DATA COLLECTION TECHNOLOGIES AND THEIR UTILIZATION IN INTELLIGENT TRANSPORTATION SYSTEMS: AN OVERVIEW

Adeeba Naz*[1] and Ifratul Hoque[2]

[1] *Lecturer, Department of Civil Engineering, BUET, Bangladesh, e-mail: adeebanaz0155@gmail.com*
[2] *Research Assistant, BUET – JIDPUS, Bangladesh, e-mail: ifratulhoque1@gmail.com*

***Corresponding Author**

ABSTRACT

In the past, transportation planners and engineers primarily relied on supply management tactics to address people's transportation requirements. However, numerous countries noticed that despite fully utilizing the transportation network, it remained challenging to accommodate the escalating demand. Consequently, there is a growing importance placed on addressing these needs strategically through demand management strategies. Among the leading strategies is the implementation of Intelligent Transportation Systems (ITS) which enables the efficient utilization of existing infrastructure. To ensure the successful implementation of ITS into the existing transportation framework, the use of advanced data collection technologies is an absolute necessity. As cities continue to grow, traffic issues in regular operations and management become increasingly difficult. Solving these issues, enhancing traffic performance, and fruitful planning of future transportation infrastructure requires the incorporation and wide use of modern technology. Numerous smart data collection technologies have already been developed and are being utilized around the world but there still exists an inertia among the general public in adopting these techniques. Proper knowledge about the technologies and their offered benefits can bring about a change in this perspective. This paper aims to provide a comprehensive overview of some of the available data collection technologies and their utilization techniques in ITS that can help in battling imminent transportation issues and aid in modernizing and improving the overall performance of the transportation sector of any country. The organized, structured form of information showcased in this paper will aid the existing literature and help decision-makers in making crucial transportation development conclusions.

Keywords: *Intelligent Transportation Systems, Technology, Data Collection, Sensors, Traffic Management*

1. INTRODUCTION

The trend of vehicular travel is increasing all around the world at an unstoppable rate, posing a challenge to urban transportation management. This large increase in the number of vehicular transports brought a mixture of social and environmental problems to our cities, including traffic jams, vehicle crashes, etc. (Chen et al., 2017). The integration of Intelligent Transportation Systems (ITS) with traditional traffic management systems is a key approach to address transportation-related issues. Failure to utilize smart technological resources or adopt ITS can lead to worsening congestion, accidents, and other transportation problems caused by increased travel demands (Sumalee and Ho, 2018).

The definition and goals of ITS can be subjective. From one point of view, Barcelo et al. (2010) suggest that ITS involves utilizing new technology to enhance the safety, efficiency, and convenience of surface transportation for both people and goods. The overarching goal of ITS is to develop, analyze, evaluate, and integrate information and communication technologies to establish an efficient traffic flow system, improve environmental quality, conserve energy, save time, and enhance the comfort of drivers and other stakeholders.

The usage of ITS is an absolute must in building smart cities. Through ITS, smart cities can implement smart traffic management infrastructure like adaptive traffic signal controls, freeway management, emergency management services, and roadside units. ITS improves safety, reduces accidents, congestion, and pollution while enhancing reliability, speed, and traveler satisfaction. It spans transportation management, operations, and policies, offering extensive benefits and research potential (Prabha and Kabadi, 2016).

The major components of ITS processes can be categorized into three main parts (Mandhare et al., 2018). Those are:

Automated Data Collection: This requires advanced and precise strategic planning through hardware like GPS-based vehicle locators, cameras, sensors, etc., and competent software.

Data Transmission: It is a vital part of rapid and real-time information communication in ITS implementation. Traffic information can be conveyed to the traveler through SMS, the Internet, etc.

Data Analysis: It involves adaptive logical analysis, error rectification, data cleaning, and synthesis. It enables the processing of data for forecasting traffic scenarios and providing real- time traffic information such as travel time, delays, accidents, route changes, and diversions.

It is evident from this categorization that efficient and accurate data collection techniques play a key role in the successful implementation of ITS. Timely and accurate traffic data enables transportation systems to monitor and manage operations that maximize the efficiency of the whole system (Faouzi and Klein, 2016) as well as generate useful information for drivers, such as the fastest routes and locations of traffic jams (Dezani et al., 2012). Real-time travel information can be very useful for advanced travel advisory systems (Ahdi et al., 2012). As huge amounts of data are gathered from different sources, it becomes easy for transportation engineers to test the most recent hypotheses and it gives researchers the opportunity to gain insights into transportation-related problems (Kurkcu et al., 2015).

This paper is divided into two sections. The first section provides a description of the various technologies that are being used around the world for traffic data collection in ITS. The last section provides an extensive representation of the use of these data collection techniques in ITS. The description of these methods of utilization can supply valuable insights for building smarter transportation infrastructure and more efficient transportation systems. Ultimately, this paper will provide an overview of the available traffic data collection technologies and their capitalization processes for the successful implementation of intelligent transportation systems.

2. DATA COLLECTION TECHNOLOGIES

Relevant traffic data is crucial for real-time applications and transportation studies. Traditional methods like traffic counts and surveys are insufficient for real-time use and ITS management. To optimize transportation services, smart and robust data collection techniques provided by ITS are needed. Overall, Traffic data collection can be primarily categorized into three major methods (Lopes et al., 2010; Prabha and Kabadi, 2016): site data, floating car data, and wide-area data. All different sorts of data collection methods can be included to be a sub-category of these three categories and all the undermentioned technologies can be used in all three methods at different capacities. Based on sources, data collected for ITS can be primarily categorized into 9 categories (Zhu et al., 2019). Based on those categories, the tools, and technologies that are required to extract these data are:

Smart Card: A smart card or chip card is a physical card that is equipped with an integrated chip. Smart cards are physical electronic authentication devices that can act as a security token or control access to a resource. The smart card is quite popular for transit systems in many countries for automated fare collection. IC cards can also be very useful in establishing big data (Zeyu et al., 2017).

Global Positioning System (GPS): Originally developed for military use, GPS systems are now accessible to the public, utilizing satellites to determine precise user locations. Signal accuracy is around 9 meters horizontally (95%) and 15 meters vertically (95%), with approximately 20 operational satellites (Bevly and Cobb, 2010). GPS data collected from crowd-sourced logging enables real-time and non-real-time ITS applications in CrowdITS (Ali et al., 2012). GPS is also used in road noise mapping and cost-effective traffic data collection through smartphones (Cai et al., 2015).

Video Camera: Video technology improves data accuracy and feasibility in transportation studies, replacing traditional loop detector systems. ITS agencies employ closed-circuit television cameras (CCTV) and regular video cameras to collect traffic parameter measurements for operational purposes. Video cameras serve as backup data sources in modern transportation systems (Faouzi and Klein, 2016). Unmanned Aerial Vehicles (UAVs) show promise for traffic monitoring, sensing, enforcement, and post-disaster management as it is highly flexible and less costly compared to conventional traffic sensors (Du et al., 2017; Zhou et al., 2015; Ke et al., 2020).

Road Side Sensors: These are sensory tools that are placed along the roadside to collect vehicular or weather information. Smart Roadside sensors can be used to provide driver assistance and traffic safety warnings (Jang et al., 2011) alongside other information. These sensors can either be passive or active. Passive sensors only receive energy whereas active sensors can transmit as well as receive energy. These sensors can also be classified as In-roadway technology or Above-Roadway Technology (Klein, 2022). Some examples of these sensors are:

Induction Loops: Inductive loops are used in a connected vehicular transportation system (CVTS). These are used in data collection processes for ITS, including vehicle detection and counting (Oluwatobi et al., 2021).

Road Tubes: Pneumatic Road tubes have been used for many years for site data collection by installing them along the roadside. (Lopes et al., 2010)

Magnetometer: These can be used to count the vehicles on a road and identify their speed (Klein, 2022; Wang et al., 2020) and can be a useful technology for traffic surveillance (Hodon et al., 2021).

Microwave Radar: These are useful sensors used to collect site data. Vehicle volume, speed, and occupancy data can be obtained by the presence of microwave detectors located at 0.3 to 0.5-mile intervals (Álvarez et al., 2013). These presence-detecting radars can be used in signalized intersection control, wrong-way vehicle detection, and highway incident detection (Klein, 2022).

LIDAR: LIDAR, which stands for Light Detection and Ranging, is a flexible, cost-effective, and multi-purpose roadside sensor. This technology has proven to be very successful in the detection of vehicles as well as pedestrians (Zhang et al., 2019). LIDARs are able to provide vehicle presence at traffic signals, flow rate, speed, and length assessment.

Electronic Toll Plazas: These use wireless systems to collect tolls efficiently while providing enhanced traffic data and saving operational costs and time.

Passive Infrared Sensors (PIR): PIR are low-cost but effective in detecting and classifying vehicles as well as estimating speeds (Odat et al., 2018). .

Acoustic Sensors: Acoustic sensors use changes in sound energy levels to detect vehicles, utilizing an array of microphones and signal processing algorithms for spatial directivity and vehicle recognition (Klein, 2022)

Ultrasound Sensors: This is a device fitted in electronic vehicles that are being frequently used as it is cheaper and more accurate than other types of devices (Jeon et al., 2014). These sensors can be a vital part of any traffic information acquisition system for determining traffic conditions (Appiah et al., 2020) and can be important to ITS in helping to improve comfort and safety at a reduced cost. (Alonso et al., 2011)

License Plate Recognition: Properly equipped cameras installed in fixed locations can read a vehicle's registration plate with high accuracy (Hadavi et al., 2020). ITS agencies have been using license plate readers to collect traffic parameter measurements for operational purposes.

Floating Car Data Collectors: Collection of localization data, speed, the direction of travel, etc. from driving vehicles are known as Floating Car Data (FCD). The tools used to collect this form of data are:

On-board Vehicle Sensors: With proper resources, an intelligent vehicle will become a mobile service provider that can assist in many traffic applications and domains (Abdelhamid et al., 2015). Typical on-board sensors in autonomous vehicles are laser scanners, radar, video cameras, wheel encoders, inertial navigation systems, etc.

Bluetooth: Bluetooth, installed in modern vehicles and roadside infrastructure, allows for the collection of travel time data from vehicles equipped with Bluetooth devices (Liu et al., 2012). Equipping a car with Bluetooth 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 (Budimir et al., 2019).

Mobile Phones: Mobile phones with GPS capabilities can also be used to collect FCD. Mobile phones can provide the spatial-temporal position of users, from which information on users' trip characteristics and travel costs could be obtained (Croce et al., 2021). A smartphone can obtain vehicle speeds (Guido et al., 2013), evaluate the safety performance on the road (Guido et al., 2012), and calibrate route choice models.

Connected Vehicles: Connected vehicles, with their bi-directional communication and data exchange capabilities, are revolutionizing transportation. These vehicles can share data and contribute to the development of adaptive traffic signal systems through the use of floating car data (Astarita et al., 2020). Intelligent Connected Vehicles (ICVs) have the potential to make transportation safer, cleaner, and more comfortable by improving traffic efficiency and reducing traffic congestion (Yang et al., 2018).

Wide Area Data Collectors: The collection of data on transportation activities across a wide geographic area is called Wide Area Data. These can include travel time, travel flow, and other traffic parameters across a region. The tools used in the collection of this form of data are:

Airborne Sensors: These sensors are able to provide a wide-area view of traffic conditions over a large geographic area.

Radio-Frequency Identification (RFID): RFID is a wireless technology with tags and readers. Readers emit radio waves and receive signals from RFID tags. RFID data can aid traffic engineers and transportation policymakers in managing road traffic and congestion (Wemegah and Zhu, 2017). By using RFID and GPS, a real-time transportation vehicle monitoring system for dangerous goods can also be developed (Yu et al., 2012).

Dedicated Short Range Communications (DSRC): DSRC is a subset of RFID technology enabling vehicle-to-vehicle and vehicle-to-infrastructure communication in Intelligent Transportation Systems. DSRC is a prevalent access technology for these communications (Guerrero-Ibanez et al., 2018).

Autonomous Vehicles (AVs): Autonomous vehicles are self-operating and can sense their surroundings without human input. Connected to the Internet of Vehicles (IoV), these vehicles utilize various sensors such as GPS modules, radar, LIDAR, and image sensors, along with onboard control modules, for data collection (Nanda et al., 2019). These vehicles can also be used for road and roadside condition data collection (Manasreh et al., 2022).

Passive Data: These mainly refer to data that are not collected through the means of active collection. The widespread use of mobile technologies has enabled the collection of a massive amount of passive data (Zhu et al., 2019), This data has the potential to be used for research purposes that were not initially intended (Kang et al., 2012). Research suggests that combining passive data like mobile phone data, internet access data, and active data can be fruitful in human mobility, travel behavior, and transportation planning studies (Chen et al., 2016; Zeyu et al., 2017). Data collected from social media like LinkedIn, and Facebook can also be sources of passive data. After adequate structuring and processing, this data can provide significant transportation information such as travel disruptions (Zheng et al., 2016). Besides these data collection tools, there are many other technologies described in other pieces of literature (Zhu et al., 2019; An et al., 2011; Mandhare et al., 2018; Hong et al., 2015) that can be widely used for their versatility and applicability in measuring various traffic parameters and they are:

Smart Grid: Smart grid technology in transportation systems utilizes digital and advanced technologies to monitor and control electricity flow, ensuring reliable power supply for electric vehicles. Research indicates that integrating Smart Grids and Intelligent Transportation Systems is crucial for optimal traffic performance (Qian et al., 2020). Data from smart grids can be leveraged to improve transportation management systems.

Telematics: This is a communication technology for the automobile industry that consists of sending and receiving information via wireless networks. It integrates wireless communications, location technology, and in-vehicle electronics to provide comprehensive vehicle data. Smartphone-based telematics systems enhance the driving experience (Wahlstrom et al., 2017). Road telematics technology, including onboard systems and real-time traffic information sharing, improves traffic data collection (Lee et al., 2010).

Transit ITS: The use of advanced technologies in public transportation systems aims to enhance efficiency, safety, and accessibility. Utilizing these, transit agencies can improve operational efficiency and create a safer and more secure public transportation system. These technologies include Automated Vehicle Location (AVL) systems, Computer-Aided Dispatch (CAD) systems, Automatic Passenger Counting (APC) systems, remote vehicle and facility surveillance cameras, Electronic Fare Payment (EFP) systems, Real-Time Passenger Information (RTPI) systems, Transit Signal Priority (TSP) systems, Automatic Train Control (ATC) systems, Advanced Traveler Information Systems (ATIS).

Vehicle Information Communications Systems (VICS): This is a technology used in Japan that provides real-time traffic and travel information to road vehicle drivers by using radio wave beacons, infrared beacons, and FM multiplex broadcasts. It supplies a simple map showing relevant information such as traffic jams, travel time, etc.

Global Navigation Satellite Systems (GNSS): GNSS is a network of satellites offering positioning, navigation, and timing services. Real-time GNSS data is valuable for measuring travel time, speed, and delays, enabling Integrated Traffic Management Systems (ITMS) to detect, monitor, and control traffic congestion (Raza et al., 2022). A significant advantage of using GNSS data is that real-time travel information can be obtained in an accurate, economical, and timely manner (Baria and Samant, 2011). Capacities of Adaptive Cruise Control (ACC) systems can be significantly enhanced by using GNSS technology along with vehicle-to-vehicle (V2V) communication (Alrifaee et al., 2013).

Probe Vehicles: Probe vehicles collect and transmit real-time traffic data, aiding in the analysis of traffic patterns, congestion, and system performance. This data helps estimate traffic flow, density, travel time, intersection congestion, road conditions, and detect traffic incidents (Seo et al., 2015; Seo and Kusakabe, 2015; Pulugurtha et al., 2014; He et al., 2019; Hainen et al., 2012).

3. TECHNOLOGY UTILIZATION IN ITS

Through the successful implementation of effective technologies into transportation activities, ITS can aid in many sectors including traffic management, road monitoring, and active real-time traffic applications. Some of the varied use of technologies in ITS are described in the following sub- sections.

Real-Time Traffic Updates: Real-time traffic updates are crucial for intelligent navigation, travel time prediction, and safety in ITS. Advanced data collection technologies support real-time traffic management algorithms like CHIMERA, which detects congestion and optimizes traffic distribution (De Souza et al., 2016). For autonomous vehicles, artificial intelligence algorithms can integrate the data generated by all the available sensors to create a complete map of the car environment which helps the vehicle control software to make real-time decisions (Tewolde, 2012). Predicting the status of the traffic networks in urban areas, and enabling online route updates can be achieved by collecting automatically sensed real-time mobile crowdsourcing data (Wan et al., 2019). By analyzing video data from CCTV, Balid et al. (2018) showcased the development of a novel intelligent vehicle counting and classification system (iVCCS) that uses wireless magnetometer sensor data for real-time traffic surveillance.

Traffic Estimation: Accurate and up-to-date traffic data is crucial for intelligent traffic management and infrastructure development. Deploying advanced technologies, such as sensor technologies, enables effective traffic estimation methods (Tasgaonkar et al., 2020). The use of cellular networks and GPS probes can also help in accurately estimating traffic information while minimizing infrastructure requirements (Chaturvedi and Srivastava, 2017).

Traffic Prediction: Forecasting traffic helps address challenges in urban road network planning and traffic control, enhancing travel time reliability. Automatic traffic data collection technologies, including RFID and sensory detectors, facilitate traffic flow prediction (Chen and Chen, 2019). Collected spatio-temporal data, such as regional flows, travel demands, intersection flows, road speed, and travel time can be effectively utilized in traffic prediction (Yuan and Li, 2021).

Smart Traffic Management System (STMS): Integration of advanced technologies and data-driven solutions in a smart traffic management system is crucial for enhancing efficiency, safety, and sustainability. In this system, effective control of road traffic situations can be ensured through ultrasonic sensors, RFIDs, and surveillance cameras (Javaid et al., 2018). Also, cost-effective solutions like sensors and RFID technology aid in managing traffic congestion and providing real- time updates (Rizwan et al., 2016). Integration of LIDARs, sensors, and IoT in a STMS improves air quality and optimizes traffic flow (Rabby et al., 2019). Connected vehicles under VANET (vehicular ad hoc network) configuration can be used to solve general traffic issues in a high-volume traffic gateway (Rath, 2018).

Connected Vehicular Transportation System (CVTS): It facilitates information exchange between vehicles and infrastructure, improving traffic management, efficiency, and safety. It enhances the operational performance of road networks and intersections, resulting in increased mobility (Jadaan et al., 2017).

Commercial Vehicle Operations and Management: This involves a combined application of sensors and ICT (Information and Communications Technology) to efficiently carry out regular commercial vehicle activities like checks and documentation services. Automatic identification and weigh-in-motion technologies in commercial vehicle operations (CVO) can enable fast and disruption-free weighing and cataloging operations (Shaheen and Finson, 2013). Canada has already implemented ITS technologies for functions like intermodal freight management, fleet management, etc. in commercial vehicle operations (Rawal and Devadas, 2015).

Public Transportation Management: ITS technology enhances the efficiency of public transport systems, increasing public interest in using them. Integrating advanced data collection technologies such as sensor networks, GPS, GSM, ZigBee, and communication networks optimizes performance in public transportation management systems (Zhou et al., 2012). Data collected through Smart On- Board Unit (SBU) that is fitted into public transport vehicles can be used in intelligent public transportation management systems to reduce risks and high accident rates (Tarapiah et al., 2014). Collected data can also be used for optimal planning of public vehicles like the scheduling of buses (Thiranjaya et al., 2018).

Parking Management: A more user-friendly, convenient, and efficient parking system can be obtained by implementing ITS technologies into parking management. Data from RFID, WSN (Wireless Sensor Network), and Adhoc network can facilitate smart parking monitoring, controlling, and management.

Emergency Vehicle Management: Congestion is a plague in transportation systems and it becomes life-threatening when it blocks the movement of emergency vehicles. Application of ITS technologies can aid in the eradication of this plague and thus help in saving lives. WSNs can be a low-cost solution for avoiding and controlling congestion and helping in emergency vehicle movement (Shelke et al., 2019). Real-time data from these technologies can help in administering a dynamic and efficient traffic light control system that will be centered around emergency vehicles to facilitate their fast movement (Younes and Boukerche, 2018). Broadcasting the route information can aid in reducing the response time of emergency vehicles significantly (Xie et al., 2017). In the future, various communication technologies (DSRC, UMTS/HSDPA, WAVE, etc.) will be capitalized to assist the fast movement of emergency vehicles (Martinez et al., 2010).

Freight Management: By leveraging ITS technologies, freight management becomes more efficient, sustainable, optimized, and cost-effective. Data on road weather and other critical relevant transport situations for freight transport management can improve truck driver awareness and fleet management which will simultaneously influence sustainable transport management and ensure environmental protection (Pell et al., 2016).

Incident Management: ITS technologies play a significant role in incident management, improving response times, stakeholder coordination, and safety. Integration of traffic state data with traffic monitoring and control enables the use of smart traffic incident management frameworks (STIMF) to address highway incidents effectively (Farrag et al., 2021). Other frameworks like s-ITSF, a service-based intelligent transportation framework, and VANET also contribute to efficient and safe accident management (Lee et al., 2015; Al-Mayouf et al., 2018). Incident management is a crucial aspect of ITS and should be prioritized in sustainable road strategies and policies (Tupper et al., 2012).

Road Weather Information Systems (RWIS): In ITS, weather monitoring focuses on real-time road condition information. ITS data collection technologies enable road services to provide up-to-date road information and collect vehicular data for service improvement (Stepanova et al., 2020). To convey route-specific weather data to road users, mobile road weather data collected from connected vehicles can be analyzed. However, implementing efficient road weather information systems on a large scale requires the development of low-cost mobile weather sensors, robust data processing, and effective decision support systems (Dey et al., 2015).

Dynamic Ridesharing Systems: A dynamic ride-sharing system aims to optimize the utilization of private vehicles by facilitating the sharing of rides among individuals traveling in the same direction. This system can be extensively assisted by using ITS technologies. Advanced Vehicle Identification System (AVIS) can also effectively provide efficiency in both ride-sharing and parcel-delivery services (Zhang et al., 2022).

4. CONCLUSIONS

This paper provides a comprehensive overview of many available data collection technologies and the sectors of transportation in which these technologies are being implemented. As the population in urban scenarios continues to grow, the scope of constructing new infrastructure is thinning. Thus, the focus is shifting from infrastructure development to the best utilization of the infrastructure facilities available and this is where the use of ITS can be revolutionary. But the positive effects of ITS technology and their applicability is still not properly understood everywhere. The maximum potential of relevant functions of ITS is yet to be experienced. If people are made more aware and educated on the topic of the benefits that ITS has to offer, then it may also help to reduce ignorance and reluctance to invest in ITS. Although ITS technologies present huge benefits such as increased comfort and safety, reduced congestion, etc., it poses serious security and privacy issues. These issues need to be carefully accounted for in the design of ITS. Also, while ITS has already gained extensive use in developed countries, the traffic situations in developing countries underscore the urgent need for its adoption. Despite the potential costs involved, developing countries need to prioritize the implementation of ITS.

This paper serves as a valuable resource for policymakers and decision-makers by organizing the available information on data collection technologies in ITS in a structured manner. It equips them with the necessary knowledge to make informed decisions regarding ITS implementation. The insights provided in this study can help researchers understand existing tools and techniques for data collection in ITS.

However, it is crucial to acknowledge the limitations of this study. The findings presented here do not include the challenges faced in implementing these technologies, and the study does not extensively cover all available ITS technologies or mention their drawbacks. Future research should address these limitations to provide a more comprehensive understanding of the field.

REFERENCES

Abdelhamid, S., Hassanein, H. S., & Takahara, G. (2015). Vehicle as a resource (VaaR). *IEEE Network*, *29*(1), 12-17.

Ahdi, F., Khandani, M. K., Hamedi, M., & Haghani, A. (2012). *Traffic data collection and anonymous vehicle detection using wireless sensor networks* (No. MD-12-SP009B4H). Maryland. State Highway Administration.

Ali, K., Al-Yaseen, D., Ejaz, A., Javed, T., & Hassanein, H. S. (2012, April). Crowdits: Crowdsourcing in intelligent transportation systems. In *2012 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 3307-3311). IEEE.

Al-Mayouf, Y. R. B., Mahdi, O. A., Taha, N. A., Abdullah, N. F., Khan, S., & Alam, M. (2018). Accident management system based on vehicular network for an intelligent transportation system in urban environments. *Journal of Advanced Transportation*, *2018*.

Alonso, L., Milanés, V., Torre-Ferrero, C., Godoy, J., Oria, J. P., & De Pedro, T. (2011). Ultrasonic sensors in urban traffic driving-aid systems. *Sensors*, *11*(1), 661-673.

Alrifaee, B., Reiter, M., Maschuw, J. P., Christen, F., Eckstein, L., & Abel, D. (2013). Satellite-and map-based long range cooperative adaptive cruise control system for road vehicles. *IFAC Proceedings Volumes*, *46*(21), 732-737.

Alvarez, P., Hadi, M., & Zhan, C. (2013, October). Using Intelligent transportation systems data archives for traffic simulation applications. In *Congreso Chileno de Ingeniería de Transporte* (No. 16).

Appiah, O., Quayson, E., & Opoku, E. (2020). Ultrasonic sensor-based traffic information acquisition system; a cheaper alternative for ITS application in developing countries. *Scientific African*, *9*, e00487.

Astarita, V., Giofré, V. P., Festa, D. C., Guido, G., & Vitale, A. (2020). Floating car data adaptive traffic signals: A description of the first real-time experiment with “connected” vehicles. *Electronics*, *9*(1), 114.

Balid, W., Tafish, H., & Refai, H. H. (2017). Intelligent vehicle counting and classification sensor for real-time traffic surveillance. *IEEE Transactions on Intelligent Transportation Systems*, *19*(6), 1784-1794.

Baria, K. V., & Samant, R. M. (2011, February). GPS/GPRS based system for vehicle tracking and traffic management. In *Proceedings of the International Conference & Workshop on Emerging Trends in Technology* (pp. 1367-1367).

Bevly, D. M., & Cobb, S. (2010). GNSS for Vehicle Control [online]. Norwood, MA, USA: Artech House.

Budimir, D., Jelušić, N., & Perić, M. (2019). Floating car data technology. *Pomorstvo*, *33*(1), 22-32.

Cai, M., Zou, J., Xie, J., & Ma, X. (2015). Road traffic noise mapping in Guangzhou using GIS and GPS. *Applied Acoustics*, *87*, 94-102.

Chaturvedi, M., & Srivastava, S. (2016). Multi-modal design of an intelligent transportation system. *IEEE Transactions on Intelligent Transportation Systems*, *18*(8), 2017-2027.

Chen, C., Ma, J., Susilo, Y., Liu, Y., & Wang, M. (2016). The promises of big data and small data for travel behavior (aka human mobility) analysis. *Transportation research part C: emerging technologies*, *68*, 285-299.

Chen, C., Luan, T. H., Guan, X., Lu, N., & Liu, Y. (2017). Connected vehicular transportation: Data analytics and traffic-dependent networking. *IEEE vehicular technology magazine*, *12*(3), 42- 54.

Chen, X., & Chen, R. (2019, October). A review on traffic prediction methods for intelligent transportation system in smart cities. In *2019 12th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI)* (pp. 1-5). IEEE.

Croce, A. I., Musolino, G., Rindone, C., & Vitetta, A. (2021). Estimation of travel demand models with limited information: Floating car data for parameters’ calibration. *Sustainability*, *13*(16), 8838.

De Souza, A. M., Yokoyama, R. S., Maia, G., Loureiro, A., & Villas, L. (2016, June). Real-time path planning to prevent traffic jam through an intelligent transportation system. In *2016 IEEE symposium on computers and communication (ISCC)* (pp. 726-731). IEEE.

Dey, K. C., Mishra, A., & Chowdhury, M. (2014). Potential of intelligent transportation systems in mitigating adverse weather impacts on road mobility: A review. *IEEE Transactions on Intelligent Transportation Systems*, *16*(3), 1107-1119.

Dezani, H., Damiani, F., Marranghello, N., Viudes, U., & Parra, Í. A. (2012, June). Mobile application as a tool for urban traffic data collection and generation to Advanced Traveler Information Systems using Wi-Fi networks available in urban centers. In *2012 IEEE Intelligent Vehicles Symposium* (pp. 288-292). Ieee.

Du, Y., Zhao, C., Li, F., & Yang, X. (2017). An open data platform for traffic parameters measurement via multirotor unmanned aerial vehicles video. *Journal of Advanced Transportation*, *2017*.

El Faouzi, N. E., & Klein, L. A. (2016). Data fusion for ITS: Techniques and research needs. *Transportation Research Procedia*, *15*, 495-512.

Farrag, S. G., Sahli, N., El-Hansali, Y., Shakshuki, E. M., Yasar, A., & Malik, H. (2021). STIMF: a smart traffic incident management framework. *Journal of Ambient Intelligence and Humanized Computing*, *12*, 85-101.

Guerrero-Ibáñez, J., Zeadally, S., & Contreras-Castillo, J. (2018). Sensor technologies for intelligent transportation systems. *Sensors*, *18*(4), 1212.

Guido, G., Vitale, A., Astarita, V., Saccomanno, F., Giofré, V. P., & Gallelli, V. (2012). Estimation of safety performance measures from smartphone sensors. *Procedia-Social and Behavioral Sciences*, *54*, 1095-1103.

Guido, G., Vitale, A., Saccomanno, F. F., Festa, D. C., Astarita, V., Rogano, D., & Gallelli, V. (2013). Using smartphones as a tool to capture road traffic attributes. *Applied Mechanics and Materials*, *432*, 513-519.

Hadavi, S., Rai, H. B., Verlinde, S., Huang, H., Macharis, C., & Guns, T. (2020). Analyzing passenger and freight vehicle movements from automatic-Number plate recognition camera data. *European Transport Research Review*, *12*(1), 1-17.

Hainen, A. M., Remias, S. M., Brennan, T. M., Day, C. M., & Bullock, D. M. (2012, June). Probe vehicle data for characterizing road conditions associated with inclement weather to improve road maintenance decisions. In *2012 IEEE Intelligent Vehicles Symposium* (pp. 730-735). IEEE.

He, Z., Qi, G., Lu, L., & Chen, Y. (2019). Network-wide identification of turn-level intersection congestion using only low-frequency probe vehicle data. *Transportation Research Part C: Emerging Technologies*, *108*, 320-339.

Hodoň, M., Karpiš, O., Ševčík, P., & Kociánová, A. (2021). Which digital-output MEMS magnetometer meets the requirements of modern road traffic survey? *Sensors*, *21*(1), 266.

Hong, Q., Wallace, R., Dennis, E., Reed, B., Tansil, W., & Smith, M. (2015). Management procedures for data collected via intelligent transportation systems. *Journal of Civil Engineering and Architecture*, *9*(09).

Jadaan, K., Zeater, S., & Abukhalil, Y. (2017). Connected vehicles: an innovative transport technology. *Procedia Engineering*, *187*, 641-648.

Jang, J. A., Kim, H. S., & Cho, H. B. (2011). Smart roadside system for driver assistance and safety warnings: Framework and applications. *Sensors*, *11*(8), 7420-7436.

Javaid, S., Sufian, A., Pervaiz, S., & Tanveer, M. (2018, February). Smart traffic management system using Internet of Things. In *2018 20th international conference on advanced communication technology (ICACT)* (pp. 393-398). IEEE.

Jeon, S., Kwon, E., & Jung, I. (2014). Traffic measurement on multiple drive lanes with wireless ultrasonic sensors. *Sensors*, *14*(12), 22891-22906.

Kang, C., Liu, Y., Ma, X., & Wu, L. (2012). Towards estimating urban population distributions from mobile call data. *Journal of Urban Technology*, *19*(4), 3-21.

Ke, R., Feng, S., Cui, Z., & Wang, Y. (2020). Advanced framework for microscopic and lane-level macroscopic traffic parameters estimation from UAV video. *IET Intelligent Transport Systems*, *14*(7), 724-734.

Klein, L. A. (2022). Roadside Sensors for Traffic Management.

Kurkcu, A., Morgul, E. F., & Ozbay, K. (2015). Extended implementation method for virtual sensors: Web-based real-time transportation data collection and analysis for incident management. *Transportation Research Record*, *2528*(1), 27-37.

Lee, W. H., Tseng, S. S., & Shieh, W. Y. (2010). Collaborative real-time traffic information generation and sharing framework for the intelligent transportation system. *Information Sciences*, *180*(1), 62-70.

Lee, J. K., Jeong, Y. S., & Park, J. H. (2015). s-ITSF: a service based intelligent transportation system framework for smart accident management. *Human-centric Computing and Information Sciences*, *5*, 1-9.

Liu, X., Chien, S., & Kim, K. (2012). Evaluation of floating car technologies for travel time estimation. *Journal of Modern Transportation*, *20*, 49-56.

Lopes, J., Bento, J., Huang, E., Antoniou, C., & Ben-Akiva, M. (2010, September). Traffic and mobility data collection for real-time applications. In *13th international IEEE conference on intelligent transportation systems* (pp. 216-223). IEEE.

Manasreh, D., Nazzal, M. D., Talha, S. A., Khanapuri, E., Sharma, R., & Kim, D. (2022). Application of autonomous vehicles for automated roadside safety assessment. *Transportation research record*, *2676*(12), 255-266.

Mandhare, P. A., Kharat, V., & Patil, C. Y. (2018). Intelligent road traffic control system for traffic congestion: a perspective. *International Journal of Computer Sciences and Engineering*, *6*(07), 2018.

Martinez, F. J., Toh, C. K., Cano, J. C., Calafate, C. T., & Manzoni, P. (2010). Emergency services in future intelligent transportation systems based on vehicular communication networks. *IEEE Intelligent Transportation Systems Magazine*, *2*(2), 6-20.

Nanda, A., Puthal, D., Rodrigues, J. J., & Kozlov, S. A. (2019). Internet of autonomous vehicles communications security: overview, issues, and directions. *IEEE Wireless Communications*, *26*(4), 60-65.

Odat, E., Shamma, J. S., & Claudel, C. (2017). Vehicle classification and speed estimation using combined passive infrared/ultrasonic sensors. *IEEE transactions on intelligent transportation systems*, *19*(5), 1593-1606.

Oluwatobi, A. N., Tayo, A. O., Oladele, A. T., & Adesina, G. R. (2021). The design of a vehicle detector and counter system using inductive loop technology. *Procedia Computer Science*, *183*, 493-503.

Pell, A., Nyamadzawo, P., & Schauer, O. (2016). Intelligent transportation system for traffic and road infrastructure-related data. *International Journal of Advanced Logistics*, *5*(1), 19-29.

Prabha, R., & Kabadi, M. G. (2016). Overview of data collection methods for intelligent transportation systems. *The International Journal Of Engineering And Science (IJES)*, *5*(3), 16-20.

Pulugurtha, S. S., Puvvala, R. K., Pinnamaneni, R. C., Duddu, V. R., & Najaf, P. (2014). Buses as probe vehicles for travel time data collection on urban arterials. In *T&DI Congress 2014: Planes, Trains, and Automobiles* (pp. 785-793).

Qian, T., Shao, C., Wang, X., & Shahidehpour, M. (2019). Deep reinforcement learning for EV charging navigation by coordinating smart grid and intelligent transportation system. *IEEE transactions on smart grid*, *11*(2), 1714-1723.

Rabby, M. K. M., Islam, M. M., & Imon, S. M. (2019, September). A review of IoT application in a smart traffic management system. In *2019 5th International Conference on Advances in Electrical Engineering (ICAEE)* (pp. 280-285). IEEE.

Rath, M. (2018, June). Smart traffic management system for traffic control using automated mechanical and electronic devices. In *IOP Conference Series: Materials Science and Engineering* (Vol. 377, No. 1, p. 012201). IOP Publishing.

Raza, S., Al-Kaisy, A., Teixeira, R., & Meyer, B. (2022). The Role of GNSS-RTN in Transportation Applications. *Encyclopedia*, *2*(3), 83.

Rawal, T., & Devadas, V. (2015). Intelligent transportation system in india-a review. *Journal of Development Management and Communication*, *2*(3), 299-308.

Rizwan, P., Suresh, K., & Babu, M. R. (2016, October). Real-time smart traffic management system for smart cities by using Internet of Things and big data. In *2016 international conference on emerging technological trends (ICETT)* (pp. 1-7). IEEE.

Seo, T., Kusakabe, T., & Asakura, Y. (2015). Estimation of flow and density using probe vehicles with spacing measurement equipment. *Transportation Research Part C: Emerging Technologies*, *53*, 134-150.

Seo, T., & Kusakabe, T. (2015). Probe vehicle-based traffic state estimation method with spacing information and conservation law. *Transportation Research Part C: Emerging Technologies*, *59*, 391-403.

Shaheen, S., & Finson, R. (2013). Intelligent transportation systems.

Shelke, M., Malhotra, A., & Mahalle, P. N. (2019). Fuzzy priority based intelligent traffic congestion control and emergency vehicle management using congestion-aware routing algorithm. *Journal of Ambient Intelligence and Humanized Computing*, 1-18.

Stepanova, D., Sukuvaara, T., & Karsisto, V. (2020, May). Intelligent Transport Systems–Road weather information and forecast system for vehicles. In *2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring)* (pp. 1-5). IEEE.

Sumalee, A., & Ho, H. W. (2018). Smarter and more connected: Future intelligent transportation system. *Iatss Research*, *42*(2), 67-71.

Tarapiah, S., Atalla, S., Muala, N., & Tarabeh, S. (2014, May). Offline public transportation management system based on GPS/WiFi and open street maps. In *2014 Sixth International Conference on Computational Intelligence, Communication Systems and Networks* (pp. 182- 185). IEEE.

Tasgaonkar, P. P., Garg, R. D., & Garg, P. K. (2020). Vehicle detection and traffic estimation with sensors technologies for intelligent transportation systems. *Sensing and Imaging*, *21*, 1-28. Tewolde, G. S. (2012, May). Sensor and network technology for intelligent transportation systems.

In *2012 IEEE International Conference on Electro/Information Technology* (pp. 1-7). IEEE. Tewolde, G. S. (2012, May). Sensor and network technology for intelligent transportation systems.

In *2012 IEEE International Conference on Electro/Information Technology* (pp. 1-7). IEEE.

Tupper, L. L., Chowdhury, M. A., Klotz, L., & Fries, R. N. (2012). Measuring sustainability: How traffic incident management through intelligent transportation systems has greater energy and environmental benefits than common construction-phase strategies for “green”

roadways. *International journal of sustainable transportation*, *6*(5), 282-297.

Wahlström, J., Skog, I., & Händel, P. (2017). Smartphone-based vehicle telematics: A ten-year anniversary. *IEEE Transactions on Intelligent Transportation Systems*, *18*(10), 2802-2825.

Wan, X., Ghazzai, H., & Massoud, Y. (2019). Mobile crowdsourcing for intelligent transportation systems: Real-time navigation in urban areas. *IEEE Access*, *7*, 136995-137009.

Wang, H., Ouyang, M., Meng, Q., & Kong, Q. (2020). A traffic data collection and analysis method based on wireless sensor network. *EURASIP Journal on Wireless Communications and Networking*, *2020*(1), 1-8.

Wemegah, T. D., & Zhu, S. (2017, October). Big data challenges in transportation: A case study of traffic volume count from massive Radio Frequency Identification (RFID) data. In *2017 international conference on the frontiers and advances in data science (FADS)* (pp. 58-63). IEEE.

Xie, H., Karunasekera, S., Kulik, L., Tanin, E., Zhang, R., & Ramamohanarao, K. (2017, June). A simulation study of emergency vehicle prioritization in intelligent transportation systems. In *2017 ieee 85th vehicular technology conference (vtc spring)* (pp. 1-5). IEEE.

Yang, D., Jiang, K., Zhao, D., Yu, C., Cao, Z., Xie, S., ... & Zhang, K. (2018). Intelligent and connected vehicles: Current status and future perspectives. *Science China Technological Sciences*, *61*, 1446-1471.

Younes, M. B., & Boukerche, A. (2018). An efficient dynamic traffic light scheduling algorithm considering emergency vehicles for intelligent transportation systems. *Wireless Networks*, *24*, 2451-2463.

Yu, M., Deng, T., & Fu, J. (2012, June). Application of RFID and GPS technology in transportation vehicles monitoring system for dangerous goods. In *2012 2nd International Conference on Remote Sensing, Environment and Transportation Engineering* (pp. 1-4). IEEE.

Yuan, H., & Li, G. (2021). A survey of traffic prediction: from spatio-temporal data to intelligent transportation. *Data Science and Engineering*, *6*, 63-85.

Zeyu, J., Shuiping, Y., Mingduan, Z., Yongqiang, C., & Yi, L. (2017). Model study for intelligent transportation system with big data. *Procedia Computer Science*, *107*, 418-426.

Zhang, Z., Zheng, J., Xu, H., & Wang, X. (2019). Vehicle detection and tracking in complex traffic circumstances with roadside LiDAR. *Transportation research record*, *2673*(9), 62-71.

Zhang, S., Markos, C., & James, J. Q. (2022). Autonomous vehicle intelligent system: Joint ride-sharing and parcel delivery strategy. *IEEE Transactions on Intelligent Transportation Systems*, *23*(10), 18466-18477.

Zheng, X., Chen, W., Wang, P., Shen, D., Chen, S., Wang, X., ... & Yang, L. (2015). Big data for social transportation. *IEEE Transactions on Intelligent Transportation Systems*, *17*(3), 620- 630.

Zhou, H., Liu, B., & Wang, D. (2012). Design and research of urban intelligent transportation system based on the internet of things. In *Internet of Things: International Workshop, IOT 2012, Changsha, China, August 17-19, 2012. Proceedings* (pp. 572-580). Berlin, Heidelberg: Springer Berlin Heidelberg.

Zhou, H., Kong, H., Wei, L., Creighton, D., & Nahavandi, S. (2014). Efficient road detection and tracking for unmanned aerial vehicle. *IEEE transactions on intelligent transportation systems*, *16*(1), 297-309.

Zhu, L., Yu, F. R., Wang, Y., Ning, B., & Tang, T. (2018). Big data analytics in intelligent transportation systems: A survey. *IEEE Transactions on Intelligent Transportation Systems*, *20*(1), 383-398.