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Transportation Research Procedia 69 (2023) 512–519

Transportation Research Procedia

www.elsevier.com/locate/procedia

AIIT 3rd International Conference on Transport Infrastructure and Systems (TIS ROMA 2022), 15th-16th September 2022, Rome, Italy

Speed data collection methods: a review

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Abstract

Various studies have been focusing on a wide range of techniques to detect traffic flow characteristics, like speed and travel times. Therefore, a key aspect to obtain statistically significant set of data is to observe and record driver behaviours in real world.
To collect traffic data, traditional methods of traffic measurement – such as detection stations, radar guns or video cameras – have been used over the years. Other innovative methods refer to probe vehicles equipped with GPS devices and/or cameras, which allow continuous surveys along the entire road route.
While point-based devices provide information of the entire flow, just in the section in which they are installed and only in the time domain, probe vehicles data are referred both to temporal and space domains but ignore traffic conditions. Obviously, it is necessary that the data collected refer to representative samples, by number and composition, of the user population.
The paper proposes a review of the most used methods for speed data collection, highlighting the advantages and disadvantages of each experimental approach. Accordingly, the comparison illustrates the best relief method to be adopted depending on the research and investigation that will be performed.

Keywords: Traffic flow detection tools; speed data collection methods; point-based devices; probe vehicles.

1. Introduction

The safety of an existing road is closely linked to the real interaction between the users and the infrastructure, and this relationship is mainly externalized by the control of vehicular speed operated by the drivers. Therefore, the observation and modelling of traffic operating conditions are crucial for the management and monitoring of a road network, especially if you want to perform an analyses in real time (De Luca et al., 2012; Dell'Acqua, 2012). For this reason, it becomes essential to develop and use predictive models of speed, able to faithfully reconstruct the actual trends along an examined road. The definition of traffic stream variables and a continuous profile of operating speed

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10.1016/j.trpro.2023.02.202

is a complex and delicate objective, as it depends not only on the model adopted but also on the availability of sample data in order to calibrate it (Malaghan et al., 2020). The collection of traffic data is a preliminary but at the same time main phase for the monitoring activities (Hossain & Medina, 2020). For this reason, over the years, several important traffic techniques have been developed, ranging from simple manual counting to the latest methods, which rely on advanced transmission technologies such as WI-FI and Bluetooth (Verma et al., 2021).

In this paper, the authors propose a review of the main techniques of data collection, useful to show at the same time their intrinsic strengths and their weaknesses. In general, available methods can be divided in two main categories. The first, known as static survey methods because they use devices installed in point-based sections along the road, are reliable and representative of the entire traffic stream; providing in addition to the speed of the vehicles also information of the entire flow such as volume and density, but only in the surveyed sections (Adnan et al., 2013; Chase et al., 2012). On the contrary, the second type of methods depend on advanced technologies, so that vehicles with GPS devices on board become probe vehicles able to communicate, even in real time, continuous speed data of the individual vehicle throughout the journey (Ajmar et al., 2019). Despite the smaller sample dimension, provide information both in the temporal and spatial domain and along the entire extent of the infrastructure (Findley et al., 2011; Prabha & Kabadi, 2016).

The proposed review, through a detailed presentation of the different methods available for detection, presented so far in the literature, allows identifying which are the most suitable techniques for the particular analysis of the traffic to be carried out. Finally, for the development of more advanced studies generally it may be necessary to use different data sources and consequently to merge their information to obtain a detailed and representative model of real traffic conditions (Gitahi et al., 2020; Ma, Wei and Qian, 2021; Park et al., 2021).

2. Speed data collection methods: analysis and discussion

Road network managers must carry out analyses to observe users' speeds along the routes to ensure safe driving and to increase the safety of the infrastructure. For an effective and efficient analysis, it would be necessary to have a huge sample of data concerning mobility, referring to each individual user who has travelled the road examined (Benekohal et al., 2004; Yu et al., 2018). The collection of a detailed sample of data would entail excessive costs both for the collection operations but also for the subsequent processing phase of the data. Therefore, different techniques of collecting traffic data and operating speed models have been developed over the years, that can be classified into two generalized methodologies: vehicle fixed detector and probe vehicles (Wang et al., 2014).

2.1. Point-based traffic detectors

Initially, the first method adopted to monitor and collect traffic data was manual counting; subsequently the traditional method was joined by more advanced devices (Fig. 1), such as survey stations, video cameras, automatic traffic meters, radar and laser guns (Minge et al., 2011).

Fig. 1. Typical modern point-based detecting station.

The manual count allows to determine just the average speed by dividing the total distance travelled by the entire running time of a vehicle; usually the errors are small and can be ignored (Adebisi, 1987; Baker & Wallace, 1982; M.

Zhao et al., 1998; Zheng & Mike, 2012). The measurements initially involve the definition of a straight stretch along the selected road, followed by the recording of the time required to cross the specified distance (Adnan et al., 2013).

The survey stations are placed at some section of the road, to record the flow and speeds of the vehicles passing under the device. The structure of the survey station may consist, for example, of a digital television camera connected to a portable PC that shows the images that it captures (De Luca et al., 2012). For more detailed traffic detection, multiple cameras are installed in the survey area. In these cases, they are installed in a variable number depending on the investigation performed. Generally, the first camera is positioned on the main road in such a way as to collect data on traffic characteristics like the available gap, speed and volume (Bassani et al., 2016; Cantisani et al., 2018, 2020; Kusuma et al., 2014; Mallikarjuna et al., 2009; Viti et al., 2008). For example, to survey a road intersection, the other cameras are installed on the secondary roads to detect other information on mobility, such as waiting times for vehicles to enter the main road. For video analysis, high-resolution cameras are used, directed at an angle of less than 10 degrees, to have an almost frontal view of incoming traffic, and installed at an appropriate height to allow an identification of the position and dimensions of the vehicles. Finally, the survey involves the use of video image processing software, which can convert screen information into real, so as to result traffic data (Kanagaraj et al., 2015).

Automatic traffic detectors consist mainly of road sensors, such as preformed loops and road tubes. The circuit is connected to the detector, generally located on the roadside. Preformed loops detect the presence of a vehicle and the distance between it and the next (Ban et al., 2010; Lindveld et al., 2000). The detection system requires that the combinations of signals coming from the sensors are preliminary processed by a microprocessor, resulting a variety of traffic data. In addition, the microprocessor can show and record all data, which can be recovered by connecting it to a computer (Adnan et al., 2013; Dell'Acqua, 2012; Hashim, 2011).

The radar and laser gun are used to perform traffic counting when temporary data collection is required, as their use is limited due to safety, cost, and inclement weather. A radar gun detects measurements from a distance of 60 to 3000 meters but requires a clear field of view to accurately measure the speed of vehicles (Parma, 2001). The laser gun is designed with a light detection technology and ranging which emits a series of infrared laser light pulses to measure both the range and velocity of the target; the technology can be improved to ignore adverse weather conditions and cross glass surface. Between the two guns, the laser has a narrower field of view to signal multiple targets, while the radar has a large field of view programmed to signal the strongest or fastest vehicle (Adnan et al., 2013; Lobo et al., 2013; Ottesen & Krammes, 2000).

Table 1 shows the main advantages and disadvantages associated with each traffic detection method exposed previously. In summary, static devices have the advantage of detecting almost the entire traffic circulating in the surveyed area, to produce a large sample of speed data. Moreover, these methodologies are realized with simple techniques and slightly suffer the difficulties associated with the adverse meteorological conditions and the high traffic flows. On the contrary, the great disadvantage is the limited spatial coverage allowed. In this way, traffic information is provided only in the time domain for the specific section investigated.

Table 1. Advantages and disadvantages of fixed surveying methods.

Detection method	Advantages	Disadvantages
Manual Count	Accurate at low speed	Inaccurate at high speeds
Survey stations	Detection of the entire circulating flow	Limited Space domain of survey
Automatic traffic detectors	Travel times provided on a continuous basis	Adverse weather conditions
Radar and Laser guns	Easy to use anywhere, being portable	High traffic disturbs the capture of all vehicles

2.2. Probe vehicles

The processes of innovation in the field of information and communication technologies (ICT) have led to the expansion and improvement of the connection by road users to the mobile network, ensuring the acquisition and exchange of information with the surrounding environment. In this way, it is possible to obtain a large amount of geo-referenced data that can be very useful for mobility's monitoring (Bar-Gera, 2007; Bertini & Tantiyanugulchai, 2004; Moore et al., 2001; Schwarzenegger et al., 2008; Zito et al., 1995). Initially, before all mobile devices were equipped with GPS sensors, vehicle movement monitoring was done with the use of mobile phones, through cell tower signal information to identify the location of the phone; this is possible with the following techniques: triangulation, trilateration, transfer steps of the tower or a combination of these (Bar-Gera, 2007; Fontaine & Smith, 2007; Lovell, 2001; Westerman et al., 1996; Ygnace et al., 2000). The use of cell tower information presents the inherent inaccuracy of the method itself, showing considerable difficulty in calculating speeds. The study of Yim and Cayford (Y. B. Yim & Cayford, 2001) performed a comparison to observe which technique between the performance of mobile phones and GPS devices was best for tracking activities. The study reveals that non-GPS-based methods – i.e., the above-mentioned cell towers -, characterized by low positioning accuracy, did not guarantee reliable monitoring, especially in road sections defined by a complex road geometry (Herrera et al., 2010).

The increasing availability of electronic mobile devices equipped with GPS, (e.g., mobile phones, handheld, smartphones, tablets, laptops and black boxes mounted on vehicles for insurance purposes) generates information and data (Fig. 2), which if collected, processed and interpreted carefully, are useful for the reconstruction of the users' driving modes, such as the routes travelled, and the speeds adopted (Fontaine & Smith, 2007; Y. Yim, 2003; Y. B. Yim & Cayford, 2001). It generates a large and complex data source, known as Big Data, that requires the definition of data mining models for storing, managing and processing all information (Valenti et al., 2016; Wu et al., 2014).

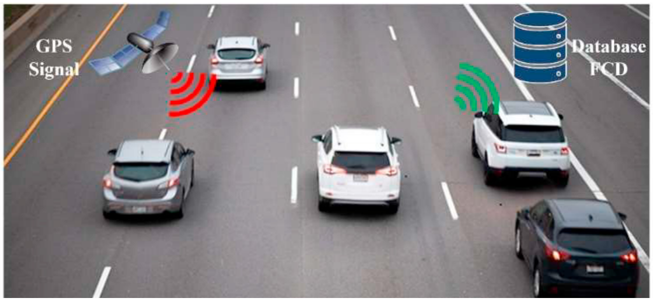

Fig. 2. Geo-referenced data emitted by sensors on-board vehicles.

The extensive collection of georeferenced data from circulating road vehicles, known as Floating Car Data (FCD), represents a new, very effective and low-cost traffic monitoring tool for the study and evaluation of vehicular traffic conditions (De Fabritiis et al., 2008; Kerner et al., 2005; Schäfer et al., 2002). The principle of the FCD is to collect traffic data by locating the vehicle with mobile phones or GPS on the entire road network; this means, essentially, that every vehicle in which there is a mobile phone or a GPS act as a sensor moving along the road network. Data about the car's location, speed and direction of travel are sent to a central processing centre and collected anonymously in a database. This data provides a new method for measuring the speed, travel time and therefore the performance of the mobility system from the observation of vehicles on the road (Herrera et al., 2010; Joe Grengs, Xiaoguang Wang, 2009; Kucharski & Gentile, 2019; Leduc, 2008; Marzano et al., 2018) no longer in fixed sections, but both in the space domain and in the time domain. As these vehicles are free to move anywhere on the road network they are considered as "floating probes" and offer numerous advantages over the traditional traffic data collection methods, because they provide a representative picture of what is really happening on the road and, since they are carried out continuously, can be run - for example - even with inclement weather conditions in one or more days of detection. A growing number of GPS-enabled connected devices have made FCD a key source of information for dynamic traffic management (Houbraken et al., 2018; Vandenberghe et al., 2012). With their support, network information can be enhanced through a reliable and comprehensive data acquisition system, which can help increase road safety and driver comfort (Huber et al., 1999; Sohr et al., 2010).

To date, the accessibility and availability of owning a smartphone is so high such that anyone can own it. The powerful computing capabilities and various functional sensors integrated into smartphones (Zhang et al., 2015) have enabled the development of innovative mobile sensing technologies (Campbell et al., 2008; Ganti et al., 2011; Khan et al., 2012; Lane et al., 2010; Loprencipe et al., 2021; Maisonneuve et al., 2009). Among the different methods the crowd sensing uses large amounts of participants to monitor the surrounding environment by collecting useful data, using the various sensors installed in smartphones: accelerometer, gyroscope, compass, microphone, camera, GPS and wireless network interfaces (Ganti et al., 2011; Lewandowski et al., 2018). In this way, smartphones become the continuous interface between user and environment, since you can integrate the internet network (Wifi,2G/3G/4G/5G) with local-area networks (Bluetooth, new generation NFC or portable Wi-Fi) allowing the smartphone to act as a router and create a connection between the mobile phone and nearby devices (Chatzimilioudis et al., 2012). This method provides, just as in the case of probe vehicles, GPS location data for vehicle tracking; the advantage is the interactive communication network since it is only necessary that there is a mobile device in the vehicle.

Several studies, based on this new technology of communication and data transfer, have proposed different methods of traffic detection and monitoring. A first traffic monitoring system, based on Wi-Fi communication, uses a single access point and a laptop to provide vehicle detection, classification, lane identification and speed estimation (Won et al., 2017). According to this approach, channel state information (CSI) models in the Wi-Fi network are captured and analysed to monitor traffic. A radio-based approach to vehicle detection and classification has also been introduced, combining ray tracing simulations, machine learning and received signal strength indicator (RSSI) measurements (Haferkamp et al., 2017). In this approach, it was noted that different types of vehicles have specific RSSI fingerprints; this aspect was used to perform a machine-based vehicle classification. The RSSI values are then be analysed in a wireless network, consisting of three transmitting units and three receivers located on opposite sides of a road.

Finally, another proposed method allows the smartphones located in road surrounding, such as on sidewalks in the pockets of pedestrians, to be used for traffic monitoring. Vehicle detection and classification into three classes is performed by analysing the strength of the radio signal received by Bluetooth beacons (Lewandowski et al., 2018), that are installed at different heights by the road, using the low-energy Bluetooth communication (BLE) commonly available in the smartphones. According to this approach, BLE beacons are used with the ibeacon protocol (Developer, 2014) to transmit data frames; the position of the device can be determined based on both the RSSI information and the GPS signal. The collected data are transmitted to a server via cellular network or WiFi communication, which performs data aggregation and classification. This latter approach, unlike the two previously presented methods, is more suitable for crowdsourcing applications, as it is economically advantageous. Because the first two require expensive data transfers (Wi-Fi) or specialized hardware to provide a short-range cost-effective networking capability (Safaric & Malaric, 2006), or directional antennas.

Table 2 shows the main advantages and disadvantages of probe vehicles. It highlights how the problem of this methodology is mainly associated with data acquisition, as it is necessary first to ensure good signal coverage along the whole development of the road network. The main disadvantage of FCD is their relatively low penetration rate in the population, which is around a value of 2-5 % (Ajmar et al., 2019; Fourati et al., 2021; Fusco et al., 2016; Wagner, 2009), despite this, various studies have demonstrated the reliability through analyses that looked for a correlation between the data emitted by the probe vehicles and those recorded by static methods, historically valid. The methodologies proposed by these studies have extracted coefficients of correlation R^2 between the two samples of data greater than 0.9; demonstrating the possibility of adopting the FCD as a tool for the analysis of operating speeds (Cantisani et al., 2022; N. Zhao et al., 2009).

Table 2. Advantages and disadvantages of probe vehicles.

Advantages	Disadvantages
Provide information on the entire road network	Low penetration rate
Automated and continuous data collection	Requires good signal coverage
Large-scale data collection activities, observing speed variation along the entire route	
Low cost per unit of data, do not require installation or maintenance of equipment along the road	

3. Conclusions

Several studies have shown that the actual speeds of vehicles in traffic stream are not always recognized and recorded by different devices that can be used for surveys, since they are characterized by diverse characteristics and working logic. Over the years, the evolution of technology has provided innovative and interesting methods for the acquisition of traffic data. This operation is essential to ensure the proper functioning of a road network, as it is a source of useful information for making all decisions relating to the management and planning of transport systems; for this reason, it is important that the collection system adopted provides accurate and reliable data.

From the analysis of the different methods of speed data collection, it is noted that the different sources have great potential but also their own weaknesses. Point-based control units collect traffic data continuously, but only for the road section where they are installed. Although they only provide information in the time domain, point sensors typically detect measurements of the entire circulating flow (e.g., volume, density, and estimated length of the vehicle). On the other hand, all vehicles, in which a device capable of sending information on mobility is installed, are probes floating in traffic. In this way, each vehicle during its motion sends to a central collection different information (e.g. speed, direction, location), so allowing the collection of Big Data, which extend into both temporal and spatial domain.

The revision of the traffic survey methods showed that each technique has its own advantages and disadvantages, because of which it was not possible to define the absolute best method. Therefore, future analysis and management activities could be much more accurate if a fusion of data from different sources is performed. Static methods, providing information on the entire circulating flow, can cover gaps that the probe networks are not able to detect, because the latter mainly focus on the continuous representation of the motion of the single vehicle. The fusion has the potential to improve speed measurement and real-time traffic status estimation by extending temporal and spatial coverage and increasing data reliability by correcting the uncertainties of a single source.

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