic programming based solution." In *American Control Conference* (ACC), pp. 2108-2113.

[57] Astarita, Vittorio, Giuseppe Guido, Domenico Mongelli, and Vincenzo Pasquale Giofrè. (2015) "A co-operative methodology to estimate car fuel consumption by using smartphone sensors." *Transport*, **30**(**3**), 307-311.

[58] Wideberg, Johan, Pablo Luque, and Daniel Mantaras. (2012) "A smartphone application to extract safety and environmental related information from the OBD-II interface of a car." *International Journal of Vehicle Systems Modelling and Testing*, **7**(**1**), 1-11.

[59] Li, Junhuai, Yang An, Rong Fei, and Huaijun Wang. (2016) "Smartphone based car-searching system for large parking lot." In *Industrial Electronics and Applications* (ICIEA), IEEE 11th Conference on, pp. 1994-1998.

[60] Sándor, Zsolt Péter, and Csaba Csiszár. (2013) "Development Stages of Intelligent Parking Information Systems for Trucks." *Acta Polytechnica Hungarica*, **10**(**4**), 161-174.

[61] Chia, Wai Chong, and Nami Salimi. (2013) "A Smart Parking and Reservation System for QR-Code-Based Car Park." In *Innovation in the High-Tech Economy*, Springer, Berlin, Heidelberg, pp. 91-101.

[62] Salin, Hannes. (2012) "Gap Analysis in Cooperative Systems within Intelligent Transportation Systems."

[63] Biancat, Jacopo, Chiara Brighenti, and Attilio Brighenti. (2014) "Review of transportation mode detection techniques." *EAI Endorsed Transactions on Ambient Systems*, **1**(**4**), 1-10.

[64] Shin, Dongyoun, Daniel Aliaga, Bige Tunçer, Stefan Müller Arisona, Sungah Kim, Dani Zünd, and Gerhard Schmitt. (2015) "Urban sensing: Using smartphones for transportation mode classification*." Computers, Environment and Urban Systems*, **53**, 76-86.

[65] Axer, Steffen, and Bernhard Friedrich. (2013) "Optimization of traffic safety on rural roads by traffic data based strategies." Proceedings *of 13thWCTR*.

[66] Biral, F., M. Da Lio, and E. Bertolazzi. (2005) "Combining safety margins and user preferences into a driving criterion for optimal control-based computation of reference maneuvers for an ADAS of the next generation." In *Intelligent Vehicles Symposium*, Proceedings. IEEE, pp. 36-41.

[67] Vaiana, Rosolino, Teresa Iuele, Vittorio Astarita, Maria Vittoria Caruso, Antonio Tassitani, Claudio Zaffino, and Vincenzo Pasquale Giofrè. (2014) "Driving behavior and traffic safety: an acceleration-based safety evaluation procedure for smartphones.” *Modern Applied Science*, **8**(**1**), 88.

[68] Meiring, Gys Albertus Marthinus, and Hermanus Carel Myburgh. (2015) "A review of intelligent driving style analysis systems and related artificial intelligence algorithms." *Sensors*, **15**(**12**), 30653-30682.

[69] Thompson, Chris, Jules White, Brian Dougherty, Adam Albright, and Douglas C. Schmidt. (2010) "Using smartphones to detect car accidents and provide situational awareness to emergency responders." In *International Conference on Mobile Wireless Middleware, Operating Systems, and Applications*, Springer, Berlin, Heidelberg, pp. 29-42.

[70] Bolovinou, Anastasia, Angelos Amditis, Francesco Bellotti and Mikko Tarkiainen. (2014) "Driving style recognition for co-operative driving: A survey" in *Proc. 6th Int. Conf. Adapt.* Self- Adapt. Syst. Appl., Venice, Italy, pp. 73–78.

[71] Bejani, M. M. and Ghatee, M. (2018). "A context aware system for driving style evaluation by an ensemble learning on smartphone sensors data." *Transportation Research Part C: Emerging Technologies*, **89**, 303-320.

[72] Kerner, B.S., C. Demir, R.G. Herrtwich, S.L. Klenov, H. Rehborn, M. Aleksic, and A. Haug. (2005) "Traffic state detection with floating car data in road networks." In *Intelligent Transportation Systems*, Proceedings, IEEE, pp. 44-49.

[73] Astarita, Vittorio, Giuseppe Guido, and Vincenzo Pasquale Giofrè. (2014) "Co-operative ITS: smartphone based measurement systems for road safety assessment." *Procedia computer science*, **37**, 404-409.

[74] Zadeh, Roya Bastani, Mehdi Ghatee, and Hamid Reza Eftekhari. (2017) "Three-Phases Smartphone-Based Warning System to Protect Vulnerable Road Users Under Fuzzy Conditions." *IEEE Transactions on Intelligent Transportation Systems*.

[75] Astarita, Vittorio, Maria Vittoria Caruso, Guido Danieli, Demetrio Carmine Festa, Vincenzo Pasquale Giofrè, Teresa Iuele, and Rosolino Vaiana. (2012) "A mobile application for road surface quality control: UNIquALroad." *Procedia-Social and Behavioral Sciences*, **54**, 1135-1144.

[76] Chugh, Gunjan, Divya Bansal, and Sanjeev Sofat. (2014) "Road condition detection using smartphone sensors: A survey." *International Journal of Electronic and Electrical Engineering*, **7**(**6**), 595-602.

[77] Mukherjee, Abhijit, and Subhra Majhi. (2016) "Characterisation of road bumps using smartphones." *European Transport Research Review*, **8**(**2**), 13.

[78] Sharma, Harit, Sulochan Naik, Ankit Jain, Ramya K. Raman, Ravi Kanth Reddy and Ravindra Balkrishna Shet. (2015) "S-road assist: Road surface conditions and driving behavior analysis using smartphones." In *Connected Vehicles and Expo* (ICCVE) International Conference on, pp. 291-296.

[79] Kaparias, Ioannis, and Michael GH Bell. (2012) "London congestion charging: successes, gaps and future opportunities offered by cooperative ITS." In *Intelligent Transportation Systems* (ITSC), 15th International IEEE Conference on, pp. 134-139.

[80] Astarita, Vittorio, Vincenzo Pasquale Giofrè, Giuseppe Guido, and Alessandro Vitale. (2017) "The Use of Adaptive Traffic Signal Systems Based on Floating Car Data." *Wireless Communications and Mobile Computing*.

[81] Hu, Jia, Michael D. Fontaine, Byungkyu Brian Park, and Jiaqi Ma. (2015) "Field evaluations of an adaptive traffic signal—using private-sector probe data." *Journal of Transportation Engineering*, **142**(**1**), 04015033.

[82] Axer, Steffen, Federico Pascucci, and Bernhard Friedrich. (2015) "Estimation of traffic signal timing data and total delay for urban intersections based on low-frequency floating car data." *Proceedings of the 6th mobility TUM*.

[83] Barthauer, Mirko, and Bernhard Friedrich. (2014) "Evaluation of a signal state prediction algorithm for car to infrastructure applications." *Transportation Research Procedia*, **3**, 982-991.

[84] Saust, Falko, Oliver Bley, Ralf Kutzner, Jöorn Marten Wille, Bernhard Friedrich, Markus Maurer. (2010) "Exploitability of vehicle related sensor data in cooperative systems." In *Intelligent Transportation Systems* (ITSC), 13th International IEEE Conference on, pp. 1724-1729..

[85] Bellavista, Paolo, Luca Foschini, and Enrico Zamagni. (2014) "V2x protocols for low-penetration-rate and cooperative traffic estimations." In *Vehicular technology conference* (VTC Fall), IEEE 80th, pp. 1-6).

[86] Krajzewicz, Daniel, Robbin Blokpoel, Alessio Bonfietti, Härri Härri, Jérôme Hausberger, and Jérémie Dubois-Lacoste. (2015) "Traffic management based on vehicular communication at low equipment rates." *22nd ITS World Congress*, Bordeaux, France, paper number ITS-2826.

[87] Gradinescu, Victor, Cristian Gorgorin, Raluca Diaconescu, Valentin Cristea, and Liviu Iftode. (2007) "Adaptive traffic lights using car-to-car communication." In *Vehicular Technology Conference*, VTC2007-Spring. IEEE 65th, pp. 21-25.

[88] Wahlström, Johan, Isaac Skog, and Peter Händel. (2015) "Driving behavior analysis for smartphone-based insurance telematics" in Proc. *2nd Workshop Phys. Anal*., Florence, Italy, pp. 19–24.

[89] Ohlsson, Jens, Peter Händel, Shengnan Han, and Richard Welch. (2015) "Process innovation with disruptive technology in auto insurance: Lessons learned from a smartphone-based insurance telematics initiative." In *BPM-Driving Innovation in a Digital World*, Springer, Cham, pp. 85-101.

[90] Händel, Peter, Jens Ohlsson, Martin Ohlsson, Isaac Skog, and Elin Nygren. (2014) "Smartphone-based measurement systems for road vehicle traffic monitoring and usage-based insurance." *IEEE Systems Journal*, **8**(**4**), 1238-1248.

[91] https://www.zerotraffic.io/whitepaper

[92] Astarita, Vittorio and Vincenzo Pasquale Giofrè. (2018) “Blockchain based system with proof of work relying (also) on traveled km for rewarding drivers (or owners of vehicles) into sharing vehicle positions in real time with road traffic management organizations.” *Italian patent* pending from 19 Genuary 2018, ref. 102018000001299, ref. 202018000001053.