Review

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Exploring Vehicle Telematics in Intelligent Transportation Systems: Applications, Challenges, and Prospects

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Abstract: Vehicle telematics aims to enhance fuel efficiency, reduce emissions, improve diagnostics, promote road safety, and optimize fleet management. Vehicle telematics solutions can be implemented using either smartphone or cyber-physical based systems, offering various applications within the realm of Intelligent Transportation Systems (ITS). This study systematically reviews the existing literature on the applications of smartphone and cyber-physical-based vehicle telematics within ITS. A comprehensive search was conducted in the Web of Science (WoS) and Scopus databases, with the search completed in October 2024. Studies focused on the vehicle telematics applications in ITS were included. Out of 397 articles related to smartphone-based vehicle telematics, 54 were selected for an in-depth review. Similarly, 37 articles were shortlisted from 210 identified studies on cyber-physical-based vehicle telematics. The review reveals that vehicle telematics is utilized in various applications, including eco-driving, eco-routing, driver behavior monitoring, vehicle health diagnostics, road pavement condition monitoring, and fleet management. This systematic review highlights the current state of vehicle telematics in ITS, analyzing and comparing different solutions developed using smartphones and cyber-physical systems. It also identifies existing challenges, reports on scientific trends, and suggests future research directions for expanding the application of vehicle telematics.

Keywords: cyber-physical systems; intelligent transportation systems; on-board diagnostics (OBD-II); smartphone; systematic literature review; vehicle telematics

1. Introduction

The rapid growth of the global population, particularly in urban areas, is reshaping the landscape of modern cities. It is projected that by the coming decades, 70% of the world's population will be living in urban environments [1]. This never-before-seen urbanization is going to present several challenges to be dealt with, especially under smart city development. One urgent problem lies in the smart urban mobility where people and goods transport have to be paramountly efficient. Thus, for instances, the number of vehicles in Europe increased up to over 250 million by 2015 that tells actually the boom rising in transportation demand [1]. In fact, this brings forth various associated challenges as traffic congestions, increased greenhouse gas (GHG) emissions, inducing both physical and psychological health in people living at cities. Only road transportation generates 29% of all GHG emissions in the world and 25% of CO_2 emissions [2]. For example, traffic jams accounted for an average cost of 97 hours and $1,348 per U.S. driver in 2018 [3]. Smart mobility now becomes a prime focus for urban planners working for the cities of the future to resolve these challenges.

1.2. Research Contextx

Smart urban mobility integrates ICT (information and communication technologies) with urban transport infrastructure to maximize efficiency, safety, and sustainability. Smart mobility treat heterogeneous data-sources—like traffic flow characterization, road pavement condition monitoring, and connected vehicle sensors—to achieve better urban transportation systems management. Big data technologies have emerged for efficient processing for storage and analysis of a very large volume of data to validate and calibrate traffic models and simulations.

Intelligent Transportation Systems (ITS) is one of the key areas where improvements take place with respect to traffic management services. The main applications here are those that help users get better information toward enhanced safety, mobility, and environmental outcomes. Rapid advancement in technology has been apparent in the transformation of the transportation industry, with the field of ITS growing as a key area of research and development today. The cornerstone in the evolution of such ITS technology is the integration and application of clever technologies, particularly smartphone-based and cyber-physical systems (CPS), in vehicle telematics. The historical data that govern systems and services, which enable much better handling and sense of adaptation that made the transport networks true in-the-field testing, are revolutionized.

Vehicle telematics is a multi-disciplinary domain that encompasses informatics, telecommunications, vehicular technologies, and computer engineering to collect and abstract the information from the vehicles to understand its implications that can further lead to improvements in transport efficiency. Applications of vehicle telematics include driver behavior classification, eco-driving and eco-routing strategies to reduce fuel consumption and GHG emissions, and fleet diagnostics and management. For instance, eco-driving techniques can enhance a vehicle's fuel efficiency by 20-45% through driving style optimization, such as reducing harsh braking and acceleration, or improving traffic flow [1]. Beyond eco-driving, driver behavior classification through vehicle telematics is instrumental in preventing road accidents, as 24% of all road accidents and 75% of fatal accidents are attributed to driver error [4]. Vehicle telematics solutions can be implemented through either smartphones or CPS.

1.3. Scope and Significance

The ubiquity of smartphones in modern society, driven by rapid advancements in mobile technology, has opened new avenues for ITS applications. Smartphones have thus become multipurpose platforms for ITS functions, being equipped with several types of sensors such as GPS, accelerometers, gyroscopes, and magnetometers. They are relatively cheap substitutes for in-vehicle dedicated telematics devices to be connected over-the-air rather than using additional hardware. Hence, numerous applications have emerged on how smartphones could be used for traffic monitoring, accident detection, and driver assistance.

Similar to advancements of smartphone towards an intelligent future, the modern acceptance and use of On-board diagnostics (OBD-II) systems in vehicles have severely affected ITS evolution. Mandated in vehicles manufactured since the mid-1990s, OBD-II systems provide a standardized interface for accessing a wealth of data from a vehicle's internal sensors and computer systems, including engine performance, fuel consumption, and DTC. Integration of OBD-II data along with smartphone\CPS based solutions should lead to more robust and precise applications in ITS. In addition to that, commercially available OBD-II Bluetooth self-support devices make this possible.

The combination of smartphones\CPS and OBD systems provides numerous possibilities for ITS applications, such as the detection of harsh driving events, the surveillance of safety, the assessment of driving behaviour, and the introduction of new motor insurances schemes. These devices could form a rich database in areas like vehicle position, speed, acceleration, fuel consumption, and much more. Design of CPS used in vehicle telematics calls for careful consideration of the computational power and capabilities.

In terms of potential, smartphone and CPS based solutions in ITS are quite promising. Nevertheless, challenges and limitations exist including, but not limited to data accuracy, privacy, battery life, and the integration of disparate data sources. Besides, each technology has country and socio-economic context-determined conditions necessary for getting an optimal approach to functionality.

This systematic literature review is conducted for ascertaining the current state of research on the use of smartphone and CPS-based systems in ITS applications. This review will describe critically how these have been used, their associated challenges and opportunities, along the existing trend and future directions in this area. It will be a consolidated repository of existing knowledge for researchers, developers, and policymakers in moving forward using vehicle telematics to enhance ITS capabilities.

This review offers an analysis focused on the current state of research in this area, exploring the various means of implementing vehicle telematics founded on smartphones and CPS, possibly discovering new applications beyond the already explored ones. In detail, the review attempts to analyze how these technologies support the different aspects of ITS, particularly in traffic management, safety, and efficiency. Additionally, we identify and examine the key challenges hindering the broader adoption and effectiveness of smartphone\CPS based vehicle telematics, thereby paving the way for future research and development efforts. By aligning our review with these specific research questions, we aim to offer valuable insights that will contribute to the ongoing evolution of this field.

This study is structured as follows: Section 2 reviews related work, Section 3 outlines the methodology for the systematic literature review, Section 4 presents the background, Section 5 discusses the results, Section 6 presented challenges, Section 7 discussed the future directions, Section 8 presented the limitations, and the final section provides conclusions.

2. Related Work

The integration of smartphones and CPS into vehicle telematics has garnered significant attention within the ITS domain. This body of research reflects the rapid advancement and potential of these technologies, both independently and in tandem. In this section, we review the existing literature on vehicle telematics applications, challenges, and future trends, highlighting key findings and identifying gaps that this systematic review seeks to address. Table 1 provides a summary of the objectives, scope, number of papers reviewed, and key insights from various studies.

Table 1. Summary of reviews on vehicle telematics in intelligent transportation systems.

Title	Aim/Objective	Study Range	Papers
A Review on improved driving efficiency by leveraging smartphone sensors in India. [5]	The aim of this paper is to investigate the various methods provided by the smartphone for achieving driving efficiency. They also focus on the fact that how a geographical location can impact on analysis of the data obtained from telematics devices for evaluating driver behavior.	2009-2022	19
Comprehensive driver behaviour review: Taxonomy, issues and challenges, motivations and research direction towards achieving a smart transportation environment. [6]	The aim of this study is to review and analyse articles related to driver behaviour and sensors and classify them into different components. Coherent taxonomy for distributing articles is conducted onthe basis of similar characteristics. Discusses the challenges and motivations encountered by previous researchers within the domain of driver behaviour and sensors	2010-2021	155

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Analyzing driver behavior under naturalistic driving conditions: A review. [7]	Exploring different devices and instruments used for extracting naturalistic driving data. Exploring the methodology used by researchers for analyzing naturalistic driving data. Exploring different factors affecting driving behavior. How to improve road safety by using naturalistic driving data?	1992-2020	135
Profiling drivers to assess safe and eco-driving behavior – A systematic review of naturalistic driving studies. [8]	Exploring the parameters used in research for profiling driver behavior. Presenting different methods used by researchers for driver profiling. Presenting different applications of profiling driver behavior.	2008-2020	14
Eco-Driving and Its Impacts on Fuel Efficiency: An Overview of Technologies and Data-Driven Methods. [9]	The objective of this paper is to find the factors of driving behavior which affect fuel consumption. To explore the modeling techniques which estimate the fuel consumption accurately based on driving behavior.	1997-2020	17
A critical overview of driver recording tools. [10]	Comparing different driver recoding tools and identify the future challenges for their applications.	2000-2020	
Systematic Literature Review on Automotive Diagnostics. [11]	To investigate the main challenges in automotive diagnostics. To identify methods which are mostly used. To investigate the problems found in those methods. To identify the problems in automotive diagnostics which are still not discussed.	2011-2017	40
Survey of smartphone-based sensing in vehicles for intelligent transportation system applications. [12]	The aim of this study is to analyze the use of smartphones for Intelligent Transportation System applications.	2007-2015	24

Several methods have been explored to enhance driving efficiency using smartphone sensors, particularly in the Indian context. A study by Chatterjee and Madhavan 2022, emphasized the advantages of smartphones over fixed telematics devices, highlighting benefits such as inherent connectivity and cost savings from eliminating additional hardware installations [5]. Despite these advantages, challenges like battery life limitations and difficulties in sensing vehicle acceleration due to changes in smartphone orientation were noted. The impact of geographical data on driver behavior analysis was also highlighted, pointing out significant disparities in road quality between developed and developing nations. A comprehensive review of driver behavior studies was conducted by Zaidan, Alamoodi et al. 2022, who categorized articles into coherent taxonomies based on shared characteristics [6]. This research stressed the critical role of data labeling in overcoming research challenges and advocated for small-scale, microscopic studies to build diverse datasets. These datasets are essential for comparing driver behaviors across different regions, contributing to the development of smart transportation systems. Various devices and methodologies used in naturalistic driving studies have been investigated, with Singh and Kathuria 2021 underscoring that driver behavior is a primary contributor to road accidents [7]. The study highlighted the growing role of smartphones as essential tools for collecting driving data, revealing drivers' tendencies to reduce speed and increase headway during distracting situations or adverse weather conditions. The importance of providing regular feedback to drivers to improve driving behavior and enhance road safety was also emphasized. Driver profiling to promote safe and eco-driving behaviors has been a key focus in recent research. In their study, Singh and Kathuria 2021 discussed parameters and methods used in driver profiling, highlighting the importance of feedback mechanisms and usage-based insurance schemes [8]. The widespread use of smartphones was endorsed due to their ubiquity and effectiveness in gathering driver behavior data. Factors influencing fuel consumption in relation to driving behavior have been examined by Fafoutellis, Mantouka et al. 2020, with various modeling techniques reviewed for accurate fuel consumption estimation [9]. The research found that driving behavior, along with weather and traffic conditions, vehicle specifications, and road geometry, significantly impacts fuel efficiency. Machine learning models such as Support Vector Machines (SVM), Random Forests (RF), and Neural Networks (NN) were identified as suitable methods for predicting fuel consumption based on driving style data. A critical overview of driver recording tools was provided by Ziakopoulos, Tselentis et al. 2020, comparing technologies like smartphones and in-vehicle data recorders [10]. The study identified cost as a significant barrier to adopting advanced tools and suggested that traditional methods, including surveys, interviews, and simulators, still hold value in research. Challenges in automotive diagnostics have also been reviewed, with de Oliveira, Wehmeister et al. 2017 noting the widespread use of OBD systems to collect vehicle data, which is then transmitted to remote servers [11]. The study pointed out that the human-machine interface is an underexplored area in automotive diagnostics and suggested the use of voice recognition to reduce driver distraction. Finally, the application of smartphones in ITS has been explored by Engelbrecht, Booysen et al. 2015, who concluded that smartphones could enable comprehensive vehicle monitoring and driver assistance systems [12]. The potential of smartphones to facilitate optimal route selection, reduce congestion, and alert authorities to the causes of traffic disruptions was highlighted.

While previous reviews have provided valuable insights, certain limitations remain. For instance, some reviews did not capture the most recent advancements in vehicle telematics technology, potentially overlooking emerging applications or challenges. Reviews that covered a broader range of driver recording tools beyond smartphones may offer a less focused analysis of the unique aspects of vehicle telematics [10]. Additionally, studies concentrated on specific areas, such as automotive diagnostics, may not fully address the broader applications and challenges of vehicle telematics within ITS [11]. This systematic review aims to fill these gaps by providing a comprehensive exploration of applications, challenges, and future trends specific to smartphone and CPS based vehicle telematics.

3. Methodology

This review was performed following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. These guidelines allow systematic reviewers to plan and conduct carefully and explicitly document what is planned, enabling others to replicate review methods and to judge the validity of methods used [13].

3.1. Research Questions

Several applications of vehicle telematics that leverage smartphones and CPS already exist. The aim of the present study is to systematically gather and review these applications developed using smartphones and CPS. Additionally, the study examines the significance, challenges, and potential future research directions of vehicle telematics. The following questions are addressed in this study:

RQ1 – What are the applications of vehicle telematics in ITS.

RQ2 – To identify challenges in smartphone-based vehicle telematics in ITS.

RQ3 – To identify challenges in cyber physical-based vehicle telematics in ITS.

RQ4 – To identify promising future research directions of vehicle telematics

3.2. Search Strategy

For literature survey, two prominent databases (Scopus and Web of Sciences (WoS)) were searched using the library portal at University of Malaya, Malaysia in October 2024. The selection of

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Scopus and Web of Science (WoS) as the primary databases was based on their comprehensive coverage of high-quality, peer-reviewed publications from reputable publishers. These databases provide extensive indexing across various disciplines, ensuring that relevant and high-impact studies on vehicle telematics are included. The literature review was restricted to the last seven years 2018-2024 because of the dynamic nature of embedded systems. Any technology older than seven years is already made redundant by new advancements. The frequency of proposed advancement in compute boards, communication modules and cloud computing platform are rather frequent.

The keyword selection process was structured to ensure the retrieval of relevant research on vehicle telematics. The search terms were derived from key concepts in the domain, incorporating variations and Boolean operators to maximize coverage. To extract the relevant material, the searched strategy was based on following key words:

- ("OBD*" AND ("smartphone" OR "smart phone" OR "mobile"))
- ("OBD-II" AND "Intelligent Transportation System")
- ("Traffic" AND "OBD-II" AND "Intelligent Transportation System")
- ("Internet of Things" AND "OBD-II" AND "Intelligent Transportation System")

These keywords were iteratively refined based on preliminary search results to ensure a balance between specificity and comprehensiveness. The rationale behind these selections was to target studies that discuss both smartphone-based and cyber-physical-based telematics solutions while capturing relevant advancements in IoT, vehicle diagnostics, and driver behavior monitoring.

By searching two databases we found 367 and 240 papers from Scopus and WoS database respectively as shown in Table 2.

Table 2. Total number of papers found in online databases.

Databases	No. of Papers Found
Scopus	367
Web of Science	240
Total	607

3.3. Inclusion and Exclusion Criteria

The following criteria were followed in selecting relevant papers,

- The proposed vehicle telematics solution should be smartphone and cyber physical based.
- The article must be published by a reputable publisher.
- Full article text is available online and accessible.
- The article has been published in the last seven years.
- No limit applied for the type of document, Therefore, content types such as journal articles, reports, conference papers, book chapters, theses, and dissertations, etc. were included

3.4. Study Selection and Data Extraction

The smartphone and CPS based vehicle telematics solution literature review was undertaken according to PRISMA framework as can be seen in Figure. 1.

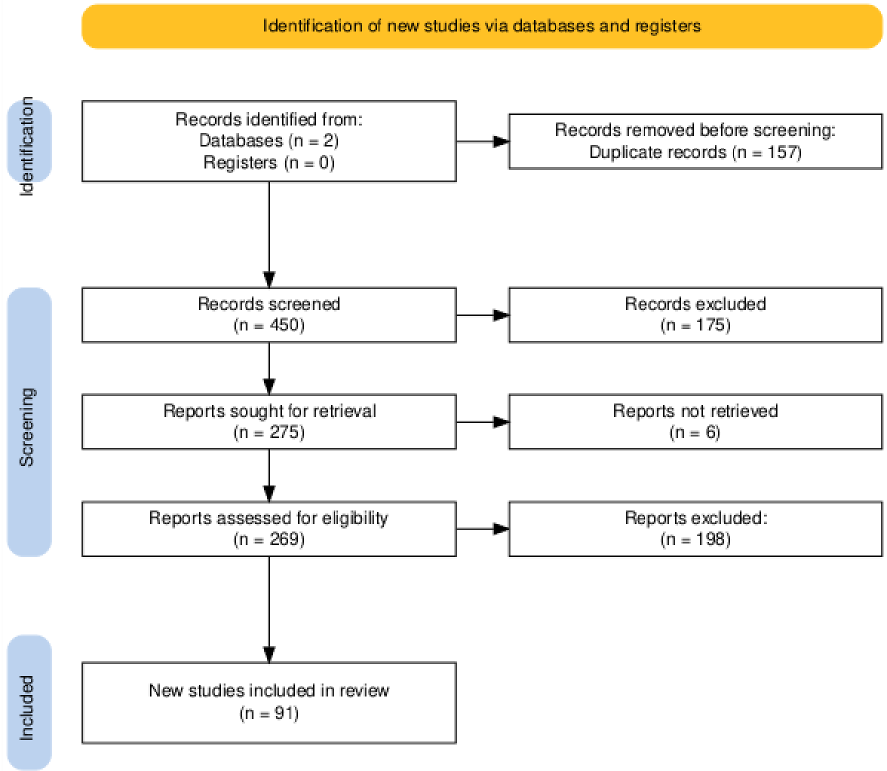

Figure 1. PRISMA flow diagram for vehicle telematics in ITS domain.

The title, abstract, keywords, authors' names and affiliations, journal name, and year of publication of the identified records were exported to an MS Excel spreadsheet. The publication selection process followed the PRISMA framework, ensuring a transparent and systematic approach. Initially, duplicate records were removed, followed by title and abstract screening based on predefined inclusion criteria. Full-text eligibility assessments were performed independently by two reviewers, with disagreements resolved through discussion or the involvement of a third reviewer. This meticulous selection process ensured that only the most relevant and high-quality studies were included in the systematic review.

3.5. Results

After searching the two databases, i.e., Scopus and WoS total **609** records were found. **450** remained after removing **157** duplicate records. After Initial scanning of title and abstract, **175** more records were discarded. **275** reports were retrieved for full text screening, but 6 reports couldn't be retrieved for full text. After screening the full text, **198** reports were discarded which did not fulfill the eligibility criteria of the systematic review. There were **91** studies that met the inclusion criteria and were selected for further analysis.

Table 3. Papers selected for systematic review.

Databases	No. of Papers Selected
Scopus	44
Web of Science	47
Total	91

4. Background

The architecture of vehicle telematics systems typically includes an OBD-II adapter, which can be easily installed on the OBD-II port provided by the vehicle manufacturer. Across nearly all the studies reviewed in this work, the ELM327 OBD-II adapter is the preferred choice. This adapter transmits vehicular data either via Bluetooth or Wi-Fi to a smartphone or a CPS for further processing. The development of the standard OBD-II in 1996 by the Society of Automotive Engineers (SAE), USA, marked a significant advancement in regulating vehicular emissions [2]. This standard led to the integration of sensor arrays in modern vehicles, which monitor emissions, diagnostics, and fuel efficiency. These sensor arrays are collectively referred to as the vehicle's Electronic Control Unit (ECU). Data from the ECU can be accessed through a single OBD-II port. The OBD-II system utilizes two types of codes to request ECU data: Diagnostic Trouble Codes (DTCs) for vehicle diagnostics and Parameter Identifiers (PIDs) for real-time vehicle performance monitoring [14].

There are five signalling protocols used for communication with the ECU via the OBD-II port: SAE J1850 (VPW and PWM), ISO 9141, ISO 15765 (CAN), and ISO 14230 (KWP2000) [2]. The primary distinction among these protocols lies in their pin configurations, which in turn determines the set of vehicular parameters each protocol can provide. Manufacturers typically implement only one signalling protocol; for example, SAE J1850 PWM is the standard used by Ford Motor Company, USA. The OBD-II port offers access to a rich portfolio of vehicle parameters, exceeding 200 in number [15]. However, the selection of specific parameters depends on the research objectives, which may include driver style classification, eco-driving/routing, accident detection/notification, fleet management, and diagnostics, among others. The most commonly selected parameters in the studies reviewed are summarized in Table 4.

Table 3. Vehicular sensor parameters used for different vehicle telematic based applications.

Variables	Nomenclature	Units	Variables	Nomenclature	Units
Acceleration	ACC	m/s2	Accelerometer	ACCM	
Air Pressure	AP		Camera	Cam	
Ambient Air Temperature	AAT		International Roughness Index	IRI	
Absolute Engine Loads	AEL		Longitude	LON	
Absolute throttle position	ATP		Latitude	LAT	
Average fuel consumption	AFC	oC	Altitude	ALT	
Air to Fuel Ratio	AFR		Angular acceleration	AcA	
Air metering	AM		Longitudinal acceleration	LonA	
Accumulated Fuel Consumption	AFC		Vertical acceleration	VerA	
Accumulated mileage	AM		Lateral acceleration	LatA	
Accelerator Pedal Position	APP		Smartphone Elevation	SE	
Acceleration Pedal Degree	APD		Long-term fuel trim	LTFT	%
Abrupt Braking	AB		Location	L	
Auxiliary emission control	AEC		Load Fuel	LF	
Air bag active	ABA		Lambda sensor	LS	
Brake Drum	BD		Mass Air Flow	MAF	g/s
Braking	B		Motor Temperature	MT	
Brake Pedal Position	BPP		Magnetometer	MAG	
Battery Voltage	BV		Mileage	M	
Battery Current	BC		Oxygen Sensor	O2	V
Battery Temperature	BT		Oil Pressure	OP	
Battery Cell Level	BCL		Oil service time	OST	

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Barometric Pressure	BP		OBD standard	OBDS	
Calculated Engine Load	CEL	%	PID check	PIDC	
Crank Position	CP		Pedometer	PED	
Cruising	CR		Relative Throttle position	RTPS	
Car Pressure	CP		Rapid Lane Changes	RLC	
DTC Number	DTCN		Relative engine torque	RET	
Distance ahead Vehicle	DAV		Relative friction torque	RFT	
Distance Travelled	DT		Real Time Clock	RTC	
Differential Pressure (Delta P) across DPF	DP		Short-term fuel trim	STFT	%
Deceleration	DEC		State of air condition	SAC	
Engine load	EL		Steering Wheel Angle	SWA	
Engine Speed	RPM	rpm	Seat Belt Alert	SBA	
Engine Temperature	ET		Shift Up Event	SUE	
Engine Coolant Temperature	ECT	oC	State of Charge	SOC	
Engine Condition	EC		Slope per segment	SPS	
Exhaust Gas Temperature	EGT		Smoothness indicator	SI	
Equiv ratio	ER		Time	T	
Engine Running Time	ERT		Time Impact Ahead Vehicle	TIAV	
Engine Fuel Rate	EFR		Throttle position	TP	%
Engine position	EP		Throttle Valve	TV	
Engine oil temperature	EOT		Tire’s Pressure	TP	
Engine operational time	EOPT		Timing Advance	TA	
Engine Idle time	EIT		Trip Time	TT	
Engine start-ups number	ESN		Torque	Trq	
Engage gear	EG		Turn signal	TS	
Fuel Level	FL		Vehicle Speed	VSS	m/s
Fuel tank level input	FTLI		Vibration	V	
Fuel Pressure	FP		Wipers Status	WS	
Fuel Flow	FF		Intake Manifold Pressure	MAP	KPa
Fuel Efficiency	FE		Intake Air Temperature	IAT	
Fuel Consumption	FC		Instantaneous Fuel Consumption	IFC	
Fuel Consumption Rate	FCR		Instantaneous Vehicle Speed	IVS	
Fuel rail pressure	FRP		Illuminance	ILM	
Fuel Temperature	FTM		Idling Percentage	IP	
Fuel metering	FM		Jerk	JK	

Fleet Tracking	FT	Knock Sensor	KS
Gyroscope	GYR	Harsh events	HE
Gear Change	GC	Headlights Status	HS
Global Positioning System	GPS	Heat control valve	HCV

Vehicle telematics plays a crucial role in improving various aspects of vehicular operation, including fuel consumption, emissions, diagnostics, road safety, and fleet management. These solutions are primarily implemented through either smartphone-based platforms or CPS. As a critical component of ITS, vehicle telematics contributes significantly to smart mobility initiatives. In the literature, vehicle telematics is also referred to as the Internet of Vehicles (IoV) or Vehicle-as-a-Sensor (VaaS). ITS leverage advanced sensing, analysis, control, and communication technologies to enhance the safety, mobility, and efficiency of ground transportation. These systems encompass a broad spectrum of applications aimed at alleviating congestion, improving traffic management, reducing environmental impacts, and maximizing the overall benefits of transportation for both commercial users and the public.

5. Results

This section addresses our first Research Question (RQ-1): What are the applications of vehicle telematics in ITS?

Vehicle telematics plays a pivotal role in ITS by transforming vehicles into mobile sensors that collect and transmit data. This data serves multiple purposes, ranging from eco-driving and eco-routing to driver behavior monitoring, vehicle diagnostics, driver safety, fleet management, and road pavement condition monitoring (RPCM). The range of applications is illustrated in Figure. 2, which categorizes them broadly into three main areas: Ecological Driving (Eco-driving/routing, driver behavior), Fleet Management (fleet management, vehicle diagnostics), and Infrastructure (identifying road network inefficiencies, road pavement conditions monitoring). However, as a relatively nascent field, many potential applications of vehicle telematics remain underexplored. For instance, [16] utilized vehicle telematics to identify road bottlenecks and assessed its cost in terms of CO_2 emissions, fuel consumption, and time delays.

5.1. Ecological Behaviour

Among the factors that can affect fuel consumption, such as: Vehicle age and condition, outside temperature, weather, and traffic conditions, ecological behavior can be one of the most important parameter [9,17].

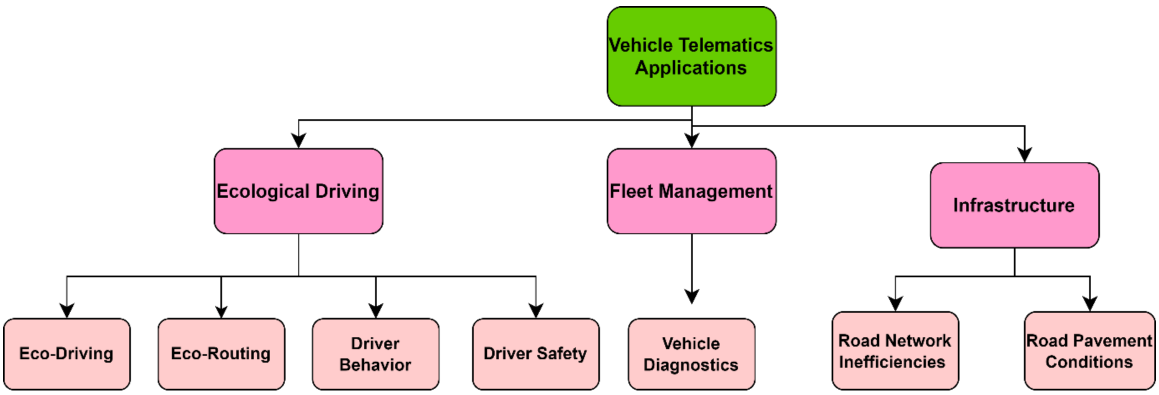

Figure 2. Applied applications of vehicle telematics in ITS.

5.1.1. Eco Driving

Eco-driving is a method that promotes driving behaviors aimed at reducing fuel consumption and lowering GHG emissions. Research indicates that eco-driving can decrease fuel consumption by 15% to 25% and cut GHG emissions by over 30% [18]. Using vehicle telematics, real-time feedback

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encourages drivers to adopt these fuel-efficient practices, which is particularly valuable given that fully autonomous and electric vehicles (EV) are still in development. Eco-driving, therefore, remains essential for improving the efficiency of current road transport. The techniques in eco-driving focus on practices like smooth acceleration, maintaining steady speeds, minimizing idling, and selecting optimal routes [19]. These habits not only save fuel but also enhance driver safety and reduce vehicle maintenance costs. In fact, drivers can boost fuel efficiency by up to 45% through eco-driving [1]. Transportation contributes significantly to global emissions, with the sector responsible for 25% of fuel consumption and 29% of carbon emissions worldwide—a number that has risen by 36% since 1990 [1]. Consequently, eco-driving plays a crucial role in mitigating the environmental impact of transportation. Aggressive driving, a major cause of traffic accidents, results in over 1.25 million fatalities globally each year according to WHO [20]. Studies suggest that smoother driving styles not only improve engine efficiency but also decrease emissions, making eco-driving an effective strategy for addressing both environmental and safety challenges.

Research highlights that eco-driving training can be beneficial, especially for drivers with poor eco-driving skills, enabling them to reduce fuel consumption by up to 20% while enhancing driving safety [21]. Shifting to a more efficient driving style can yield up to 25% fuel savings depending on the vehicle type [22]. There are five widely recognized eco-driving practices that significantly affect fuel consumption and emissions [23]:

1. Avoid rapid starts and accelerate smoothly.
2. Decelerate smoothly by releasing the accelerator early while keeping the car in gear.
3. Maintain a steady speed by anticipating traffic flow.
4. Shut down the engine during extended stops.
5. Shift gears as soon as possible and avoid high engine revolutions [21].

By implementing these techniques, drivers can improve safety, save fuel, and reduce emissions, making eco-driving a practical and impactful approach to sustainable transportation.

Both studies, [9] and [24], focused on analyzing vehicle fuel consumption by leveraging data from OBD and smartphone devices, identifying key factors that influence fuel usage and evaluating model effectiveness for accurate prediction. In [9], the authors review literature on eco-driving and present models for calculating fuel consumption, highlighting five main components: driving style, road geometry, vehicle specifications, traffic, and weather conditions, with driving style—particularly speed and acceleration—being the most significant factor. They assess the applicability of Machine Learning models, such as NN, SVM, and RF, for predicting fuel consumption based on driving behavior data. Meanwhile, [24] investigates vehicle fuel consumption using an affordable OBD-II interface combined with mobile technology, employing models like multivariate regression (MR), decision trees (DT), and NN. This study identifies vehicle design, weight, acceleration, speed, and engine load as critical factors and reports that while regression models achieve reasonable accuracy, NN outperforms them in error metrics. The authors suggest further improving prediction accuracy by integrating additional variables, such as weather conditions and specific driving scenarios, to optimize fuel efficiency.

Studies [25], [17], and [26] explored various data-driven platforms and frameworks aimed at analyzing driver behavior, fuel consumption, and promoting eco-friendly driving through advanced techniques and technologies. The "Driving Styles" platform conceived in [25] uses data mining and NN on OBD-II data to classify driving behaviors along characteristics such as speed, acceleration, and RPM. It can automatically identify route type and driving style, showing that aggressive driving increases fuel consumption by 20%, averaging 8 liters per 100 km compared to 6.6 liters for calmer driving. Study [17] introduced for assessment eco-efficient driving patterns, a data enrichment framework focused on real-time data acquisition, contextual data enrichment, and analytics. Data from nine different drivers during a seven-week period revealed the possibility of enriched automotive data for sustainable transportation linking driving behavior with fuel consumption and emissions. Finally, a fuzzy inference system (FIS) based approach is proposed within the IOV for encouraging eco-friendly driving [26]. The system identified driving nature and provided real-time recommendations to reduce CO_2 emissions through an OBD device and cloud processing using MQTT for communication. The application of these IoT communicating protocols has also been discussed in this particular study, which focuses on demonstrating their involvement in improving driver performance and facilitating the advancement of IoT-based transportation systems.

Studies [18], [27], [28], and [29] have investigated new methodologies for predicting as well as optimizing vehicle fuel consumption concerning smartphone data, OBD-II devices, and machine learning models. In [18], a smartphone-based approach was proposed, using driving behavior data from mobile phones and fuel consumption data from OBD systems to predict fuel usage. This study applied back propagation neural networks (BPNN), support vector regression (SVR), and RF, with the latter achieving the highest accuracy, making it feasible for large-scale use without extensive OBD installations. In [27], the authors developed a real-time fuel consumption estimation system for gasoline vehicles, introducing a Powertrain-based Model (using fuel injection data) and a Vehicle Dynamics-based Model (using GPS data). Field tests showed an average estimation error of around 6%, proving its compatibility with passenger vehicles and adaptability for broader vehicular applications. Study [28] build on fuel consumption modeling by using real-world OBD and smartphone data to assess eco-driving behaviors' impact on fuel efficiency. A Gradient Boosting DT model, achieving a mean absolute percentage error (MAPE) of 9.8%, was developed, with Shapley Additive Explanations (SHAP) further clarifying factors that influence fuel consumption, offering practical insights for real-world fuel efficiency improvements. Finally, [29] investigated how fuel type, air filter condition, and fuel filter cleanliness affect consumption in a multipoint injection (MPI) engine across urban, rural, and highway settings in Quito, Ecuador. This study found that higher-octane fuel (92) can reduce fuel use by up to 24.38% compared to lower-octane fuel (85), underscoring fuel type's significant role in enhancing efficiency across various driving conditions.

Studies [22] and [21] evaluates gamification-induced platforms for eco-driving behavior by using Internet-of-Things sensors, mobile technology, and real-time feedback systems. The GamECAR project [22] created an innovative interactive platform to promote and support healthy driving habits through activations of gamification in driving. In combination with in-vehicle, physiological variables, the system captures behaviour-based descriptions on fuel consumption, braking, accelerating, and gear changes, producing an eco-score for the driver to motivate or encourage a positive change. Gamification helps use rewards, challenges, and other means to bring in competition by motivating the drivers to switch to more eco-friendly driving yet keeping the drivers safe on the road. A framework combining serious gaming elements with IoT sensors for eco-driving was discussed in [21]. The system collected information such as throttle position, RPM, speed, and jerks through the OBD-II interface for real-time feedback that could create a fuel-lean and emission-free habit. The study identified throttle position as a key indicator of eco-driving behavior and employed a game-based scoring system to reinforce sustainable driving practices.

Studies [30], [31], [1], and [32] introduced diverse tools and frameworks for enhancing vehicle data analysis and eco-driving practices using OBD-II, CAN bus, and telematics within smart and sustainable transportation systems. In [30], "ObdCanCompare" is introduced as a tool for collecting and comparing data from both OBD-II and CAN bus interfaces using a smartphone, finding that CAN bus's higher sampling frequency (up to 5 Hz) offers an advantage over OBD-II's 1 Hz for driving-related decisions. The authors also developed a Social Driving app that ranks drivers on eco-driving metrics like GPS location, speed, fuel consumption, and CO_2 emissions, with companies offering rewards based on driver performance. Study [31] explored an autonomous Edge OBD-II device for real-time vehicle data collection, highlighting how varying PID response times across vehicles suggested a need for vehicle-specific data processing to support Industry 4.0 and improve decision-making. In [1], Roger Young et al. discussed vehicle telematics in the context of intelligent cities focusing on OBD-II and FMS standards for data extraction. They discovered that while OBD-II is more easily accessed, FMS provides finer information suitable for fleet management. Their analysis has again highlighted the telematics role in emissions reduction and urban sustainability via eco-driving. Finally, [32] examined discrepancies in fuel consuming measurements derived from on-board fuel consumption meters (OBFCMs) among about 1000 vehicles, reporting hybrid vehicles surprisingly consuming more fuel. By using a cost-effective OBD reader and mobile app, this study highlighted OBFCMs' potential to improve energy efficiency monitoring and regulatory insights, aiding sustainable transportation efforts through real-world fuel consumption analysis.

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Studies [33], [34], and [35] focused on predictive models and monitoring systems that link vehicle parameters, emissions, and driving behaviors to support eco-driving and regulatory compliance. In [33], a model using OBD and Arduino sensors was developed to investigate relationships between vehicle internal parameters, such as vehicle's speed, RPM, and exhaust emissions. Although the study found low predictive accuracy, with adjusted R-squared values around 0.1, it emphasized the need to understand these parameter-emission connections to advance eco-driving strategies. Study [34] examined NOx emissions from heavy-duty vehicles (HDVs) using OBD data in the context of China's China VI emission standards. Findings revealed a 64% reduction in NOx emissions for China VI-compliant vehicles compared to China V, with adjustments for idling and cold starts enhancing data accuracy. The study projected that full adoption of China VI standards by 2023 could prevent over 1.7 million tons of NOx emissions, showcasing OBD data as a practical tool for real-time emission monitoring. In [35], a system integrating emissions data with driving behavior was presented using an Exhaust Extraction Device (EED) and an upgraded OBD-II module. It has linked the pollutants such as CO_2 and NOx with some metrics such as engine RPM to showcase the effect of driving behavior on emissions. A lightweight and cost-effective alternative to traditional portable emission measurement systems, this enabled real-time tracking of emissions while providing eco-driving feedback through mobile and backend integration.

Eco Routing

Eco-routing is a strategy that can be utilized to identify routes that offer the most fuel-efficient travel of vehicles, focusing on fuel consumption minimization as well as GHG reduction [19]. This is particularly importantly related to the kind of road which is selected and can be, for example, highways which tend to operate smoothly and without much stop in comparison with urban streets and country roads, which reduces fuel consumption because of its effects on vehicle emissions. Being more fuel efficient routes also contributes significant environmental protection measures since fuel consumption correlates highly with pollutant emissions; thus, carbon and air pollution reduce significantly [36-38]. Of primary importance in eco-routing is the form of modeling and estimating fuel consumption for a particular road concerning many factors such as road type, traffic condition, and vehicle parameter. Integrating this into a navigation system would help eco-routing drivers in making informed decisions which can be an advantage in being beneficial to the environment while saving fuel. Thereby, this is providing assistance from using eco-routing technology to utilize emission-saving travel by drivers.

Studies [39], [40], [19], and [41] presented various systems to optimize route planning and fuel efficiencies to earn more for the driver and motivate eco-friendly driving from data-driven insights. ProfitMax was introduced in [39] as a recommendation system for taxi route maximization on profit generating productivity through balancing time efficiency with fuel consumptions. ProfitMax allows slight deviations from the route to save time without significantly raising fares and shows a 10% reduction in fuel consumption and considerable increase in income when tested against real-life data. Study [40] proposed an algorithm that reconstructed traveled routes without GPS, relying solely on smartphone accelerometer and gyroscope data to calculate distances and turns. This method achieved 78% accuracy in route reconstruction within a 1200 km^2 area, with a 95.5% accuracy among the top five suggested routes. In [19], a two-phase framework was outlined for optimizing fuel consumption, beginning with a Personalized Fuel Consumption Model (PFCM) based on driving behaviors and road conditions. Integrating real-time traffic data in the second phase, this system, tested with taxi data in Beijing, showed a potential 20% fuel savings with route prediction errors under 7% over distances of 10 km or more. Finally, [41] presented EasyRoute, a smartphone-based route recommendation system that used an OBD-II adapter to create personalized fuel consumption profiles. EasyRoute leveraged crowdsourced traffic data to recommend the most fuel-efficient routes, achieving predictions with 30% less relative error compared to baseline models, enhancing route and fuel efficiency for drivers.

Driver Behavior

Driver behavior profiling through vehicle telematics has gained significant importance, driven by the need to improve road safety and reduce environmental impact. Insurance companies are

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increasingly using smartphone apps equipped with sensors like accelerometers, magnetometers, and GPS to monitor driving habits [42]. These systems track unsafe behaviors such as speeding, distraction, and aggressive driving, all of which are major contributors to road accidents. According to the National Crime Records Bureau (NCRB) in India, over 80% of road fatalities are attributed to negligence by drivers, indicating the importance of vehicle telematics in identifying risky driving behaviors and providing feedback for encouraging safer driving [43]. Apart from safety, driver behavior profiling is also tied to environmental impacts given modern ITS objectives focuses on emission reductions. It was also confirmed by the literature that driving style highly influences fuel economy and pollution level. Accelerations, velocities, braking, idle-time and other similar behaviors which influence fuel rates are the direct indicators of fuel efficiency and emissions. In contrast to traditional methods of evaluating drivers, telematics allows for the categorization of drivers and focuses on specific behavioral patterns in order to achieve increased driving effectiveness, decrease fuel usage and decrease the negative impact on the environment. This makes vehicle telematics not only an effective means to increase road safety, but also a method to encourage drivers choose options that are less harmful to the environment.

Table 4. Component breakdown of smartphone-based vehicle telematics solutions. (RPCM = road pavement condition monitoring).

Study	OBD-II Parameters	Smartphones Parameters	ML/DL Techniques	Application Layer	Application
[18]	T, GPS (x, y, z), VSS, RPM, Trq, SAC, O_2, IFC	T, GPS(x, y, z), SE, GPS speed, ACC(x, y, z), AcA(x, y, z)	RF	Cloud	Eco driving
[25]	VSS, ACC, RPM, mass MAF, MAP, AIT	GPS, ACCM	NN	Remote Data Center	Eco driving
[27]	VSS, MAF, FL	T, ACC, GPS	-	-	Eco driving
[22]	B, SUE, RPM, CR, FC, GC, ACC	GPS		Spark Works Cloud	Eco driving
[21]	TP, RPM, VS, JK	GPS	-	-	Eco driving
[17]	CEL, RPM, VS, TP, FTL, RTP, ATP B, ATP C, ATP D, APP E, APP F, Relative APP, EFR	ACCM, GYR, uncalibrated GYR, MF, uncalibrated MF, RV, GRV			Eco driving
[28]	FC, VSS, ACC, DEC, HE, SI, IP	ALT, SPS, ACCM, GYR, GPS	Gradient Boosting DT	Cloud	Eco driving
[34]	AP, Lon, Lat, VSS, RET, RFT, RPM, EFR, FTL, ECT			Local	Eco driving
[35]	RPM			Web server	Eco driving
[29]	MAP, VSS, IAT			Local	Eco driving
[26]	VSS, ACC, JK, FC			Cloud	Eco driving
[24]	EL, RPM	GPS	NN		Eco driving
[32]	FC			Mobile app	Eco driving
[39]	IVS, AFC, T	GPS	-	Local-Smartphone	Eco Routing
[19]	D, VSS, FC	GPS			Eco Routing
[41]	IVS, AM, AFC, T	GPS		Smartphone	Eco Routing
[44]	VSS, RPM, TP, FC	GPS	NN	Web server	Driver safety (Correlation

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					btw Heart Rate and Driving style
[45]	VSS, ALT, ACC, Roll, Pitch, Yaw, DAV, TIAV		FCN-LSTM		Driver Identification
[46]	ACC, B,	ACCM, GPS, O		Cloud	Driver behavior/Driver safety
[43]	RPM, VSS, EL, TV	GPS	K-Means		Driver profiling and Diagnostics
[47]	VSS, RPM, BV,			Local Smartphone	Driver safety/driver behavior
[42]	ACC, VSS, TP, FL, RPM		Markov model K-Means, Adaboost	Complex Event Processor	Driver safety/behavior
[48]	VSS, RPM		Fuzzy Logic	IBM Bluemix cloud database	Driver behavior
[49]	ECT, RPM, VSS, O_2, MAF	GPS			Driver behavior
[30]	RPM, VSS			Cloud	Driver behavior
[50]	RPM, TP, SWA, ECT, VSS	ET, WS		SQLite database	Driver behavior/ Driver safety, mobile phone
[51]	SHRP2 Naturalistic driving dataset		SVR		Driver profiling/ behavior
[52]	VSS, EL, ECT, MAP, RPM, MAF, IAT, AFC	ALT, LonA, VerA,	ANN	Local	Driver behavior
[53]	VSS, ACC, SWA	LonA, LatA, GPS, Cam	RF	Cloud	Driver behavior profiling
[54]	VSS, RPM, ECT	Cam		AWS Cloud	Driver behavior
[55]	EC, TP, BV	GPS		nodeJs servers	Fleet management (Car position tracking)
[56]	VSS, RPM, EL			Cloud	Fleet management
[57]	VS, RPM, M, FC, Acc AB, TM, RLC	GPS		AWS Cloud	Fleet management
[58]	VSS, RPM, FT, FE, FL	GPS, GYR, ACCM		Cloud	Fleet management
[59]	VSS, RPM, ECT, FP, EL, TP, AFR			Local SP	Vehicle Diagnostics
[60]	DP, RPM, APP, MAF, EGT			Smartphone	Vehicle Diagnostics
[61]	AAT, ECT, BP, FP, MAP, T, DN, OS, PC, ER			Data Cloud	Vehicle Diagnostics
[62]	HCV, VSS, BD			Smartphone app	Vehicle Diagnostics

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[63]	VSS, MAP, EP, RP, APP, ECT, CEL,T, FTL			Smartphone app	Vehicle Diagnostics
[64]	VSS, SOC, BV, BC, BT, BCL, MT			Android Tablet	Vehicle Diagnostics
[65]	RPM, ECT, VSS, FRP, TP, MAP	ACCM, GPS, RTC		Smartphone app	Vehicle Diagnostics
[66]	VSS, ECT, IAT, RPM			Android tablet	Vehicle Diagnostics
[67]	SWA			Smartphone	Route derivation (Vehicle Parking)
[68]	MAF, ECT, EGT			Firebase	Fleet management (Car rent companies)
[69]	ACCM, GYR, VSS	GPS			RPCM (Road grade estimation)
[40]	VSS	ACC, GYR			Route derivation
[70]	VSS	ACCM, GYR, AcA	ANN		RPCM (Pothole detection)
[71]	VSS, RPM	T, ACC		Remote Server	RPCM (Slippery Road detection)
[72]	APP, RPM, VSS	IMU, Cam, BT	CNN		RPCM (Pothole detection)
[73]	VSS, APD from sensors D and E), RPM, AEL, CEL	IRI, Lon, Lat, Alt, GPS			RPCM (Noise estimation)
[16]	VS, RPM, FF, MAF	T, GPS-Lat, GPS-Lon		AWS Cloud	Road Network Inefficiencies, (Bottleneck detection)
[74]	VSS, RPM, EL, AAT, TP, AP, SWA, RPM, HS, WS, BPP	GYR, ACCM, MAG, AP, ALT, ILM, PED		Cloud	Road Network Inefficiencies
[75]	VSS	GPS(x, y, z), ACCM, GYR	K-means, K-medoids, Fuzzy, GMM	Data server	RPCM
[76]	VSS, ACC, FCR	ACCM		Android app	Driver Safety

Studies [77], [78], [79], [53], and [80] present different possible ways of evaluating and enhancing driving protection and efficiency in risky situations and reducing the negative impact on the environment by examining driving manner and behavior. Nine dangerous driving behaviors was mathematically characterized in [77] and it provided the foundation on driver alert system that incorporates image, location and motion data analysis modules to identify risky habits. This integrated approach generated real-time records of unsafe driving behaviors. Study [78] introduced a risk assessment solution specifically for HAZMAT drivers, validated through two months of naturalistic data from 39 drivers and assessed with the Analytic Hierarchy Process-Entropy Weight method to provide an objective safety measure. In [79], a driver drowsiness detection solution was proposed, combining OBD-II data and a dashboard-mounted camera to monitor driver alertness and issued warnings as needed. Research paper [53] presented a framework using data from the Strategic Highway Research Program 2 (SHRP2) to evaluate driver risk profiles by analyzing crash events, near-misses, and routine driving. With machine learning models like RF and Deep Neural Network (DNN), the framework identified 13 behavior-based predictors of driver risk, with RF achieving the highest accuracy. This framework was proposed as a cloud-based tool for real-time driver risk profiling, which could benefit insurance and fleet management sectors. Finally, [80] focused on developing a realistic driving cycle for India, utilizing COTS hardware via OBD ports and IoT for data storage, aiming to improve emissions testing and fuel efficiency for light vehicles. This study underscored the impact of driving style on fuel consumption, especially for hybrid and EV, and advocated for an open-source, affordable prototype to advance sustainable urban transportation in India.

Studies [48], [51], [81], and [82] proposed innovative IoT-based and data-driven frameworks for monitoring and analyzing driving behaviors, emphasizing safety, risk assessment, and cost-effectiveness in automotive telemetry. In [48], an IoT-based driver attitude monitoring system was developed using fuzzy logic to analyze speed and RPM data from OBD-II. Data was transmitted to the IBM Bluemix server via a smartphone for further analysis, categorizing driver behavior into "good" or "bad" based on sample frequency, with average sample values providing the highest accuracy in identifying good behavior. In [51], a data-driven framework was presented to calculate drivers' risk scores for profiling applications using the SHRP2 NDS dataset.

Study used DT and SVR and concluded that while both models estimate risk scores, SVR provides better accuracy levels and that even the minimal event sampling provided good accuracy levels with SVR. Study [81] presented a low-cost design for an automotive telemetry data acquisition system that utilizes OBD-II sensors, GPS and an Inertial Measurement Unit (IMU) interfaced with a Raspberry Pi. This versatility makes it possible to gather vast volumes of information regarding fleet monitoring and fault diagnosis, and to progress the development of economical vehicle data acquisition systems. Finally, [82] presented a driving style assessment system aligned with the IoT reference model, structured into four layers: Sensing, Network, Application, and Business is the four-layer model of smart city. This system assessed driving style based on safety, economy, and comfort using data from OBD-II, an accelerometer, and GPS signal and ranked the driver on eight criteria. It was proved particularly in identifying qualities of a driver in treatments where visual representations such as spider diagrams helped in interpretation, to improve on driver safety in diverse transport settings.

Several research articles [49] and [4] proposed use of IoT based systems in monitoring drivers and their behavior for safety, insurance and traffic analysis. In [49], author presented the Vehicle Monitoring and Analysis System (VMAS) which is an IoT based system that analyzes drivers behaviour using data obtained from OBD-II, an Android application and cloud storage. VMAS extracted data from the vehicle and produced alarm messages whenever it recognized excessive speeds or risky states of the vehicle such as overheating of the engine, oxygen sensor, or mass airflow sensor. The authors explained that VMAS could be used as a tool that insurance companies and/or transportation authorities can use assess drivers' behavior. Meanwhile, [4] proposed a classification system that categorized driving behaviors into four types: classified as dangerous, aggressive, safe, and normal, based on features extracted from acceleration and speed acquired from OBD-II and GPS. Statistical analysis revealed small differences of speeds detected by OBD-II and the speeds detected by the mobile applications, further indicating the effectiveness of the system. The study was intended to improve road safety by feeding drivers real-time information about their behavior with a view of modifying the behavior voluntarily and thereby possibly decrease on accident frequency.

Research papers identified in the field of driving behavior analysis employ vehicle OBD-II data and other sensors to observe and categorize this action, primarily for the purpose of improving safety on the roads and reducing fuel consumption. For example, [83] developed an unsupervised K-means clustering method to categorize typical driving movements like starting, gear shift, and engine braking with OBD-II data. It created a way of categorizing driving behaviors, which gave indications on fuel usage and emissions, and its effectiveness in different car models. In [14], an approach for detecting braking and clutching were presented using signals like car speed and RPM, classification of behaviors during braking and gear change, and comparison of motorized and non-motorized approaches. Another study [52] employed a cost-effective system using both OBD and smartphone sensors to classify driving styles and predict traffic conditions, utilizing artificial neural networks (ANNs) and SVM as baselines, with bagging techniques improving model accuracy for imbalanced data. The MobiScout application, discussed in [54], was a cloud-based tool that collects real-time data through smartphone sensors, smartwatches, and OBD devices, providing a cost-effective approach to naturalistic driving studies and enhancing understanding of driver behavior and health metrics. In [50], the AutoLog framework focused on detecting smartphone usage while driving, identifying distractions such as texting or calling, which could lead to dangerous driving behavior. Lastly, a solution presented in [79] used image processing to detect driver fatigue and drowsiness, combining camera-based facial feature analysis and OBD-II data to monitor and alert drivers about fatigue, thus improving road safety, especially for fleet management.

Driver Safety

Driver safety is a core element of ITS, with vehicle telematics data offering significant benefits by monitoring drivers' physical and mental states, including indicators of drowsiness, fatigue, and stress. Such systems provide real-time feedback and alerts, enhancing driver awareness and reducing accident risks. The data from vehicle telematics not only encourages responsible driving but also supports insurance policies that reward safer behavior, thereby reinforcing road safety and lowering environmental impact through reduced accident rates and emissions. Driver distraction, a prominent cause of accidents globally, accounted for 35% of crashes in Spain in 2015, with similar trends observed in Canada and the U.S., where distracted driving is linked to up to 25% of police-reported accidents [84]. Distractions like phone usage, adjusting vehicle controls, or eating while driving, along with the driver's emotional or physical state (e.g., stress or intoxication), can severely impact road safety. Mitigating these distractions is crucial for effective fleet management, shaping insurance policies, and promoting overall traffic safety.

Aggressive driving behaviors—including speeding, ignoring traffic regulations, and lane indiscipline—are associated with roughly one-third of vehicle accidents [78,85-87]. The likelihood of accidents for high-risk drivers is approximately every 50,000 miles, compared to every 500,000 miles for low-risk drivers [78,88]. Additionally, issues like driver fatigue, drowsiness, and distractions from mobile phone use further elevate the risk of on-road incidents [78,86]. This growing concern has led to extensive research on driver safety solutions to address these factors effectively. Given the staggering global toll of 1.3 million road accident deaths [86,89], the need for prompt Emergency Medical Services (EMS) is critical. Various accident detection and notification systems have been developed, as detailed in studies [86,90]. For instance, [90] introduced a Car Data Recorder (CDR) to detect and report accidents, utilizing recorded vehicle data for post-accident analysis by authorities. Additionally, the system in [86] identifies accidents by monitoring vehicle orientation, including roll, pitch, and abrupt movements, as well as airbag deployment data. These innovations underscore the importance of immediate accident response and data-driven insights to enhance post-crash analysis and preventive strategies.

In [45] author proposed a model for driver identification and fingerprinting with the use of deep learning algorithm in connected cars. They proposed new driver identification model based on data obtained from smartphones and OBD-II, using Convolutional Neural Network (CNN), Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM). They used cross-validation techniques which gave reproducible results when applied on realistic data. FCN-LSTM outperformed and achieved an accuracy of 89.86%, with UAH-Driveset dataset, 95.1% with Security Driveset dataset, 62.13% with OSF Multimodal dataset and 93.92% with HCILAB dataset. Furthermore, they implemented the model in Automotive Grade Linux (AGL) Framework for driver classification and anti-theft system.

Many research studies in driving behavior analysis use combinations of vehicle diagnostic data and physiological or environmental sensors to assess and improve driver safety and road awareness.

For example in [44], the authors investigated the correlation between heart rate and driving behavior by developing an Android application that collected driver physiological data via a heart rate sensor and vehicle data using an OBD-II adapter. Their study spanned 14 routes totaling 6 hours and categorized data into urban, suburban, and highway environments, showing that aggressive driving behaviors can increase heart rate by 2.5% to 3% beats per minute (BPM). Another study [47] introduced a hybrid solution, integrating hardware and software to monitor driving behaviors and manage smartphone usage, using OBD-II and accelerometer data. Their Android-based system restricts phone use once a speed threshold of 10 km/h is reached, helping reduce distracted driving. The study's survey results suggested that while drivers, especially teenagers, are open to minimizing phone use, they still tend to respond to incoming messages or calls while driving. In [42], a real-time driver behavior monitoring and alert system was presented, combining OBD-II data with smartphone sensors and a Complex Event Processor (CEP) backend server for data processing. This system was utilizing a Markov model and k-means clustering to identify anomalous driving and the Adaboost algorithm to monitor safe driving with a 90% accuracy rate of detecting and notifying the driver on risky behaviors.

Several driving behavior and accident identification studies employ IoT enabled systems and vehicle attached sensors to increase safety, caution drivers and facilitate better approaches to handling accidents. For instance, [46] introduced "SmartDrive", an intelligent IoT system that alerts drivers to traffic risks and danger zones. They employ some features of smartphone sensors and connectivity to track different behavioral patterns like hard braking/acceleration and provide notifications in case the speed limit is breached. In the same way [91] proposed an accident detection and reporting system that was designed to overcome the shortcomings of current technologies and intended for actual implementation, rather than in a simulated environment. The work also talked about advancements in data communication with emergency services and cars, their diminishing sizes, and integration into various car models to improve the overall efficiency of accident response. Another study [76], employed G-force data from OBD-II and smartphone accelerometer to identify vehicular accidents and determined thresholds between collisions and minor vibrations to assist post-accident analysis. In [90], the authors developed a CDR prototype to aid in traffic accident investigation by recording pre-incident vehicle conditions, such as gas pedal position and RPM, and using accelerometer data to detect accidents. This system provides real-time notifications to authorities upon detecting an accident, offering accuracy rates of 84.8% for RPM and 74.4% for vehicle speed. Another low-cost solution is presented in [86], where a standalone system integrated an IMU, GPS, and GSM module to detect accidents and notify EMS. Using jerk as a metric, this system determined crash severity and sent relevant details to EMS, providing an affordable solution for lower-end vehicles. These studies highlight the growing role of integrated sensor systems and IoT in advancing road safety and accident response.

In [46,87,92], researchers proposed different solutions for improving driver's contextual awareness of the surrounding environment. The objective was to let the driver take action accordingly. Hong et al. proposed a system's architecture and functional blocks for a trust based services in connected cars environment [92]. Using data mining algorithms on OBD-II's data, the system has the capability to predict dangerous driving behavior. Authors in [46,87] presented the design of an intelligent IoT system capable of inferring and warning about road traffic risks and danger zones. This risk assessment is based on data obtained from vehicles and their driver's smartphones, thus helping to avoid accidents and seeking to preserve the lives of the passengers. The study [93] developed a system that enables a car to communicate its own abnormal driving behavior to the other cars in the region while also receiving alerts about other drivers' problematic driving behavior. Researchers designed a safety driving assistance system in [87] and it promptly alerts the driver when unsafe driving behaviors are observed.

Several recent studies leveraged IoT, OBD-II, and data analytics to enhance driver behavior profiling, vehicle maintenance, and prediction of dangerous driving behaviors. For instance in [43], the authors developed an Android application for car self-maintenance and driver profiling by obtaining DTC and analyzing driver behavior. This system used two methods for profiling: one based on GPS coordinates and another on visual and analytical analysis of engine parameters like RPM,

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vehicle speed, engine load, and throttle valve position, utilizing machine learning and data analytics techniques. In another study, [92] introduced a framework for analyzing and predicting dangerous driving behaviors by integrating IoT and OBD-II data through the SLICE engine, which enabled real-time context awareness and inference on IoT nodes. The system builds a DT model with the help of the Weka library with the accuracy of 95% in identifying hazardous driving behaviors without focusing on the excessive speed of the car. This framework is designed to improve safety and offer trustful services in connected car scenarios while classifying and predicting dangerous driving actions. All these studies evidence the capacity of utilizing IoT mechanisms in real-time and preventive driving analysis and control.

Fleet Management

Fleet management is another critical application of vehicle telematics within ITS. By collecting and analyzing data on vehicle usage, telematics systems can optimize fleet operations, improve fuel efficiency, and reduce maintenance costs. Advanced data analytics can provide insights into vehicle performance, enabling predictive maintenance and extending the lifespan of fleet vehicles.

5.2.1. Fleet Management

Fleet management encompasses comprehensive transportation management and monitoring, including for vehicles like cars, trucks, airplanes, and ships [94]. It is essential for companies that depend on transportation to mitigate risks related to vehicle investment and monitor driver behavior. Integral to fleet management is maintaining real-time insights into vehicle maintenance status, such as oil change schedules or impending Vehicle Technical Inspection (VTI) deadlines, which supports managers in ensuring timely and safe operations [57]. Fleet management spans the entire vehicle lifecycle, from acquisition to disposal, with goals of enhancing operational efficiency, improving service quality, and reducing risks. Fleet managers face five key challenges in achieving effective fleet management: (1) driver behavior and safety, (2) fuel efficiency, (3) real-time tracking and theft prevention, (4) damage control, and (5) addressing theft and fraudulent insurance claims. However, advances in vehicle telematics are providing feasible solutions to these challenges. With telematics, real-time data on vehicle performance, location, and driver actions can be leveraged to optimize fleet operations, promote safety, and reduce costs, marking significant progress toward efficient fleet management.

Several studies introduced innovative ideas of fleet management based on OBD-II data, IoT, cloud computing, and other advanced technologies for vehicles' supervision, drivers' behavior, and optimisation of operational activities. In [55], In [55], the authors developed an online fleet management system that combines the functions of OBD, IoT, and Cloud Computing with web and mobile Apps; Fleet managers are capable of tracking the position of vehicles in real time, gaining real time vehicle information, and analyzing the driving behavior of drivers. This system provides notifications and represents information that can enhance decision making. Likewise, [85] designed and implemented an IoT cloud-based visual fleet management system to address real issues in the industry which include; safety and behavior of drivers. This solution combined the OBD data with pre-processing computer vision for improved monitoring and tracking such as; Lane Departure detection and Traffic Signal recognition. It also had face authentication and driving pattern analysis for the restricted use of the car and boost the safety of the company's fleet. In [56], the authors suggested a cloud architectural model for sharing of vehicle information in Industry 4.0 environment. This system which implements OBD-II, Smartphone and a cloud server transfer data using 4.5G technology and offered good information for a number of services such as usage history of the vehicle, fuel efficiency and real time road conditions. Another study, [95], described an OBD-II based system for GPRS based fleet monitoring to capture and transmit data about the engine RPM, speed, and temperatures to a central database for Fleet maintenance and monitoring. Additionally, [2] developed a wireless OBD-II system for monitoring the speed, distance and fuel efficiency of vehicles. Information was transferred to a webserver using WiFi and the driver could navigate through the information using a GUI for real time analysis, GPS tracking for ITS development and getting a proper tool for fleet evaluation. Altogether, these works demonstrate the significance of combined

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OBD-II and IoT platforms in the context of the advanced fleet maintenance and increased operational security.

Many IoT solutions are being proposed to optimize car tracking, drive rental operations, and optimize fuel consumption in urban mobility services. For example in [68], the authors proposed the system known as the “ForRent” an android car rental application that dealt with car rental damage scams. It captures the physical and forensic state of the vehicle and leverages OBD-II data to create evidence for renters and rental businesses during a transaction. In another study, [96] proposes an IoT system for real-time data acquisition of vehicles involved in goods distribution in urban areas, whereby WSN can be used to capture several parameters without a lot of cabling and hence costs are incurred. The above solution is advantageous to the logistics operators since it enhances the flow and flexibility in the performing commercial operations. Similarly, [97] proposed the VISCar system for car rental firms with real-time control of driving style and fuel rates. The IoT system of VISCar optimizes the fuel consumption by studying the utilization of the engine parameters such as the speed, throttle position and distance. The system thus assists the rental companies in generating specific reports on the driving practices with the aim of cutting on the fuel expenses and advancement in the techniques of handling vehicles. The success and feasibility reflected from these studies demonstrate that IoT and OBD-II have the capability and potential to improve car rental security, optimize urban logistics, and upgrade driving behaviors in a fuel-efficient manner, making a vast contribution to the IoT application in Auto and Fleet Management.

In [58] author proposed a solution for traffic management system based on cloud Vehicle Ad-Hoc Network (VANET) and smartphone. They proposed their solution for economic cars that do not have the capability to run VANET. Their hardware system consists of OBD-II, smartphone, and a cloud platform. They collected the data from OBD-II, VANET and smartphone and shared this data with another vehicle. Application server on cloud detected the nearby vehicle using GPS and if there was any traffic congestion problem, notification was generated to the driver for changing the route to avoid traffic congestion, and also to traffic police for managing the traffic.

Several recent studies highlight the use of IoT, OBD-II, and machine learning for enhancing vehicle monitoring, safety, and operational efficiency. For instance in [98], the authors proposed a low-cost IoT-based automobile monitoring system that uses machine learning algorithms, such as K-Nearest Neighbors (KNN) and Naive Bayes (NB), to predict vehicle conditions like engine temperature and tire pressure. With a prediction accuracy of 93%, this system leverages OBD-II data and onboard sensors, aiming to improve vehicle diagnostics and support the development of connected cars. Future enhancements include scalability and mobile app integration for real-time monitoring. In [99], an IoT system was developed to predict accidents, monitor vehicle emissions, optimize fuel consumption, and improve traffic management using OBD-II and smartphone applications. This system was structured into four layers: physical, processing, communication, and application, and utilizes technologies like Raspberry Pi and Android smartphones for real-time data transfer and visualization. The paper emphasized the potential of IoT systems to improve road safety, environmental sustainability, and transportation efficiency. Similarly, [100] presented an IoT-based vehicle tracking system that used a Raspberry Pi, GPS, and GSM/GPRS technologies to monitor vehicle location and speed in real-time. By connecting to OBD-II, the system provided essential vehicle data and transmited location information to a central server, enhancing vehicle management, safety, and efficiency. These studies underline the growing role of IoT and advanced technologies like machine learning and smartphone applications in improving vehicle diagnostics, road safety, and fleet management.

Vehicle Diagnostics

Human error and vehicular malfunctions are primary contributors to road accidents, with global road statistics indicating over 1.3 million fatalities and 50 million injuries annually [4], [86,89]. Timely fault detection and preventive diagnostics in vehicles are crucial to mitigating these risks. Vehicle diagnostics involves a comprehensive evaluation—either manual or electronic—of a vehicle’s systems to detect potential faults. Modern vehicles are equipped with onboard computers that interface with diagnostic tools, making it easier to identify specific issues. Various research works [101] have proposed diagnostic and maintenance solutions focused on monitoring critical vehicle

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parameters such as engine conditions, braking systems, steering, and airbag functionality. These systems continuously assess vehicle performance, issuing alerts when any parameter exceeds a predefined threshold. By enabling early detection of potential failures, these solutions are instrumental in supporting accident prevention efforts and promoting safer roadways.

Recent advancements in OBD-II data logging and analysis underscore its versatility in vehicle diagnostics, emissions monitoring, and maintenance optimization. For instance, [102] presented the design of an OBD-II data logger using Arduino, capable of streaming vehicle sensor and GPS data to a remote server. The device monitors the effects of climate, particularly cold conditions, on oxygen sensor performance, with applications in emissions analysis, maintenance planning, and road condition alerts. Its affordability and scalability suggest potential for widespread deployment, with future research aimed at better understanding vehicle emissions across diverse climates. Similarly, [60] highlights the utility of OBD-II data and explored its integration with a UniNOx sensor to monitor NOx emissions. The authors developed a smartphone application to read and upload data to a project website, as well as vehicle emulators for testing, allowing them to simulate real-world conditions without relying on physical vehicles. This approach underscores the value of OBD-II data in environmental monitoring and vehicle diagnostics while enabling more flexible testing methodologies through emulation. Together, these studies demonstrate the potential of OBD-II technology to enhance vehicle monitoring, emissions management, and research adaptability.

Table 6. Component breakdown of cyber physical system based vehicle telematics solutions.

Embedded Systems	Comm	OBD-II Parameters	Application Layer	Application	Ref
RPi, MPU600	Wi-Fi	VSS, RPM, ACC	Web server	Driver Behavior	[81]
Arduino, MQ gas sensors	No	VSS, RPM, MAP, TPS, relative TPS, CO, CO2	Local	Eco-Driving	[33]
Freematics ONE+	-	VSS, RPM, MAP, TPS, ECT, O2, AAT, FTM		Driver Behavior	[83]
Arduino Mega, sensors (noise, vibration)	Wi-Fi	VSS, RPM, MAF, AFR, IAT	ThingSpeak	Road Network Inefficiencies, (Bottleneck detection)	[103]
Freematics ESP32 OBD-II kit	Wi-Fi	VSS, RPM, EL	Local server	Driver Behavior	[4]
Freematics ONE+	-	VSS, RPM, ECT, IAT, IMAP, O2, RPM, TPS, LTFT, STFT	Local	Driver Behavior	[14]
RPi 3, GPS Module	Cellular	VSS, RPM, EL, ACC, RJ, T, GPS	Cloud	Driver Behavior	[82]
Freematics ONE+	Cellular	VSS, RPM, EL, TPS, BV, MAF, MAP	Amazon Web Services	Eco-Driving	[31]
Frematics ONE V4	Wi-Fi	VSS, RPM, IAT, EL, TPS	Firebase\ Mobile App	Driver Behavior	[80]
AVL Device, FMS Gateway	Cellular	VSS, RPM, MAF, EL, IAT, IMAP, LS	Android App	Eco-Driving	[1]
Arduino Mega, ADXL345 accelerometer	Cellular	VSS, RPM, TPS, ECT, ABA, GPS	Local	Driver Safety	[90]
Arduino ATmega 328, IMU (BNO055)	Cellular	ABA, ACC, GYR	No	Driver Safety	[86]

RPi 3, Pi camera	Wi-Fi	VSS, RPM, ECT, TPS, GPS	Android App	Driver Behavior	[79]
Tiny4412 CPU Board, SJ5000x camera, MPU-6050	Cellular-4G	VSS, RPM, TS, ACCM, GYR, GPS	Cloud Platform	Driver Behavior	[77]
Advanced Driving Assistance Systems (ADAS)	Cellular	VSS, L, T, M, near crash events, cell phone usage, driver distractions.	Cloud Platform	Driver Behavior	[78]
RPi 3, Ultrasonic Sensor, LCD Screen	XBEE Pro 900HP	Local Monitoring Display	No	Driver Safety	[87]
Notebook Laptop	Wi-Fi	-	Local server	Driver Safety	[92]
Raspberry Pi 4B+, PiCAN 3, Arduino, MPU9250	Cellular	GPS, ACC (x, y, z), Inclination (x, y, z), VSS, RPM, APP, AAT	Web Server	Driver Safety	[91]
RPi 3	Wi-Fi	VSS, TP, CP, V, ECT, CO2 emission, FL, GPS.	Cloud \ Android App	Fleet Management	[98]
Carambola2	Wi-Fi	VSS, DT, FC, MAF, GPS	Local Server	Fleet Management	[2]
RPi 3, sensors (DHT11, Reed switch, LDR PIR), Logitech camera	Cellular	VSS, MAF, FL, GPS	IBM Bluemix	Fleet Management	[85]
STM32F103	BLE	MPU-6050, LDR, GPS	Cloud	Fleet Management	[96]
RPi, 3G USB Modem	Wi-Fi	VSS, MAF, FL, GPS	IBM Bluemix \ Android App	Fleet Management	[97]
RPi 3	Cellular	-	Android App	Fleet Management	[99]
RPi	Cellular	VSS, RPM, IAT, MAF, TPS, relative TPS, AP	Local Server	Fleet Management	[95]
RPi, SIM868 Module, OBD-II, GSM, GPRS	Cellular	GPS, VSS, T	Web Server	Fleet Management	[100]
Arduino Uno	Cellular	Oxygen sensor	Local Server	Vehicle Diagnostics	[102]
RPi 3	Wi-Fi	Engine diagnostic data	Local Server / Android App	Vehicle Diagnostics	[104]
Arduino Uno	Wi-Fi	VSS, RPM, MAP, IAF, EG, DT, FC	-	Vehicle Diagnostics	[89]
RPi 3	Cellular	VSS, RPM, ERT, TT, DT, GPS	Firebase	Vehicle Diagnostics	[105]
RPi 3	Wi-Fi	VSS, RPM, FM, AM, AEC, GPS.	Web Server	Vehicle Diagnostics	[101]

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Arduino	Wi-Fi	RPM, MAP, LF, BP, ECT	Cloud Platform	Vehicle Diagnostics	[106]
Arduino Mega2560, RPi 3B, Pi Camera	Wi-Fi	VSS, RPM, ECT, TPS, GPS	Android App	Vehicle Diagnostics	[107]
RPi	Wi-Fi	VSS, RPM, ECT, EL, EOT, FP,BV.	Cloud Platform	Vehicle Diagnostics	[108]
OBD-II connector	Wi-Fi	OST, M, EOPT, EIT, ESN	-	Vehicle Diagnostics	[109]
IN-VGM (In-Vehicle Gateway Module)	Cellular	Autonomous vehicle parameters	Cloud Platform	Vehicle Diagnostics	[110]
RPi 3B+	Cellular	VSS, RPM, ECT, LTFT, STFT	Cloud Platform \ Mobile App	Vehicle Diagnostics	[111]

Recent research has shown the value of integrating IoT with OBD-II systems to advance vehicle diagnostics, connectivity, and fault detection. For instance, [106] introduced a wireless engine diagnostic system that leverages IoT to address the limitations of traditional OBD-II setups. The system was structured into three stages: CAN-bus data collection, data conversion, and cloud transmission. Using Arduino and ESP8266, it reliably transmitted data to the cloud for real-time analysis, marking an improvement in vehicle monitoring. The authors suggested future work to enhance data management and security in CPS. Similarly, [59] presented an automatic fault detection system using an Android application that reads vehicle data via OBD-II. The application analyzed sensor data, alerting the user to any detected faults, enhancing preventive maintenance for vehicles. Meanwhile, [107] developed a low-cost connected vehicle system using Raspberry Pi, Arduino, and Wi-Fi, creating a bridge between a vehicle's OBD-II and a smartphone for vehicles without built-in connectivity. This system also incorporates additional sensor units to monitor systems not covered by the original OBD-II, allowing for comprehensive vehicle diagnostics. Furthermore, the system includes a driver assistance feature, such as a rear camera, to aid in driving and parking. Collectively, these studies illustrate the expanding role of IoT and connected systems in making vehicle diagnostics more accessible and real-time, ultimately contributing to enhanced vehicle safety and maintenance practices.

Recent advancements in vehicle diagnostic systems emphasize the growing integration of OBD-II technology, cloud computing, and mobile applications for comprehensive vehicle monitoring. For example, [61] described an Android-based diagnostic system incorporating OBD-II, an Android application, and a cloud server. Here, the OBD-II collected vehicle data from the ECU, which was displayed on the Android application and sent to the cloud for storage and analysis, providing accessible real-time data to users. In [105], the authors developed a diagnostic solution that included a GPS and dashboard camera for added security and accident documentation. Their system, which integrates an OBD-II with an Android app and Firebase cloud storage, not only monitors vehicle health but also allows location tracking and video recording, enhancing both security and maintenance capabilities. Similarly, [111] presented an IoT-based vehicle monitoring system that uses an OBD-II scanner, a Raspberry Pi, and a cloud application. This system supports real-time and historical data tracking, delivering reports and diagnostics through a mobile app. By using cellular connectivity, it enables remote monitoring, improving safety through timely fault detection in the engine and cooling systems. In [104], the use of a Raspberry Pi with OBD-II is highlighted for real-time diagnostics, with Bluetooth connectivity to an iSaddle OBD-II scanner. This setup takes advantage of the multitasking capacity of Raspberry Pi, offering efficient real-time diagnostics, which surpasses traditional Arduino-based systems for this purpose. Another cost-effective approach for EVs diagnostics is described in [64], where the authors utilized an ESP32 interface and Android app for a low-cost OBD system focusing on battery and motor health. The proposed system, costing only $28, offers an affordable solution for monitoring battery parameters and motor performance in EVs,

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ensuring efficiency and safety. Finally, [65] investigated thermostat malfunctions using OBD data. By analyzing coolant temperature data via the ELM327 diagnostic tool, the study identified abnormal behaviors caused by faulty thermostats. The results confirmed that OBD data can effectively detect these issues, preventing potential engine damage and improving fuel efficiency. Together, these studies illustrate how integrating OBD-II with IoT, cloud services, and mobile applications is transforming vehicle diagnostics, providing accessible and real-time data that enhances vehicle safety, maintenance, and operational efficiency.

Several recent works are devoted to the design of cost-effective vehicle health management systems that utilize IoT and OBD-II to improve safety, especially in areas with high accident rates. For instance, [89] implemented a low-cost human adaptive technology vehicle health management system that helps to prevent traffic accidents due to malfunctioning of vehicles in real time. When the data from the OBD is supplemented with the data from other sensors, the system can watch various components of the automobile constantly and detect faults in time. This approach also ensures the safety of drivers than those who are in the field and helps to cut expenses that are used in vehicle maintenance thus making the vehicles more efficient on the roads. In [101], an IoT-based diagnostic system was proposed with focus on the high rate of accident and incidents on the Indian roads. This system employed a Bluetooth-enabled Raspberry Pi and a vehicle diagnostics OBD-II technology for live condition monitoring. The system transmits fault codes to the drivers and informs them about certain problems that may cause accidents. This diagnostic solution wants to improve the operation and protection of vehicles through the use of IoT protocols, which is in harmony with revitalizing the necessity of lesser fatal accidents in the country. The two papers demonstrate the relevance of using affordable remote and smart diagnostic IoT devices for enhancing road safety by diagnosing and solving car health complications ahead of time. Since many of these systems address affordability and wide-spread application, they can be widely adopted in practice, which is highly effective for changing the trends in vehicular safety.

New research in the automotive digital investigations reveals novel methods of acquiring essential evidence from automobiles especially in traffic-related offenses and crimes. In [63], the authors presented a detailed approach to automotive forensics analyzing data acquired from computationally well-primitive Android smartphones connected to automobiles through Bluetooth using OBD-II adapters. They identified three major data sources: Bluetooth HCI snoop logs and circular logs in Android, and diagnostic data of a specific application. In this way, in combination with all the above data, the study created an exhaustive timeline of the driver behaviors, which can be useful in some situations, such as, for instance, acts like vehicle- related crimes or traffic accidents. This work thereby provides a rationale for integrating a number of digital artefacts to enhance the forensic precision and offers a framework for data collation and examination in this fast-growing field of motor vehicle forensics. Similarly, [66] examined various affordable techniques for capturing digital evidence from the automotive systems, including the dashboard camera, ECU, and Android head-unit. The study used tools like the Autopsy and OBD Auto Doctor to extract data like location histories, speed, and performace, thus showing how such information can be useful in legal cases. It is also important to mention that this research focused on elevated tools and low demands on hardware, providing strategies for the law enforcement agencies to use in acquiring vehicle data without having to spend a lot of money. Such an approach allows for broader study, potentially leaving no stone unturned which could have led to crime, or which may have occurred because of it. As both papers have indicated, the increased application of digital forensics in vehicles demonstrates how incorporating advanced technology into a car can reveal vital evidence to aid criminal investigations.

Present studies present proven technologies on vehicle optimization, diagnostics, and maintenance to increase its efficiency, reliability, as well as decrease costs and overall expenses. In [110], Monkey King Evolutionary (MKE) Algorithm is proposed as a novel memetic evolutionary framework for optimizing the vehicle navigation to minimize gasoline consumption. This algorithm was seen outperforming conventional path-finding algorithms such as A* and Dijkstra by providing more fuel-efficient choices. Furthermore, the paper proposes a CNN model with visual attention for the vehicle classification that provides the comparable performance with respect to the methods

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surveyed herein employing less computational resources compared to large-scale CNNs. Additionally, an automotive fault diagnosis system is established by means of Auto Associative Neural Networks (AANN) and Adaptive Neuro Fuzzy Inferential System (ANFIS) resulting in a decreased rate of false positives in diagnostics. Finally, a distributed consensus based progressive control approach is presented using the Radial Basis Function (RBF) neural networks for the coordinated movement of non-holonomic autonomous mobile vehicles in assigned paths to improve vehicle independence and synchronization. Predictive models for oil properties are developed in [109] for motor oil degradation by considering the specific driving parameters. Total acid number (TAN), oxidation onset temperature (OOT), and selected other chemical indices associated with oil degradation are discussed, and their relationship with such parameters as service time, mileage, and operating time are analyzed. Thus, it was determined that oil conditions can be accurately forecasted using linear models with R-squared exceeding 0.99, evidence of a high precision of the models. Crude obtained through testing on a range of different synthetic oils depicted somewhat unusual degradation characteristics, and therefore unusual attention should be paid to certain parameters to define when the oil should be changed. This research adds knowledge to the causes of oil degradation with respect to driving conditions and fills the gap of enhancing tailormade maintenance solutions that would improve on the durability and efficiency of car engines. All these papers point to the possibility of improving vehicular dynamics and performance as well as bringing in better predictive models that can help in the evolution of new forms of green and efficient transportation systems.

Technology such as Augmented Reality (AR) and indoor positioning innovations and technologies are used to improve electronic car diagnostics and navigation for the company while making the technologies more available and safer for consumers. In [62], to enhance the fault diagnosis in cars, an AR tool was implemented where the user interface of a mobile application is marked with faults. Based on the data received from the OBD-II system and CAN bus, the tool identifies problems in brake, tire, or some components of the automobile engine. The collected data is processed by an ESP32 microcontroller, which through Bluetooth communicates with an Android application implemented in Unity 3D, where the diagnostic data is mapped onto a model of a car. This interface will let users pinpoint possible problems and their causes easily. This may potentially diminish repair durations and boost road safety by correcting failures early. The AR-based diagnostic system in [108] further explored IoT integration with vehicle diagnostics, utilizing a Raspberry Pi and OBD-II scanner. This, indeed, is a real-time based system that helps to display the health status of a vehicle and send alerts on important parameters using an AR app for timely maintenance of vehicles. Further, urgent issues related to that property are notified through an email, and users are informed of the required repairs. The next versions of this tool may be enriched with voice-controlled diagnostics and increased amounts of data from the sensors for a more engaging audience. For indoor navigation, [67] proposed a proactive vehicle positioning system that can be applied to such places as parking lots where GPS can hardly be utilized. This system makes use of an OpenXC dongle which is inserted into the car's OBD port and a smart phone application. To do this, the system collects data such as the angle of the steering-wheel, the current speed indicated by the odometer and gear/ignition status, it charts where the car has gone being enclosed spaces. This AR navigation solution enhances positioning decisions especially in GPS restrained environments and therefore provides real world uses for vehicle interior control. These AR applications demonstrate how digital interfaces can transform vehicular diagnostics and navigation, offering more accurate diagnostics in less elapsed time, while improving drivers' awareness of surroundings in complicated situations.

Infrastructure

Transportation and road networks are critical to a nation's economy. Road accidents mostly resulting from aspects like carelessly driving, speeding or poor road network have dire consequences in terms of economic and social impacts [72]. The states of roads can be observed using vehicle telematics to identify suboptimal areas and potential risks of accidents allowing for the timely management of road conditions. Furthermore, increasing the level of knowledge among drivers about the relationship between the style of driving regarding fuel consumption and safe traffic conditions can result in reductions in cost and improved efficiency of traffic in general.

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5.3.1. Road Pavement Condition

Evaluating road pavement reflects the condition or state of road with a view of enhancing the efficiency and safety of the roads. Telematics based solutions that have dedicated sensors within the vehicles are able to provide real time data on road conditions, helping authorities prioritize the need for repair and maintenance. This approach is highly preventive to road related mishaps and generally enhances driver's experience on the road.

The latest developments in pothole detection systems focus on affordable and practical solutions that use OBD-II, smart phone sensors and NN data for the determination of road pavement imperfections. In [70], the authors proposed a low cost method to detect potholes based on OBD-II along with the smartphone's GPS sensors, accelerometer and gyroscopes. When applying ANN for data analysis, the developed system successfully detects potholes with accuracy more than 90 percent making it reliable for practical purposes. This integration of OBD-II data with smartphone-based sensors is a promising approach towards roadway maintenance safety augmentation. Similarly, [72] introduced a trigger-based pothole detection and localization system using two primary detection modes: based on image and on data respectively. In the image-triggered approach, visual data is collected by the smartphone camera, while in the data-triggered approach, the accelerometer data is used to detect potential potholes. These triggers are then checked for their authenticity using OBD-II data, more specifically by looking at speed of the car and position of the accelerator pedal in order to determine the quality of the ride. While pavement distress identification has only occurred on the second trip, this would have double benefits as it not only captures potholes but also gives an indication of the poor quality of the road which is helpful in enhancing ride comfort and safety of the driver. Both methods enhance the idea of intelligent transportation and provide cost-effective means of assessing road quality.

Research on road grade and pavement surface condition identification particularly at a low cost incorporates smartphone and vehicle data through crowdsourcing. In [69], the authors provided the low-cost approach to estimate the road grade/slope by using additional data available from smartphone sensors including accelerometers, gyroscopes, OBD-II/GPS data for vehicle speed. From the experiments they were able to establish that the information for determining road grade came mainly from the gyroscope, but the accelerometer data was useful in eliminating the drift of the gyroscope. Testing of the algorithm in the field on a 9 km route demonstrated that the proposed approach delivers more accurate road grade estimates compared to the baseline approach five-fold. This particular solution is easy to implement and offers the prospect of a variable solution to the problem of mapping road grades in real time. Similarly, [75] examined pavement roughness evaluation using smart city systems. The analysis merged vehicle sensor and GPS data, and machine learning, including k-means and k-medoids clustering, to categorise pavements based on their conditions into six groups. This technique improves the frequency and capability of pavement evaluations over the existing methods, which are usually expensive and time-consuming. The high accuracy reported in this paper when it comes to the identification of road anomalies propels automated maintenance scheduling hence promoting smart city transport systems. The two methods underscore the possibility of smartphone and OBD-II data to enhance road condition surveillance and analysis, presenting actual and cost-effective ways of managing the urban physical environment.

Two studies showcase the integration of smartphone and OBD-II data to address road safety and commuter health concerns in innovative ways. In [71], the authors introduced VehSense, a smartphone-based platform for detecting slippery road conditions. By analyzing discrepancies between ground speed (derived from smartphone sensors) and wheel speed (from OBD-II data), the system infers skidding events. Field tests conducted on snow-covered roads validated that VehSense effectively detects skidding, demonstrating its potential to enhance driver safety in icy conditions. In [73], researchers investigated the risk of noise exposure for freeway commuters, particularly on weaving segments where vehicles change lanes frequently. They develop a Noise Exposure Dose (NED) model using a DT approach, taking into account weaving segment design and engine operations. Data from an OBD-II adapter, a smartphone roughness app, and a digital sound meter were used to assess vehicle movement, pavement conditions, and interior noise levels. The study found that interior noise is closely related to pavement roughness and freeway configurations, with

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the model achieving high accuracy (R = 0.93, NRMSE < 6.7%). The findings indicate that while hearing impairment risk is generally low, interior noise can vary significantly based on road conditions and traffic patterns, making real-time noise monitoring an essential factor for commuter health and comfort.

Road Network Inefficiencies

The latest work points to the application of CPS and Cooperative Intelligent Transport Systems (C-ITS) to mitigate traffic problems and increase road safety. In [103], the authors design a low-cost CPS that utilises OBD-II telematics for congestion identification and computation of the respective economic and environmental cost in terms of fuel consumption, time and CO_2 emission. The system involves the vehicular data and GPS together; the data collected needs to be forwarded to the cloud for processing. During a five-day trial in Peshawar, it was established that evening bottlenecks were solely responsible for 51 percent of fuel consumption and half of the CO_2 emissions, demonstrating the rational for applying real time traffic management. Similarly in [16], authors designed BotlnckDectr – a cloud-based platform for bottleneck identification that quantifies how bottlenecks affect travel time, fuel consumption, and emissions. As the system operates with an OBD-II device and AWS cloud services, vehicle data with GPS coordinates are logged and transmitted by an Android application. Some of these field tests showed that road infrastructure plays a huge role in congestion and that without adequate research on urban planning, fuel and emissions costs will continue. The paper [74] developed a modular structure of C-ITS that included OBD-II, CAN bus, and external sensors to support the vehicle and the cloud. On Bluetooth, Wi-Fi, and, or cellular networks, the developed system offers real-time alerts concerning the dangerous roads conditions. It is thus proven effective for weather and road application, which facilitates enhancement of Road Weather Models (RWMs) and other road safety features. Through these investigations, it is possible to see how telematics together with cloud-solutions can improve traffic flows as well as safety standards while also minimizing pollution and fuel wastage in context of city driving.

Key Takeaways: Vehicle Telematics Applications in ITS

- **Eco-Driving & Eco-Routing**: Vehicle telematics enables fuel-efficient driving behavior, reducing fuel consumption by **15-25%** and greenhouse gas emissions by over **30%**. Machine learning models improve fuel consumption prediction accuracy.
- **Driver Behavior Monitoring**: Telematics-based profiling improves road safety by identifying aggressive driving patterns, drowsiness, and risky behaviors, aiding **insurance telematics** and policy enforcement.
- **Fleet Management**: IoT-integrated telematics enhances vehicle diagnostics, reduces maintenance costs, and improves operational efficiency, particularly for **commercial fleets and smart mobility services**.
- **Road Infrastructure Monitoring**: Telematics supports road pavement condition monitoring (RPCM) by utilizing onboard sensors to identify road quality issues and suggest infrastructure improvements.

6. Challenges

This section addresses the Research Question (RQ2 & RQ3):

RQ2 – To identify challenges in smartphone-based vehicle telematics in ITS. RQ3 – To identify challenges in cyber physical-based vehicle telematics in ITS.

There remain numerous improvements yet to be made and several problems to solve or take cognizance of in order for smartphone and CPS integrated vehicle telematics to reach their specialty potential within ITS.

6.1. Real Time Data Transmission

Real-time data support is imperative for many types of vehicle telematics applications; however, real-time data communication is often jeopardized due to poor and unreliable cellular networks. It is a common process for vehicle data collection through an OBD-II adapter and its transmission to a smartphone, with the direct transmission to a remote server over the internet. The region that has limited cellular coverage which does not allow the data to be transmitted in real-time may result in

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delays or loss of data, so addressing this challenge will require very robust solutions that will allow continuing data transmission even when there is intermittent internet connectivity.

6.2. Data Granularity and Contextual Awareness

The merge of the smartphones with the OBD-II adapters can collect large amounts of data, but fail to take external contextual factors such as weather, traffic density, or road geometry into account which is important to model driving behavior and fuel consumption accurately. For example, a decrease in a driver's speed in very heavy rain may be incorrectly interpreted as a form of cautious driving behavior, as opposed to being affected by a weather phenomenon. The limitations of this lack of context add complexity to the models and even lead towards incorrect conclusions [9].

6.3. Data Security and Privacy

Transmitting vehicle-related data over the internet raises important issues about security and privacy [112]. The systems for vehicle telematics generally include a wide range of sensitive personal information on the users, i.e., location and travel data; thus, such systems are attractive for cyber-attacks. Securing both the transmission and storage of this type of data has become very imperative, especially in scenarios where future mobility is said to involve useful connected and autonomous vehicle features. Hence, advanced security methodologies as well as comprehensive privacy safeguard measures need to be established to protect the telematics data of vehicles while ensuring that such data can only be accessed under very strict conditions and with user consent.

6.4. Data Management and Scalability

The vehicle telematics systems are generating huge data that are very difficult to manage and scale. A fleet management application covering ten vehicles generates about 300 GB of data per day, totalling around 9 TB per month. The managing, storing, and analysing that amount of data would require the use of big data paradigms. Despite having explored various big data-based approaches and analytics techniques for this challenge, there is still a need for further improvement toward more efficient and scalable solutions to manage an increased data influx [15,112,113].

6.5. Data Robustness and Device Variability

Really naturalistic driving experiments, which are the most effective among all methods of acquiring actual driving behavior and fuel consumption data, are quite often confronted with the problem of data robustness. The data may vary in quality and accuracy owing to the differences among various devices like smartphones and OBD-II adapters. Drivers using different smartphones cause incongruences in data collection thus making it hard to achieve uniformity and reliability in the data obtained. One of the ways to solve these issues would be standardizing the devices used in such experiments or validating accuracy of such devices among all participants [9].

6.6. Data Availability and Representativeness

A most challenging aspect of vehicle telematics research is the availability of large representative datasets. Most studies conduct their research using smaller samples, frequently fewer than 100 drivers, since experimentation is very costly and participants tend to be averse to being monitored. This has a significant effect on the statistical power of studies, while questions arise regarding the generalization of the data. Hence, large and diverse datasets should be collected that represent a broader spectrum of driving behavior in order to formulate driver behavior models that can be generalized [114].

6.7. Data Synchronization

It is another greatest challenge that may be data synchronization when data generated from different sources, e.g., OBD-II and GPS. Proper synchronization is important for event research on the driving situation, for instance, overtaking, intersections, and vehicle positions. Any variations in timing during reported data from said sensors result in inaccuracy. For instance, GPS data delays such as in comparison with OBD-II merely create a skewed picture of analyses carried out. An

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accurate synchronization of such data streams is, therefore, a prerequisite for a very high accuracy in vehicle telematics applications [115].

6.8. Sensor Limitations

Sensor limitation in vehicle telematics is further complicated by the fact that it is mostly designed to include low-complexity sensors such as GPS. For instance, if there are tunnels or urban canyons formed between tall structures, GPS sensor signals will be lost [116]. Furthermore, the use of additional sensors, such as high-resolution cameras, can increase system complexity and cost, while smartphone cameras remain impractical due to power consumption and mounting issues [12]. The comprehension and resolution of sensor limitations have a major role to play in improving vehicle telematics reliability and effectiveness.

6.9. Power Consumption

Power consumption is a major challenge in intelligent vehicle systems, including the sensors and smartphones that are used for telematics [117]. Most sensors are power-hungry in operation, which leads to speedy draining of the batteries for the vehicle or the device. Particularly, in the cases of smartphone-based systems, such features adversely affect battery life. Hence, low-power solutions or integration with outside power source are needed to continuous operation of these systems without losing utility.

6.10. Key Takeaways: Challenges in Vehicle Telematics

Vehicle telematics faces several key challenges that impact its effectiveness and large-scale adoption. **Data privacy and security** remain a major concern, as telematics systems collect vast amounts of sensitive vehicle and driver data. Unauthorized access or data breaches could compromise user privacy, necessitating the adoption of **blockchain-based security frameworks** and **differential privacy techniques** to enhance protection. Another significant challenge is **scalability in urban environments**, where the increasing number of connected vehicles generates massive data volumes that can overwhelm existing cloud-based infrastructures. Implementing **edge computing** and **fog computing** can help process data locally, reducing latency and bandwidth requirements.

In regions with **limited network connectivity**, real-time telematics applications may suffer from transmission delays or data loss, particularly in remote or underground environments. To mitigate this, hybrid communication models incorporating **V2X (Vehicle-to-Everything) technology, Low-Power Wide-Area Networks (LPWAN), and edge caching** can improve data reliability and system resilience. Additionally, **power consumption in embedded telematics systems** poses a challenge, as continuous sensor data collection and wireless transmission can drain battery life in mobile and in-vehicle devices. Optimizing energy efficiency through **low-power processors, adaptive data sampling, and energy-efficient networking protocols** is essential for sustainable telematics deployment.

Another critical issue is **standardization and interoperability**, as different vehicle manufacturers use proprietary telematics protocols, leading to fragmented systems that hinder seamless data integration. Establishing **unified telematics standards and open APIs** can facilitate better cross-platform compatibility, enabling more efficient data exchange across different automotive ecosystems. Addressing these challenges through innovative solutions will be crucial in ensuring the long-term success and widespread adoption of vehicle telematics in ITS

7. Future Direction

This section encompasses the possible future research avenues that vehicle telematics can take within ITS-related contexts, which addresses Research Question (RQ4): "What are the promising future research directions for Vehicle Telematics?"

Vehicle telematics has already been leveraged in various applications to provide smart city benefits. Examples include the assessment of driver style, eco-driving and routing, fleet management, and even vehicle diagnostics. However, much potential remains with vehicle telematics applications that have not been explored or demonstrated yet.

One major area is improving road network efficiency with particular reference to road link resistance and bottleneck detection. Previous studies have looked into bottleneck detection and cost incurred in terms of CO_2 emissions, fuel use, and time wastage [16]; however, there are many open avenues for expanding this research. A fleet of connected vehicles could be deployed to assess link resistance across large metropolitan areas, providing comprehensive insights into inefficient road segments. These insights could then inform strategies to optimize traffic flow by mitigating or eliminating these inefficiencies.

Another avenue worth exploring in research relates to the condition monitoring of road pavements. Indeed, the influence of pavement conditions on traffic flow is well documented [118,119]. Recent studies have begun exploring the potential of integrating vehicle telematics systems with IMU sensors and AI algorithms to monitor pavement conditions [120,121]. Further research about this subject may allow more reliably and real-time assessments, generally benefitting road maintenance and safety.

A future perspective on work might be focused on designing a more compact derivative of the Raspberry Pi-based hardware system to increase practicality and, induce easier installation into cars of different makes. Further, improving compatibility with many other car models would definitely contribute. However, achieving such compatibility is relatively difficult due to the constraints of the OBD port, its nonstandard implementations, and the diverse restrictions imposed by car manufacturers. Thus, overcoming these challenges would increase versatility and usability in real-world applications [91].

Driving behavior is very important to vehicle emissions. More data gathering and thorough processing are needed to identify the most optimal driving characteristic for emissions reduction. With increasing data, an emerging correlation will be expected between driving behavior and vehicle emissions that would lead towards more effective evidence-based suggestions for environmental minimization [35].

Future studies could progress further by exploring more cost-effective modifications in the design and implementation of the proposed system while optimizing performance and battery health of EVs under any conditions. More efforts will be required to overcome current constraints with automotive-grade microcontrollers, Electromagnetic Compatibility (EMC) testing of the OBD interface board, and testing through a vast variety of EV. Besides, the mobile application may also be further refined to include additional operating systems, making the system accessible and applicable at a wider user base [64]. Currently, the mobile application is limited only to the Android platforms, which greatly hinders many intended users from using the OBD system. An eventual project under the same could expand the app's compatibility to iOS or even other operating systems. This additional benefit is likely going to expand the customer base, extending on the versatility and adaptability of the system with a diversity of users [64].

Although integration of OBD data with smartphone sensor data has a great promise to address many road-predictive capabilities much wider than vehicle emissions, fuel usage, and road infrastructure analysis-- for example, pothole detection--future works can further enhance such models by adding vision sensors like cameras and radars for detection accuracy [52]. Additionally, application of advanced deep learning methodologies, particularly for temporal data, like RNN and LSTM networks, could enable the system to address even more complicated and ever-changing prediction tasks, thereby increasing its applicative and effective range into new areas.

Furthermore, telematics data concerning vehicles poses great possibilities for fulfilling validation and calibration of the tools involved in urban road network planning and design. Traffic modeling and simulation software, such as VISSIM and SUMO, serve as key ingredients for urban planning [122,123]. Nonetheless, they are very often deprived of detailed road usage and driver profile data. This rich telematics infusion into the respective models would enhance their capabilities, leading to better urban transportation planning and infrastructure development.

Moreover, future studies should be focusing on investigating the influence of road types-another important area for research to include road geometry (i.e., urban vs. rural driving environments)-by developing specific models for each category. It is easily predictable that better external variables (like levels of traffic congestion) will lead to improvement on the models' accuracy and performance.

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With new technologies in the vehicle to collect or process data of huge magnitude, thus far-imagined modeling will one day find considerable use in increasing its application as possible datasets become more realistic for vehicles on the road [28].

Vehicle telematics solutions face challenges in dynamic network environments, especially in areas with limited or intermittent connectivity. Traditional cloud-based architectures rely on continuous data transmission, which may be disrupted due to poor cellular coverage. To address this, some telematics systems employ edge computing techniques, caching data locally on embedded devices before synchronizing with central servers once connectivity is restored. Additionally, solutions leveraging vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication can improve data resilience by utilizing nearby vehicles or roadside units as relay nodes.

Scalability remains a critical consideration for vehicle telematics solutions in large urban centers. Integrating telematics data with smart city frameworks can enhance urban mobility, optimize traffic flow, and improve emergency response systems. However, scaling these solutions requires robust data management strategies, efficient cloud-based analytics, and standardization across diverse telematics devices. Future developments should focus on interoperability with city-wide IoT ecosystems, leveraging AI-driven predictive analytics for large-scale deployment.

The energy efficiency of telematics solutions is a significant concern, particularly for mobile and embedded systems. Continuous data collection from OBD-II adapters, GPS, and accelerometers can rapidly drain battery life. To mitigate this, recent studies explore low-power communication protocols (e.g., Bluetooth Low Energy), energy-efficient data transmission strategies, and hardware optimizations, such as dedicated power management circuits. Future work should focus on developing adaptive power-saving algorithms to extend battery life while maintaining data accuracy

In conclusion, while vehicle telematics has already contributed substantially to ITS, its full potential remains untapped. Future research should focus on exploring these underdeveloped areas to further enhance the efficiency, safety, and sustainability of urban transportation systems.

7.1. Key Takeaways: Future Directions in Vehicle Telematics

- **AI-Driven Telematics**: Integration of deep learning for advanced driver profiling, accident prediction, and autonomous vehicle telematics.
- **5G and Edge Computing**: Enhanced connectivity and low-latency data processing to improve **real-time vehicle-to-infrastructure (V2I) communication**.
- **Sustainable Telematics**: Adoption of low-power telematics solutions for electric vehicles (EVs) and hybrid vehicles to reduce power consumption.
- **Smart City Integration**: Expansion of telematics into **intelligent traffic management** systems, enabling seamless vehicle communication with urban infrastructure.

8. Limitations

While this study provides a comprehensive analysis of vehicle telematics in ITS, certain limitations should be acknowledged. First, the literature search was confined to **Scopus and WoS**, which, although covering a broad range of reputable publications, may have led to the omission of relevant studies indexed in other databases such as **IEEE Xplore and Google Scholar**. Additionally, the review focused on research published between **2018 and 2024**, which may not fully capture recent advancements in **5G-enabled telematics, AI-driven vehicle analytics, and blockchain-based vehicular data security**. Moreover, some of the included studies might have inherent **selection biases**, influenced by factors such as **limited sample sizes, specific geographic scopes, or variations in experimental methodologies**. Lastly, this review primarily examines **smartphone and cyber-physical-based telematics solutions**, which, while widely adopted, may not fully encompass emerging approaches such as **edge computing, V2X (Vehicle-to-Everything) communication, and decentralized data architectures**. Future research could explore these evolving technologies to provide a more holistic understanding of the field.

9. Conclusions

Vehicle telematics has emerged as a transformative technology in ITS, offering immense potential to improve road safety, driving efficiency, and environmental sustainability. Through applications such as driver behavior profiling, eco-driving, and real-time monitoring of driver safety, telematics systems provide actionable insights that benefit both individual drivers and fleet managers. By utilizing data from onboard sensors, telematics enables more informed decision-making, encouraging safer driving practices and reducing harmful emissions. Furthermore, these systems contribute to the advancement of traffic management by optimizing road usage and enhancing vehicle performance.

The integration of telematics into ITS also opens promising avenues for future research. Unexplored areas such as road network efficiency, pavement condition monitoring, and the validation of urban traffic models highlight the ongoing potential of telematics in shaping smarter, safer, and more sustainable cities. As the transportation sector continues to face challenges like increasing emissions and accident rates, telematics offers a viable path toward a more efficient and eco-friendly future. Continued research and innovation in this field will be crucial for realizing the full potential of vehicle telematics and addressing the evolving needs of modern transportation systems.

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