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Review Article

Road Intersection Coordination Scheme for Mixed Traffic (Human-Driven and Driverless Vehicles): A Systematic Review

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Autonomous vehicles (AVs) are emerging with enormous potentials to solve many challenging road traffic problems. The AV emergence leads to a paradigm shift in the road traffic system, making the penetration of autonomous vehicles fast and its coexistence with human-driven cars inevitable. The migration from the traditional driving to the intelligent driving system with AV's gradual deployment needs supporting technology to address mixed traffic systems problems, mixed driving behaviour in a car-following model, variation in-vehicle type control means, the impact of a proportion of AV in traffic mixed traffic, and many more. The migration to fully AV will solve many traffic problems: desire to reclaim travel and commuting time, driving comfort, and accident reduction. Motivated by the above facts, this paper presents an extensive review of road intersection mixed traffic management techniques with a classification matrix of different traffic management strategies and technologies that could effectively describe a mix of human and autonomous vehicles. It explores the existing traffic control strategies and analyses their compatibility in a mixed traffic environment. Then review their drawback and build on it for the proposed robust mix of traffic management schemes. Though many traffic control strategies have been in existence, the analysis presented in this paper gives new insights to the readers on the applications of the cell reservation strategy in a mixed traffic environment. Though many traffic control strategies have been in existence, the Gipp's car-following model has shown to be very effective for optimal traffic flow performance.

1. Introduction

1.1. Overview. This paper presents a systematic review of road traffic flow control strategies which are based on traffic theories. It also looked at the fundamentals impact of driving behaviour on traffic flow parameters with emphasis on mix-traffic management at road intersection. The theoretical introduction to traffic management, traffic rules, and regulation is presented in Section 1; also covered in this section is an introduction to the relevant traffic terms and concepts. Section 2 reviewed the state of the art in traffic and mixed traffic intersection management, covering the different types and means used in managing road traffic at intersection. Section 2.1 deals with introducing Intelligent Transportation Systems, covering the history of intelligent transportation and autonomous intersections. The transition from human-driven to autonomous vehicle technology is covered in Section 3, with details of the differences involved in the vehicle autonomy process stages. The classification matrix of the related works is presented in Table 1 covering means of vehicle communication and mix-traffic management approaches. Also covered in Table 2 are some key intersection performance indicators like efficiency, fairness in traffic scheduling, safety, and scalability features of each of the traffic control approaches. A summary of the pros and cons of the approaches is also captured in this section. The research gap is discussed in Section 5 with a justification for the proposed strategy, while the summary was covered in Section 6.

The proposed integration of autonomous and human-driven vehicles is associated with many challenges, ranging in how will AV and HV coexist harmoniously in an

Table 1: Categorisation based on centralised intersection control.

Method	Vehicle type	Communication	Performance	Fairness	Safety	Scalability	Cost	Complexity
Cooperative eco-driving model	AV and HV	V2I and V2V	++	++	+	+	+	Minus;
Fuzzy-based	AV	V2V	++	++	++	++	+	Minus;
Automatic merge control	AV	V2V and V2I	+	++	++	+	Minus; minus;	+
Vehicle platooning	A	V2V and V2I	+	+	+	++	+	Minus; minus;
	H	Signal	+	++	+	++	Minus;	+
Cooperative adaptive cruise control	AV	V2V	+	+	+	++	++	+
Game theory-based intersection control	AV	Signal	+	++	++	+	+	Minus;
Genetic algorithm	AV	Signal	+	++	++	+	++	+
Optimisation approach	AV (CVIC)	V2V and V2I	+	++	+	++	++	Minus;
	HV (MPC)	V2V and V2I	++	++	++	+	++	Minus;
	AV (multiagents)	Signal	+	++	+	+	Minus;	Minus;
Safe velocity and acceleration	HV and AV	V2V	+	++	++	++	++	++
Buffer-assignment based coordinated	AV	V2V and V2I	+	++	++	++	++	++

Table 2: Categorisation based on decentralised intersection control.

Method	Vehicle type	Communication	Performance	Fairness	Safety	Scalability	Cost	Complexity
Job scheduling	AV	Signal	+	+	++	+	–	–
Optimisation of connected vehicle environment	AV and HV	Signal	++	++	++	++	++	++
Marginal gap intersection crossing	AV	V2V and V2I	++	++	++	++	++	++
Merge control using virtual vehicles to map lanes	AV	Signal, V2V and V2I	++	++	++	+	++	++
Autonomous agent-based scheduling	AV	V2V and V2I	++	+	+	++	+	+
Virtual platooning	AV	V2V	++	++	++	+	+	–
Our approach: Space-time cell with HV and AV	AV and HV	Signal, V2I and V2V	– –					
Virtual platooning	AV	V2V	++	++	++	+	+	–
Space-time cell reservation	AV and HV	Signal, V2I and V2V	* *	* *	++	* *	* *	+

enhanced Gipp's car-following model, implementation of road technologies to support the coexistence, addressing the control communication barriers between the vehicle types, social acceptability, and many more. The efficient use of the existing road infrastructure for a novel intersection control management is the feasible solution for cities where road redesign, expansion, and additional construction are deemed challenging. Generally, innovative traffic management aims to improve the traffic flow system by integrating modern technology and management strategies to develop a robust traffic management scheme that aims to prevent traffic collisions/accidents and create a seamless traffic flow. The increase in population and number of vehicles without a corresponding increase in road infrastructure leads to most cities' current worsening traffic control status. Road traffic management involves using predefined rules to organise, predict, arrange, guide, and manage road users, both stopped and moving traffics. Road traffic includes vehicles of different types, pedestrians, bicycles, and all types of vehicles. By default, the traffic management system is guided by protocols mostly executed by traffic signal lights. The conventional traffic control system uses lights, signals, pedestrian crossings, and signalling equipment located at the intersection zone to control traffic flow. Traditional traffic management system uses time-based scheduling for traffic management at road intersections. The innovative traffic scheduling system improves the idle time associated with time-based management by involving a set of applications, management, or command-control and signalling system to improve a road intersection's overall traffic performance and safety. Traffic management applications gather complex real-time traffic information (vehicle type, vehicle speeds, in-road, and roadside sensors), analyse it, and use it to provide safe and efficient traffic control services for all vehicles using the road facility in real time. However, Tesla, Incorporation, based in Palo Alto, California, developed electric cars with high-tech features like autonomous vehicles and has been changing the growing impact of autonomous car integration. Besides the coexistence of mixed traffic on the roads, traffic risks are predominantly high at road intersections because of the multiroad and multitraffic participants who converge from different routes to diverge after crossing the intersection.

Conventional vehicles observe road traffic rules to protect drivers' safety and everyone using the road system. At intersections, human drivers are guided by light traffic systems, while the driverless vehicles came in with new technology for accessing the road facilities involving vehicle-vehicle and vehicle-infrastructure communication. The mixed-vehicle integration process has to be built on the existing road and traffic control infrastructure meant for human-derived vehicles. These technological infrastructures involve vehicles, road systems, and efficient traffic control strategies such as car-following model, Cruise control, and lane-keeping assist system, which have been used in the human-driven vehicle type control process. Areas of innovation will be based on a hybrid strategy to address a mixed traffic scenario considering the vehicle type independent behaviour. However, for the transition period to the intelligent transportation system, traffic flows which involve the coexistence of automated-driven and manually operated vehicles are unavoidable. In this AV and HV coexistence situation, it will be difficult for the driver of a human-driven vehicle to predict the movements of an autonomous vehicle and vice versa, mainly because they both use different communication parameters. However, this systematic review document analysed and classified state of the art in mixed traffic management, emphasising the coexistence of human and autonomous vehicles with a proposal for a hybrid strategy for controlling the mixed-vehicle. Based on the reviews of the current research gap in the mixed traffic system, a proposal is made for an alternative strategy for managing hybrid vehicles at the intersection and supporting the mixed-vehicle integration process. Consideration is based on simulating an efficient and safe traffic management scheme at road intersections to address a combination of autonomous and human-driven vehicles. Autonomous vehicles are defined by several different levels, depending on their capabilities, for example, levels of human control. Intervehicle communication (IVC) and road-vehicle communication (RVC) are technologies that help drivers perceive the surrounding traffic situation that guide the safety navigation process. Additionally, the collision point at the road intersection is identified and used to assign vehicles crossing the intersection sequentially. Also, a safe distance model helps drivers maintain a safe distance from the cars ahead by automatically adjusting the vehicle's speed. A cooperative ITS combines the mixed driving behaviour functions and enables collaboration between the different vehicle types and their technologies, but it only works with different autonomous vehicles. The introduction of new technology is not usually automatic, and new ones are gradually replacing the current human-driven vehicles technology. There is an obvious need to integrate driverless vehicle movement parameters with human-driven vehicles to midwife the smooth transition to a fully intelligent transportation system. This mixed-vehicle integration is necessary because conventional vehicles currently occupying the road cannot just be phased out sooner and consider the enormous autonomous advantages.

Traffic conditions are usually evaluated from traffic characteristics assessment, utilising several methods, typically being cleaved into data-driven, model-based, or both. A summary: the distinct traffic flow modelling methodologies include microscopic, macroscopic, and mesoscopic flow models. Microscopic traffic models give a detailed, high-level account of an individual vehicle's motion. Traffic group conditions are represented using an aggregated behaviour for macroscopic traffic models, generally concerning mean speed and mean density over a specified period or an observation distance. Mesoscopic models employ microscopic and macroscopic approaches by utilising varying levels/degrees of detail to model traffic behaviour. Some road locations are modelled with aggregated measurements as macroscopic, and the remaining locations are modelled down to the details of individual vehicles as is done in the case of microscopic models. In most cases, modelling traffics at the macroscopic levels is adequate to generate a sustainable mix-traffic model because they proffered the alternatives for most experimental purposes such as traffic control/management, road intersection cell reservation, and road infrastructure model alternatives.

1.1.1. Classification of Traffic Control Means. Based on the current state-of-the-art in-vehicle technology and road traffic management for human-driven and driverless vehicles, there are two main approaches to controlling traffic flow within an intersection; this includes the following:

(i) Traffic signal light: The HVs use traffic light in its control process, and it consists of the installation of signals lights that controls traffic streams by using different light indicators. This technology controls traffic statically and dynamically. Its primary aim is to prevent the simultaneous movement of two or more incompatible traffic streams by assigning and canceling the right-of-way to a particular traffic stream. However, right-of-way assignment is performed by different signal indicators to a stream of traffic, which is done by conventions:

Green light = allow passage of cars
amber = get ready to move or to stop
Red = forbidden passage.

The duration of amber, red, and green intervals in some countries is determined by traffic regulations, and it is most frequently specified as 3 seconds for amber and 2 seconds for red-amber indication.

(ii) V2V and VI communication: This is for AVs. It involves a traffic intersection control scheme without light. In this case, an autonomous or semiautonomous vehicle accesses an intersection using vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication means in smoothly controlling vehicles.

The investigation response to research questions: the following findings were made from the primary studies concerning the research questions:

Question 1. How does human drivers and autonomous vehicle behavioural parameters coexist? The studies revealed the different components of human-driving and autonomous driving system. While the work of [1–4] were interested in safety, [5, 6] worked primarily on describing mixed traffic behaviour.

Question 2. How can the human driver's behaviour be predicted? The studies show that component features considered in predicting the human driver's attitude on the road [1–4] are in agreement in terms of the factors to be considered in predicting the behaviour in mixed traffic.

Question 3. What is the traffic flow performance when cross collision avoidance traffic control method is applied? The different mechanisms adopted on this were treated by [4, 7, 8], which described these as complex, heterogeneous backgrounds.

2. Review of Related Literature

The earliest global traffic signals control system was established outside the Houses of Parliament in Britain on 10 December 1868 [9]. The system is operated manually with semaphores to control traffic by alternating the right-of-way to traffics at a fixed time interval. The few existing traffic flow models [10, 11] used in modelling a mix-traffic involve different types of human-driven vehicles, pedestrians, and cyclists, whose behavioural patterns are heterogeneous but were implemented based on the concept of homogeneous traffic model strategies. An Intelligent Traffic System (ITS) application aims to provide innovative services by combining traffic control strategies with communication technologies for a seamless and optimal traffic flow. Figure 1 represents fully intelligent transportation system features involving all traffic participants (this includes vehicles, cyclists, pedestrians, and animal like dogs), with seamless communication between all the participants. The ITS feature provides a communication platform for all the road users, ranging from communication among traffics, communications between traffic and road infrastructure, traveller's information, and most importantly, improved traffic safety. The primary measurement parameters for an efficient road traffic management system are as follows.

(i) Good driving experience.
(ii) Reduction in commuting/travel time.
(iii) Congestion reduction.
(iv) Traffic efficiency improvement.
(v) Fuel consumption reduction.
(vi) Accident reduction.
(vii) Pollution reduction.

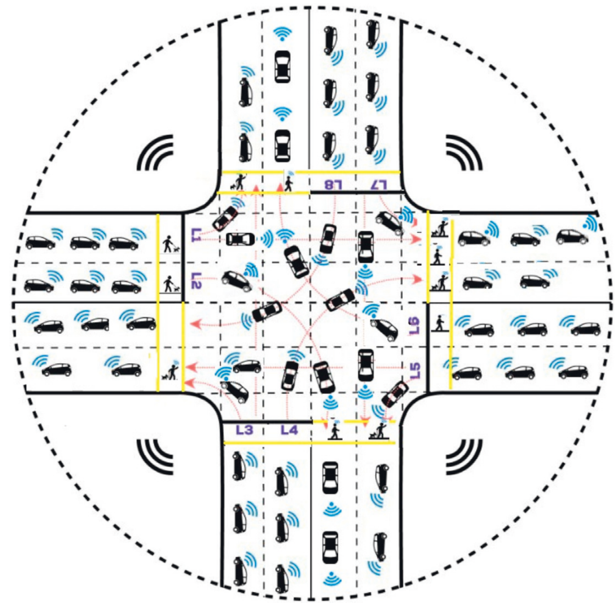

Figure 1: Intelligent transportation involving traffics, pedestrians, and animals.

An early approach to automation in vehicles started with the Automated Highway System (AHS) [12–15]. This review focuses on the impact of autonomous vehicle integration on road intersection capacity utilisation and the flow efficiency in a mixed traffic scenario of AVs and HVs. Papers [16, 17] proposed a coordinated intersection signal design for mixed traffic flow of human-driven and connected vehicles. The advent of automated vehicles led to the birth of vehicle-to-vehicle and vehicle-to-infrastructure communication, which inadvertently led to road intersection control management without traffic lights but has smooth and efficient traffic flows with reasonable safety measures. Automated vehicles (AVs) have shown the capacity to improve the safety and efficiency of traffic flow with its environmental awareness by reducing and mitigating traffic accidents in real time with a seamless flow of traffic and the suitable safety measures [18–21]. However, according to [22], the road's capacity can be increased with an increase in the cooperation level between vehicles when their behaviours are homogeneous, but this feature could be extended to a heterogeneous traffic system by improving the cooperation levels between AVs and HVs. Improving the cooperation level between AVs and HVs makes this study of traffic mix more complex considering the underlining difference in the behaviour of the two cars categories. Moreover, the simulation results from the study by [23] show that, from mixing automated vehicles (AVs) and human-driven (or manually controlled) vehicles, the road capacity will start decreasing when compared with homogeneous traffic. Paper [23] states that the road capacity of mixed traffic could increase 2.5 times when the percentage of automated vehicles is more than 70%.

2.1. Intelligent Transportation System. An intelligent transportation system is an innovative traffic control management application that guarantees an efficient traffic flow system with a better informed, safer, more coordinated, and more creative use of traffic information and infrastructure. It is an economically optimised solution to general traffic problems. ITS employs traffic and road infrastructure technologies to reduce congestion by monitoring traffic flow performance using sensors or cameras or analysing mobile phone data and rerouting traffic through navigational devices as the need may arise. The advent of Intelligent Transportation Systems (ITS) in the last decades has resulted in a dramatic change in traffic management. ITS have changed the approach to traffic planning, monitoring, management/control, and throughput enhancement. Intelligent transport systems (ITS) are compatible with modern vehicles as they use state-of-the-art communications devices (electronics, navigation) and data analysis technologies to enhance the throughput of the existing road traffic system. This review aims at investigating the measure to be taken in integrating AV and HV using ITS to benefit HV traffic behaviour in the following aspect: safety, throughput, comfort, fuel reduction, and decreasing other unfavourable environmental effects.

Models with intelligent transportation features like Advanced Traveller Information Systems (ATIS) [5] and Advanced Traffic Management Systems (ATMS) [24] provide travellers with real-time information for travel decision making purposes like the shortest path to its destination and traffic congestion measures, respectively. The ITS, which are classified into three categories: mobility, safety, and environmental, will drive the integration process of AVs and HVs. Other ITS model applications include

(i) smart city traffic systems,
(ii) vehicle navigation equipment (Satnav),
(iii) vehicle cruise control systems,
(iv) platooning.

The popularity of autonomous vehicles is increasing, and it is highly expected that the coexistence of AV and HV will persist as a part of the intelligent transportation system (ITS) for many decades. The traffic coexistence of AVs and HVs will benefit HVs in a mixed traffic environment by enhancing the performance parameters of AV (like shortening the inter-vehicle distance of AV) and HVs throughput and safety in a mixed environment. Traffic congestion in most cities has been overgrowing with universal mobility pressure and safety issues. Irrespective of the fact that the number of traffic is on the rise constructing new roads is constrained by meager public funds and deep environmental concerns. Robust traffic control management and traveller services are essential to enhance the efficiency of the existing road system infrastructure and improve the quality of service in a mixed-vehicle environment without constructing additional road capacity separately for AV and HV. Intelligent Transportation System (ITS) requires a specific traffic environment and behaviour for productive traffic observation and management.

2.1.1. Autonomous Vehicle (AV)

2.1.1. Autonomous Vehicle (AV). An autonomous vehicle senses and observes its surrounding environment and takes an informed decision based on its aim, target/destination, and the surrounding environment for its safety [25]. A fully autonomous vehicle does not need direct human intervention to achieve its movement objectives when in motion. Autonomous vehicles are intelligent-based vehicles [1, 26] that control themselves with electronics devices of ultrasonic sensors, radars, and sensors-video cameras. Some of the advantages of autonomous vehicles are the significant increase in road safety, which reduces traffic deaths, harmful emissions, travel time, and fuel economy. Besides, autonomous vehicles eliminate stop-and-go waves of traffic with an increase in lane capacity. The communication features of the autonomous vehicle create a potential platform for the application of seamless and highly safe traffic management approaches. The actual reality of autonomous vehicles is yet to appear after years of confidence from the information technology and car technology industries. In 2015, BMW launched a self-driving prototype car along the autobahn [27], with the promise that, by 2020, entirely unaided self-driving vehicles would come to stay in real life but, unfortunately, in the last month of 2020, this dream has not come to reality because of the challenges associated with the AV and HV integration process.

In 2019, Musk claimed that a one million global fleet of Teslas self-driving cars would be in place by 2020 [28]. These Teslas robotics taxis, like cars, will earn their owner money while they sleep or are on holiday. This projection by Musk has not been realised as of today because of the challenges involved in the autonomous vehicle integration process for a seamless AV coexistence with conventional vehicles (HV). Besides, Waymo, in 2018 [29], asserts that its fleet of 20,000 Jaguar I-Pace electric cars would utter up to one million autonomous cars per day soon. However, it did not feel very confident that December 2021 is feasible for the realisation of the full fleets of autonomous vehicles, which can take us to the shops or workplace from home and extended the self-drive to cover everyday activities. This full emergence of a fully autonomous vehicle on the road is hindered by the following significant challenges: coexistence with the human-driven vehicle and useful sensors for seeing the environment around them and detecting objects such as pedestrians, other vehicles, and road signs. The problem surrounding the current human-driven vehicle road system and its coexistence with autonomous vehicles could be solved with machine learning applications for its safety behaviour. Besides the above challenges, we still have the challenges associated with autonomous vehicles' regulation and social acceptability.

2.1.2. Human-Driven Vehicle (HV). A human-driven vehicle has a human being at the wheel that controls the vehicle's full kinetic operations based on human perception. Human drivers' behaviour is unpredictable and associated with a delay in making a driving decision. Autonomous vehicles' behaviour is in the sink with intelligent driving systems where vehicles sense the environment and create a driving decision in real time based on current traffic environment status, which serves as input to the system. The traffic flow theories relate to different traffic modelling approaches, namely: microscopic, macroscopic, and mesoscopic traffic flow models. These followed a matrix of categorisation of the different traffic management schemes with their pros and cons; this can be seen in Tables 2 and 3. Traffic management parameters involve a set of applications and management tools to enhance the efficiency of road transportation systems, all-inclusive traffic control, effectiveness, and security. An efficient traffic light signal system should regularly maximise the available intersection space by adjusting traffic control and coordinating traffic parameters based on the available vehicles. This consists of the installation of signal lights that control traffic streams by using different light indicators whose primary aim is to prevent simultaneous movement of two or more incompatible traffic schedules by assigning and canceling the right-of-way to a set of traffic schedules [30–34].

Most research studies conducted for mixed traffic systems [35] assume an environment of different vehicles size and a mix of vehicles and human beings, while very few researchers have investigated a combination of automatically and manually operated vehicles. Contribution from [7] whose work concentrated on fully mixed environments of human and autonomous vehicles (but the focus was on straight roads) investigated and quantified driver behaviour changes due to the spread of autonomous vehicles. This review paper focuses on a hybrid intersection that combines different traffic control strategies and clarifies how to cope with safety and efficient traffic flow in a mixed environment. Wakui et al. [8] proposed a reduction in the time it takes for a vehicle to pass through an intersection using IVC and RVC technology through the collision avoidance model. However, their experiments assumed that the vehicles passing through the intersection only were autonomous vehicles implementing ITS functions and a mixed environment of human beings crossing the road. Sharon et al. [36] also proposed an intersection entry using a traffic signal that has sensing technology to detect nonautonomous vehicles, as well as technology that communicates with autonomous vehicles.

3. Transition from Human-Driven to Autonomous Vehicle Technology

The rate of autonomous vehicles emergence appears to be increasing with a glaring impact on human drivers vehicle performance. Modern vehicles are designed with some autonomous attributes, such as adaptive cruise and electronic stability control systems. Vehicle autonomy is a stagewise process with a baseline from the human-driving system and subsequent enhancement to address the human-driving system's challenges. According to [6, 37], the vehicle automation process has been divided into five levels based on the level of human assistance. The vehicle autonomy level is a gradual automation enhancement in the human-driving system to a fully autonomous vehicle driving system. We have six levels of vehicle autonomy stages.

3.1. Level 0: No Automation. This stage is the traditional driving system where a human being is responsible for absolute vehicle control. At this level, there is 100% human control for the vehicle. Human drivers handle the vehicle's motion (acceleration and deceleration process), steering control, and safety intervention systems response.

Table 3: List of data sources.

Source type	Name of database
Online databases	IEEEXplore, springer, ACM, ArXiv DOAJ, PUBMED, DfT
Search engines	Google Scholar, citeSeerx

3.2. Level 1: Driver Assistance. Here, the human driver is being assisted with the task of controlling the speed of each one of the vehicles via cruise control and position and through lane guidance. The human driver must be active and observe roads and vehicles every time and take control when the need arises. The human driver is responsible for controlling the vehicle steering wheel and the brake/throttle pedals. At this level of automation, the steering and pedals control of the vehicle is done by a human being. For example, the vehicle adaptive cruise control and parking assistant system belong to this level of automation.

3.3. Level 2: Partial Self-Driving. At this automation level, the computer is designed to control the vehicle's speed and lane position in some defined or secluded environment. The driver may disengage off the steering control and pedals at this level but is expected to observe navigation to assist in the vehicle control if the need arises. The control of the vehicle at this level is fully automated in a particular environment. This level of automation provides the driver with options to intervene in controlling both pedals and the steering wheel at the same time automatically if necessary.

3.4. Level 3: Limited Self-Driving. This level is the beginning of the complete disengagement to complete control and fully independent control of vehicles in some secluded environment. It involves comprehensively monitoring the vehicle's motion along the road and then triggers for drivers' assistance as the need arises. When a vehicle is in self-control mode, the driver does not need to monitor vehicle road and traffic navigation but must be ready to control when required. This stage is associated with the risk of safety liability for incidence. At this critical automation level, the vehicle has a specific model to take driving charge in certain conditions, but the driver must take the control back when the system requests it. The driver's attention is highly needed as the vehicle on its own can make lane changes and event response decisions and uses the human driver as a backup in a high-risk environment.

3.5. Level 4: Full Self-Driving under Certain Conditions. This level involves complete vehicle control with or without a human driver in certain situations or environments. An example of this condition is urban ride-sharing. The driver's role, if present, is to provide the destination of the vehicle. This level is safer than level 3 as the vehicle has complete control of itself under a suitable or isolated/controlled environment without any request for driver's intervention. The vehicle takes care of its safety challenges at this level.

3.6. Level 5: Full Self-Driving under All Conditions. This is the destination of vehicle automation where vehicles operate absolutely on their own. At this level, human intervention is not needed as the vehicle drives its self. This is an entire automation stage without any human intervention. The level of full vehicle autonomy goes with the state-of-the-art environment control protocols, advanced detection devices, and vision response and uses real-time obstacle position measurements for guidance and safety purposes.

4. Autonomous Intersection Management

The emergence of an autonomous driving system led to the advent of autonomous road intersections management system. In most cases, an autonomous road intersection does not make use of traffic light control because it is assumed that all the AVs make use of sensors. For an intersection to be autonomous, it must be equipped with sensors, roadside communication units, and other intelligent transportation system devices.

In the proposed intersection control scheme, conventional vehicles use a traffic light signal system, while autonomous vehicles access road facilities via wireless communication platforms: vehicle-vehicle and vehicle-infrastructure communication. Human-driven vehicles only involve driver-to-road infrastructure communication (one-way communication), while autonomous vehicles are equipped with intelligent navigational collision avoidance features with a 2-way communication system. The deployment of new technologies is usually a gradual process with high-risk factors being considered. The latest technology will gradually replace the current technology while integrating autonomous vehicle movement parameters with the human-driven vehicle to midwife; the smooth transition to a fully automated or intelligent city is necessary for society to enjoy the full benefit of AVs.

Papers [2, 3, 38] suggest that autonomous vehicles have a very high prospect to increase traffic efficiency by reducing traffic congestion through improved cooperation among vehicles. Also, AVs can enhance the efficiency of intersection capacity, enhance the safety margins in a car-following/platoon model, and improve the road users' welfare. Research in autonomous vehicles and their integration process has been in researchers' eyes for a while because of the increasing population with existing traffic congestion challenges, urbanisation, and the enormous advantages of autonomous vehicles.

4.1. Classification of Means of Traffic Control. Consideration is based on the two principal means of traffic control communication and flow management at an intersection. Based on the state-of-the-art in-vehicle technology and road traffic management strategy as it is applied to human-driven and autonomous vehicles, below is a list of the traffic light communication means:

(i) Traffic Light Control: Most nations usually adopt two types of traffic light control processes. These are the fixed time and dynamic/event-driven traffic control modes.

Fixed time-based scheduling systems: This control process is configured to turn on and off or switch in between the different road segments using the three lights sequentially after a given period, in terms of control flexibility and coordination capability.
Event-driven scheduling system, which is the dynamic traffic light control systems, on the other hand, is more appropriate for dense traffic control based on queue length and vehicle arrival sequence or is on the traffic density from each trajectory.

(ii) Connected Vehicle Control: This traffic control process involves vehicles that communicate with each other (V2V) or roadside units (V2I). The connected vehicles control process schedules traffic at road intersections without traffic lights. These control measures allow the traffic agent to access the vehicle location and trajectory information which is used in analysing and managing services such as collision prevention or traffic lane maintenance and other traffic control measures. The work is based on Gipp's model of collision avoidance. In this case, autonomous or semiautonomous vehicle accesses intersections using vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication means [4, 39–42].

An efficient urban traffic management and control framework strategies are usually designed based on centralised and decentralised approaches.

(i) Centralised Approach: This approach has in common at least one scheduling component of all the road segments. It can also power the traffic light and at the same time incorporates vehicle-to-infrastructure (V2I) or vehicle-to-vehicle communication. In some instances, an intersection agent (IA), upon the receipt of requests from vehicles to cross the intersection, schedules them and determines the best crossing sequence as proposed by [43]. In this method of traffic control strategy, as reflected in Table 2, at least one factor in the traffic scheduling characteristics or features is centrally decided for all vehicles in the scheme through a coordination unit. When a significant decision is made for at least one of the factors, it is called a centralised approach [44–47].

(ii) Decentralised Approach: Instead of using traffic lights or a manager, the decentralised solution relies on vehicle-to-vehicle (V2V) contact synchronisation, enabling vehicles to cross an intersection without anticipating their potential trajectory. In this category and Table 3, all the vehicles are handled as autonomous agents but use the interaction between vehicle-to-vehicle and vehicle-to-infrastructure to maximise their communication and control efficiency. In this case, however, the individual agents (vehicle) receive information from other vehicles and/or roadside infrastructure to enhance performance criteria like safety, efficiency, and travel time before accessing the intersection [48–53]. The correlation used in intersection control with the underpinning technologies with the evaluation of its performance matrix is as shown in Table 3.

4.2. Classification Matrix for the Different Traffic Control Measure. In general, homogeneous and heterogeneous traffic control strategies were reviewed based on mixed traffic environment compatibility. The classification assessment aims to look out for the traffic control features that could benefit the coexistence of AH and HV. Each column header of the classification matrix table describes the performance index of various methods and identifies which characteristics are to balance. Tables 1 and 2 present a detailed picture of components for consideration in developing a robust hybrid-based system with some degree of safety, high performance, low costing, scalability, and adaptability. The classification categories are based on the following criteria:

(i) Method: This involves the underpinning features of traffic management strategy consisting of systematic planning, designing, control, implementing, observation, measurement, formulation, testing, and modification of the traffic management system to solve a complex traffic problem. Most traffic control methods involve direct communication between traffics and road infrastructures, such as signs, signals, and pavement markings. The primary objective of any traffic control system is to guarantee safety and optimised traffic flow. The control strategy orchestrate the traffic flow, such as deciding which car may drive or wait.

(ii) Vehicle Type: Vehicle type means the category of vehicle driving system characteristics of human-driven or autonomous driven vehicles. This component describes the two-vehicle distinct category: autonomous vehicles (AVs) and human-driven vehicles (HVs). Besides, the vehicle classification is done based on the communication capability with the intersection control unit, while the assumption is made for all the vehicles to be of the same physical dimension.

(iii) Performance Index (PI): This is a measure of traffic flow efficiency, where +, ++ mean good and best performance, respectively. Every traffic intersection control model has a performance index (PI) that indicates the overall efficiency of the vehicle's control method. The traffic control efficiency s is measured based on the delay associated with traffic flow. The traffic control performance measurement and monitoring significantly impact the design, implementation, and management of traffic control models and, to a large extent, contribute to the identification, comparison, and assessment of alternative traffic management strategies.

(iv) Means of Communication: These are the channels within a medium that vehicle and roadside devices use in sending signals or messages across to each other at the road intersection. Traffic light signal and vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication are their means of vehicle control communication. This represents the means of vehicle intercommunication where the signal from a traffic light, V2V, and V2I wireless transmission of data that occurs between vehicles is communicated for AV. Road intersection-vehicular communication systems involve networks in which vehicles and roadside units communicate for a free and safe traffic flow. The communicating devices (vehicles/drivers and road roadside devices) provide each other with traffic information such as expected arrival time, speed, position, and direction, effective in collision avoidance and traffic congestion.

(v) Fairness: In the intersection management contest, fairness is the impartial and just treatment or behaviour without favoritism or discrimination to traffics. Fairness metrics are the waiting time used in traffic network engineering to determine whether traffic participants are treated fairly, considering traffic efficiency. The fairness measure to traffic requests at the intersection is based on a classification algorithm using the vehicle of the first arrival and queue lengths. This feature takes care of the waiting time among vehicles, in which case, the principle of "FIFO" is obeyed at the point of an intersection unless there is a priority request from an emergency vehicle.

(vi) Safety: The road traffic safety matrix refers to the approaches and strategies applied in preventing traffic collisions or road accidents at the intersection. Every traffic management solution usually defines the potential collision areas before making optimal decisions about which countermeasures to use and when they should be used to fix intersection safety issues. This deals with the percentage efficiency of the control system's safety in preventing vehicle collisions or accidents. Though there is no ideal system considering human error, health and safety issues are paramount in traffic management methods.

(vii) Scalability: "Scaling a road intersection" means to "increase or grow several roads that join together in an intersection" or "increase the size of a road segment network or several intersections that make up the intersection network generally." This is the estimate of a system's potentials to vary the roads infrastructure like roads size, and the number of the lane is of interest. Besides, scalability is related to both efficiency and cost in response to changes in application and device processing demands. For a new system to serve the test of time, the system must pose the capability or potentials to be expanded to address more complex traffic control challenges and scenarios with a different type of road network and size. This scalability component addresses the following question: is the new system robust enough to be applied in another area of the traffic intersection management problem? What is the risk factor involved in applying it to more complex traffic intersections?

(viii) Cost: This cost component could be quantified with a variable. In analysing the intersection design and deployment cost of different traffic control methods, the comparison process could be based on any of the following cost matrices:

The initial project capital cost: This takes care of the cost of implementation and deployment, which involves the total cost of preliminary design and analysis of the method, right-of-way, utilities, and construction.

Operation and maintenance cost: This is an ongoing cost associated with the intersection throughout and the design life. According to [54], the relative or average annual cost of lighting an intersection includes maintenance and power supply, which is in EU nations.

Delay cost: According to the Texas Transportation Institute's 2012 Urban Mobility Report [54], the cost of an hour of delay of vehicles at road intersection is . This report quantifies the amount of congestion in cities across the US and provides many cost-related impacts of congestion.

Safety cost: This is the computation of the expected number of collisions that may be associated with each of the control methods. This component looks at how safe the strategy is and the cost of the risk factors associated with it.

(ix) Complexity: The design and implementation of a road traffic intersection range from a simple road network joining two roads to a complicated and convergence of several high-volume multilane road networks. The management of intersection is directly proportional to its complexity. The more complex an intersection is, the more expensive it will be to maintain or manage it. Besides, complexity describes how complex an intersection is and its time to execute a traffic scheduling algorithm. Therefore, complexity deals with how difficult the traffic control can be implemented in real time and how to resolve the errors.

Tables 2 and 3 show a matrix of classification used to quantify the quality of each traffic control feature concerning traffic management strategy and efficiency. The signs 0, +, −, ++, and − − are used in this order to show statistical impact levels of nonimpact, adverse impact, positive impact, major negative impact, and significant positive impact, respectively. A detailed pros and cons matrix of each reviewed traffic management method was analysed in Table 3.

4.3. The State of the Art in Mix-Traffic Management. Currently, there is a large diversity of research going on in mixed traffic generally, which are mostly directed towards different traffic participants: human-driven vehicles (cars, buses, trucks), motorcycles, bicycles, and pedestrians, which exposes very few design details for a mix of HVs and AVs. To fully embrace the emergence of AV and HV, research in a mix of human-driven and autonomous vehicle coexistence is necessary to provide the enabling environment needed for the integration process. Generally, the state of the art in the conventional human-driven traffic management applications was implemented using the event-driven traffic light control system. However, there are drawbacks in the level of traffic cooperation, throughput, and safety when these methods are implemented in a mixed scenario because of the complexities involved in a mix of AV and HV behaviour. The emergence of autonomous vehicles has moved human drivers' role from active control operation to a passive supervisory role. With a closer look at the modern road vehicles, one will observe a high-level advancement in the automation of most vehicle devices, like adaptive cruise control, obstacle maneuvers, and automated brake systems, to mention but a few. Paper [55] proposed a reducing horizon model predictive control (MPC) with dynamic platoon splitting and integration rules for AVs and HVs, which mostly ease out the trajectory problem and prevent any shock wave but do not concurrently optimise the trajectory and signal timing of the road intersection. There are some traffic management techniques; paper [56–60] investigated the impact of integrating AVs on the existing roads to coexist with the HV's, but most of the model performance efficiency is below average because of the cooperation levels of the vehicle type. The heterogeneous nature involved in the driving behaviour and the vehicle communication parameters will naturally exacerbate the cooperation level between the two vehicles, thereby drastically reducing the traffic flow efficiency. How will the mix work with different vehicle behaviour in a mixed traffic system while maintaining the full vehicle characteristics at reasonable traffic efficiency? The current research on mixed traffic [56–60] looked critically on a highway road system using the following three main traffic flow characteristics components:

(i) Vehicle characteristics.

(ii) Driving behaviour.

(iii) Road system characteristics.

This work appears interesting, but it was only restricted at the microscopic level which will definitely give one a different result at the macroscopic level when many vehicles are involved.

In a mix-traffic system, microscopic models are used to model each vehicle as a kind of particle. The interactions among cars are modelled with simulations with each component of the proposed framework verified. Each car type is modelled with the cars and the road interaction protocol system implemented in the proposed mix-traffic framework. This framework is verified through simulations involving 3-way and 4-way intersection environments with a full detailed assessment of the impact of each vehicle type. The critical challenge in agent-based traffic simulation is recreating practical traffic flow at macro and micro levels. By seeing traffic flows as emergent phenomena, [61] proposed a multiagent-based traffic simulator because drivers' behaviour is a crucial factor that gives rise to traffic congestion. According to [62], car agent's behaviours are often implemented by applying car-following theories using a continuous one-dimensional road model. Paper [63] proposed a multilevel agent composed of agents models involving micro-meso, micro-macro, meso-macro simulation framework to address a large scale road mixed traffic system using an organisational modelling approach. The multiple-leader car-following model involves a heterogeneous mixture of vehicle types that lack lane discipline. According to [64–66], these traffic conditions lead to a complex driving maneuver that combines vehicle motion in the lateral and longitudinal direction that needed to address multiple-leader following. Papers [66, 67] sought to simplify mixed traffic modelling by developing a control technique based on the concept of virtual lane shifts, which entered on identifying significant lateral changes as a signal of a lane-changing situation. Because the vehicle's behaviour is not homogeneous, the following driver's behaviour is not necessarily influenced by a single leader but is mainly dependent on the type of the front vehicle.

4.4. Connected Vehicle Communication. Vehicle-to-vehicle ($V2V$) and vehicle-to-infrastructure ($V2I$) communications are both possible in a connected vehicle system [68]. The cooperative adaptive cruise control (CACC) systems can safely drive vehicles with very short head-ways by forming platoons to increase road traffic flow capability [30, 31, 69]. CAVs' advanced technologies open up a world of possibilities for developing novel traffic flow management approaches, such as cooperative adaptive cruise control (CACC), speed harmonisation, and signal control, to name a few. With much room for improvement in traffic safety, quality, and environmental sustainability, the intersection coordination scheme has obtained broad research interests [70–73] [53, 74–76]. For several years, the idea of following a vehicle with a short gap in CACC has been generalised to provide a new and efficient intersection control model, in which nearly conflicting vehicles approaching from different directions will cross the intersection with marginal gaps without using a traffic signal. Optimising the level of cooperation between vehicles will enable automated vehicles to reach their maximum potential to reduce traffic congestion, reduce travel time, and increase intersection capability. However, Omae et al. [30] suggested a virtual platooning system for automated vehicle control at an intersection that allows vehicles to pass through without pausing, but this approach is not feasible in a mixed environment because of the presence of HVs. Vehicles in both lanes are deemed to be in a virtual lane situation, and their intersection interference is taken into account. They are separately managed so that they can safely follow the leading platoon's vehicle. The system, which was tested using four electric vehicles fitted with automated driving and V2V communication technologies at a one-way intersection, resulted in a significant reduction in traffic congestion.

4.4.1. Review Strategy. This systematic review of Road Intersection Coordination Scheme for Hybrid Vehicles (Human-Driven and Autonomous Vehicles) is based on the below guidelines as reflected in Table 3.

4.4.2. Inclusion and Exclusion Criteria. The review strategies employed the inclusion and exclusion criteria of the selected primary studies research materials reflected in Table 4. This table contains the publication source, the category, and the numbers of material utilised.

The exclusion criteria include the following:

(i) Materials with inadequate reference information.
(ii) Articles concerned mainly with the human-driven traffic scheduling scheme.
(iii) Studies that also review papers of homogeneous traffic management without addressing mixed traffic scenarios.
(iv) Conference papers, which have also been published in a journal.

The inclusion criteria include the following:

(i) Articles on general mixed traffic management.
(ii) Articles that discussed traffic intersection scheduling scheme.
(iii) Journals ranked by the Scientific Journal Ranking (SJR).
(iv) Conferences ranked by the Computing Research Education (CORE).
(v) Papers presented in the English language.

By applying the inclusion and exclusion criteria, 44 studies were selected, as summarised in Table 2. Table 3 shows a distribution of the materials from the search by year of publication.

4.4.3. Data Extraction and Analysis Based on Traffic Control Parameters. Table 5 gives a snapshot of the relationship between the primary studies used in this review. From this, we can extract the important information from the selected studies. The following strategies are adopted.

(i) Answer the individual research question.
(ii) Search for additional information within the study.

Table 4: Selected primary studies.

Sources	Journal	Conf.	Paper	Selected
IEEEXplore	3	62	62	32
Springer	18	6	24	7
CiteSeerX	1	1	2	1
Google scholar	2	3	2	2
DfT	2	4	3	2
Total	26	75	93	44

(iii) Identify research gaps and provide recommendations for further studies.

The classification matrix in Tables 1 and 2 summarises the traffic control strategies, their performance, and findings from the primary studies. From the investigation, each paper is reviewed and analysed to know the exact problem solved and the strategy used in solving it. This included the component of interest and the features or characteristics of the parameters required in solving the problem. The research review also seeks to determine if the studies considered the impact of the traffic flow control strategies on traffic efficiency, safety, and travel time constraints. While [9, 11, 12, 15, 17] solved the intersection optimisation and efficiency problem, [15, 18, 19, 40] presented the techniques for analysing intersection safety.

5. Research Gap

There appears to be a wide range of adoptable microscopic simulation models for lane-following homogeneous traffic based on the current literature [77]. Gipp's car-following model's unidirectional (longitudinal) interaction is not suitable for two-dimensional mixed traffic modelling. The existing mix-traffic models are unable to describe the lateral vehicle interactions using the theory of the car-following model because of the driver behaviour. The number of vehicle types present and the relationship between the lateral and longitudinal characteristics and vehicle speed play a significant role in managing heterogeneous traffic behaviour in a mixed AV and HV. The current literature confirms that there are typical constraints in the car-following model [78] which are its rigidity to longitudinal vehicle dynamics parameters: safe distance, maximum speed, and acceleration/deceleration rate. Besides, the recognition and integration of these traffic parameters that control the complex 2-dimensional vehicle behavioural models of traffic participants are critical tasks towards a new research direction. Currently, there has been minimal real-time data from mix-traffic of AV and HV studies; the little that is available consists mainly of assumptions based on the traffic flow theories and simulation. Most existing traffic models are only suitable for describing a homogeneous traffic environment using healthy lane behaviour. To solve the mix-traffic problem effectively, a model should simultaneously describe AV and HV types' lateral and longitudinal behaviours using the microscopic simulation model. As a result, an in-depth analysis of vehicle lateral and longitudinal movements is needed to assess driver behaviour in this heterogeneous traffic flow system. Currently, no widely used traffic theory could exhaustively simulate a 2-dimensional mix-traffic flow involving a lateral and longitudinal behavioural model because of the intricate human-driving behavioural pattern involved. It is only a robust 2-dimensional traffic flow model that can perfectly describe the characteristics of vehicles with complex behaviour that can successfully simulate a mix-traffic of AV and HV. However, few studies attempted to develop an integrated and robust driving behaviour model, but the proposed model efficiency was below average. Some of the model are as shown below:

Table 5: Problem solved in primary study.

Type of problem	Study
Communication	[10, 14–17, 20]
Intervehicle time	[5, 19, 23, 26, 28]
Entry distance	[9, 32, 34, 35, 37]

(i) Multiple-leader car-following, road tides (rise and fall of the road surface).

(ii) Tailgating (driving dangerously close to a leading vehicle making it impossible that they would be able to avoid a crash if the driver braked quickly).

(iii) Filtering (which involves moving past queues of stationary or slow-moving traffic).

(iv) Swerving in a dull mix-traffic setting (involves using operational data received to identify a potentially high-risk or unsafe driving behaviour by the first vehicle).

Most existing mix-traffic models employed the basic principles of homogeneous traffic models development, which deviate from the heterogeneous nature of a mix of AV and HV. Paper [79] proposed a Generate-Spatio-Temporal-Data (GSTD) algorithm for generating two-dimensional moving points over time as a line in three-dimensional space or rectangular data that follow an extended set of distributions. This work of [79] was extended by [80, 81] with the introduction of new parameters to create more realistic object movements and permit the creation of trajectories originating from objects moving in an obstructed environment. However, the works of the above three authors did not consider a road intersection as the basis of its simulation. In contrast, other researchers like [82] considered their model as a network but not in a mixed traffic environment.

Traffic intersection is the major part of the road segment that experiences high traffic congestion and high-risk level. The regression approach or the gap-acceptance method is often used to analyse the intersection performance, but previous research [83–85]has found that the gap-acceptance approach has a few disadvantages, like its inability to be used on traffic streams that do not follow a consistent pattern of cars behaviour. The gap-acceptance theory fails when a mixed behaviour of aggressive and gentle cars coexists. The basic car-following model was designed for homogeneous traffic conditions whose parameters utilisation cannot effectively address mix-traffic conditions. In a heterogeneous traffic behaviour scenario, the current research direction in mixed traffic is to apply the technique of the homogeneous car-following model to heterogeneous mix-traffic models. A proposal is made for the combination of the intelligent driver model (IDM) [86] proposed for a single-lane road with the Gazis–Herman–Rothery (GHR) heterogeneous traffic behaviour model for a complex 2-dimensional mixed traffic of AV and HV. This will go a long way to address the research gap of evaluation of 2-dimensional traffic using both a linear and IDM traffic flow model. However, Gipps' model modification was used on a single-lane route to provide vehicle-type-based parameters for various combinations of cars, trucks, and buses.

Simulation of Mixed Traffic Mobility (SiMTraM) is a standard car-following model simulator that could be modified to create a new approach to modelling heterogeneous traffic flow conditions involving AV and HV. Also, Simulation of Urban Mobility (SUMO) is an open-source multimodal traffic simulation package that is a compact, microscopic, and continuous system which is used to simulate mixed traffic involving vehicles, public transport, and pedestrians. It is designed to manage massive traffic networks. However, SiMTraM and SUMO have a downside as they cannot comprehend vehicle behaviour in various traffic environments. In addition to modelling a mixed traffic mix flow scenario, assessing the effect of each traffic participant on individual vehicle behaviour is needed for an effective description of the traffic flow. This model can account for the dynamic interactions between individual vehicles, road structures, and the need for model calibration and validation using real-time data.

Because drivers tend to maintain a safe gap with other vehicles to avoid a collision, the safe distance modelling approach is reliable in simulating the longitudinal movements of different vehicles in a mixed traffic stream. Furthermore, compared to fuzzy logic models, cellular automata models appear to be more appropriate for modelling lateral interactions or lane-changing behaviour of vehicles that evolve through a number of discrete time steps. Incorporating vehicle-type-dependent behaviour in mixed traffic conditions of car-following models to precisely recognise the driving behaviour is the right direction to go in optimising a mix of AVs and HVs coexistence. In the basic car-following model, a traffic collision is imminent when the leading vehicle's operation is uncertain, resulting in a decrease in relative spacing between the vehicles group, thereby jeopardising the safe following distance. Azevedo made an essential contribution to developing a safe distance model that successfully estimated actual vehicle behaviour in various traffic conditions. However, the model's accuracy in estimating the safe distance remains unclear because the safe distance is a critical aspect of the traffic model which needs to be captured in the circular automation.

6. Conclusion

This section presents the summary background of literature in mixed traffic management, with fundamentals in describing traffic control systems and details of the impact of traffic control parameters. The related literature on conventional traffic management, intelligent transportation, and mix-traffic management systems is captured in detail. The state-of-the-art methods in managing heterogeneous traffic systems are investigated with suggested solutions to addressing mixed traffic problems from the state-of-the-art mixed traffic management strategies. From the above review of traffic modelling, it is often hard for mesoscopic models to discretise or represent traffic accurately and they are therefore not often used in traffic simulation and modelling. The microscopic and macroscopic traffic simulation modelling approaches are often used in traffic modelling because they can easily describe the full details of an individual vehicle and group of vehicles, respectively. From the fundamental diagrams of traffic flow, the proposed AVHV control mixed traffic flow could be realised by combining both microscopic and macroscopic traffic model parameters. However, microscopic models and simulation tools could perfectly forecast traffic in a more detailed way. Therefore, the microscopic model is proposed to predict the behaviour of individual vehicles in mix-traffic settings effectively. The review of the state-of-the-art mix-traffic modelling capabilities indicated that no single traffic model could effectively address a mix-traffic of AV and HV. Existing analytical models, such as the car-following models, have demonstrated greater flexibility with less computational workload than rule-based cellular automata models, which use complex rules to simulate vehicle dynamics. In modelling an efficient 2-D behavioural traffic flow model that can accurately describe a mix of AV and HV behaviour environments, there is a need to incorporate more than one traffic flow model with varieties of performance parameters. The proposed model involves integrating the existing traffic simulation models with the required modification to meet the functionality involved in a mix-traffic setting. The proposed single-lane-based model considers the left and right lanes as agents for joining the vehicle platoon or the new lane. These behavioural features of the model are what will make vehicle coexistence possible. Based on the preceding, three traffic models (reservation nodes, car-following, and collision avoidance by Gipps) were identified for integration and enhancements to support a mix of AVs and HVs model flow at a road intersection. There has been much improvement in mix-traffic management strategies over the years, but the state of the art has not addressed the challenges of mixing-traffic using the 2-dimensional gap-acceptance method in a car-following model. From the review of the findings, the currently available mix-traffic models cannot be directly utilised to simulate a traffic mix involving AV and HV without modification to the identified essential traffic parameters of lateral motion holistically in each vehicle type for the model. The proposed transition to the fully autonomous driving vehicle has generated various expectations ranging in an increase in driving comfort, decrease in delay, reduction in traffic incidence, increase in road comfort, decrease in carbon emission, decrease in fuel consumption, and decrease in driver shortage. Within this envisaged transition and integration of AVs and HVs period of the coexistence, there is a need for a robust technology to be put in place to drive and support the transition process seamlessly. Though this study showed positive results using logical reasoning, implementing this traffic management system depends on the existing infrastructure, and the technology is potentially cost-ineffective.

Data Availability

The data are included in the main body of the report.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] W. Payre, J. Cestac, and P. Delhomme, "Intention to use a fully automated car: attitudes and a priori acceptability," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 27, pp. 252–263, 2014.

[2] M. Heilig, T. Hilgert, N. Mallig, M. Kagerbauer, and P. Vortisch, "Potentials of autonomous vehicles in a changing private transportation system - a case study in the stuttgart region," *Transportation Research Procedia*, vol. 26, pp. 13–21, 2017.

[3] C. Pakusch, G. Stevens, and P. Bossauer, "Shared Autonomous Vehicles: Potentials for a Sustainable Mobility and Risks of Unintended Effects," in *Proceedings of the ICT4S 2018. 5th International Conference on Information and Communication Technology for Sustainability*, pp. 258–269, Toronto, Canada, May 2018.

[4] D. Fajardo, T.-C. Au, S. T. Waller, P. Stone, D. Yang, and T. C. Au, "Automated intersection control: performance of future innovation versus current traffic signal control," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2259, no. 1, pp. 223–232, 2011.

[5] Y. C. Liu, "Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveller information systems," *Ergonomics*, vol. 44, no. 4, pp. 425–442, 2001.

[6] J. E. Domeyer, J. D. Lee, and H. Toyoda, "Vehicle automation-other road user communication and coordination: theory and mechanisms," *IEEE Access*, vol. 8, pp. 19860–19872, 2020.

[7] T. Hara and R. Kiyohara, "Vehicle approaching model for t-junction during transition to autonomous vehicles," in *Proceedings of the 2018 International Conference on Information Networking (ICOIN)*, pp. 304–309, IEEE, Chiang Mai, Thailand, January 2018.

[8] N. Wakui, R. Takayama, T. Mimura, N. Kamiyama, K. Maruyama, and Y. Sumino, "Drinking status of heavy drinkers detected by arrival time parametric imaging using sonazoid-enhanced ultrasonography: study of two cases," *Case reports in gastroenterology*, vol. 5, no. 1, pp. 100–109, 2011.

[9] E. A. Mueller, "Aspects of the history of traffic signals," *IEEE Transactions on Vehicular Technology*, vol. 19, no. 1, pp. 6–17, 1970.

[10] S. Marisamynathan and P. Vedagiri, "Modeling pedestrian delay at signalized intersection crosswalks under mixed traffic condition," *Procedia-Social and Behavioral Sciences*, vol. 104, pp. 708–717, 2013.

[11] P. Emami, M. Pourmehrab, M. Martin-Gasulla, S. Ranka, and L. Elefteriadou, "A comparison of intelligent signalized intersection controllers under mixed traffic," in *Proceedings of the 2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, pp. 341–348, IEEE, Maui, HI, USA, November 2018.

[12] R. Horowitz and P. Varaiya, "Control design of an automated highway system," *Proceedings of the IEEE*, vol. 88, no. 7, pp. 913–925, 2000.

[13] X. Y. Lu, H.-S. Tan, S. E. Shladover, and J. K. Hedrick, "Automated vehicle merging maneuver implementation for ahs," *Vehicle System Dynamics*, vol. 41, no. 2, pp. 85–107, 2004.

[14] J. J. B. Vial, W. E. Devanny, D. Eppstein, and M. T. Goodrich, "Scheduling Autonomous Vehicle Platoons through an Unregulated Intersection," 2016, https://arxiv.org/abs/1609.04512.

[15] S. Annell, A. Gratner, and L. Svensson, "Probabilistic collision estimation system for autonomous vehicles," in *Proceedings of the 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, pp. 473–478, IEEE, Rio de Janeiro, Brazil, November 2016.

[16] H. Qi, R. Dai, Q. Tang, and X. Hu, "Coordinated intersection signal design for mixed traffic flow of human-driven and connected and autonomous vehicles," *IEEE Access*, vol. 8, pp. 26067–26084, 2020.

[17] Z. Yang, Y. Feng, and H. X. Liu, "A cooperative driving framework for urban arterials in mixed traffic conditions," *Transportation Research Part C: Emerging Technologies*, vol. 124, Article ID 102918, 2021.

[18] D. Schrank, B. Eisele, and T. Lomax, "Tti's 2012 urban mobility report," vol. 4, The Texas A&M University System, College Station, TX, U.S.A, 2012.

[19] J. Rios-Torres and A. A. Malikopoulos, "A survey on the coordination of connected and automated vehicles at intersections and merging at highway on-ramps," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 5, pp. 1066–1077, 2017.

[20] S.-H. Lin and T.-Y. Ho, "Autonomous vehicle routing in multiple intersections," in *Proceedings of the 24th Asia and South Pacific Design Automation Conference*, pp. 585–590, ACM, New York, NY, U.S.A, January 2019.

[21] R. Abduljabbar, H. Dia, S. Liyanage, and S. A. Bagloee, "Applications of artificial intelligence in transport: an overview," *Sustainability*, vol. 11, no. 1, p. 189, 2019.

[22] G. M. Arnaout and J.-P. Arnaout, "Exploring the effects of cooperative adaptive cruise control on highway traffic flow using microscopic traffic simulation," *Transportation Planning and Technology*, vol. 37, no. 2, pp. 186–199, 2014.

[23] S. Huang and W. Ren, "Autonomous intelligent vehicle and its performance in automated traffic systems," *International Journal of Control*, vol. 72, no. 18, pp. 1665–1688, 1999.

[24] M. Shahgholian and D. Gharavian, "Advanced Traffic Management Systems: An Overview and a Development Strategy," 2018, https://arxiv.org/abs/1810.02530.

[25] S. Le Vine, A. Zolfaghari, and J. Polak, "Autonomous cars: the tension between occupant experience and intersection capacity," *Transportation Research Part C: Emerging Technologies*, vol. 52, pp. 1–14, 2015.

[26] T. Luettel, M. Himmelsbach, and H. J. Wuensche, "Autonomous ground vehicles-concepts and a path to the future," *Proceedings of the IEEE*, vol. 100, pp. 1831–1839, 2012.

[27] A. Lari, F. Douma, and I. Onyiah, "Self-driving vehicles and policy implications: current status of autonomous vehicle development and Minnesota policy implications," *Minn. JL Sci. & Tech*, vol. 16, p. 735, 2015.

[28] C. A. Kanthack, "Autonomous vehicles and driving under the influence: examining the ambiguity surrounding modern laws applied to future technology," *Creighton Law Review*, vol. 53, p. 397, 2019.

[29] P. Bazilinskyy, M. Kyriakidis, D. Dodou, and J. de Winter, "When will most cars be able to drive fully automatically? Projections of 18,970 survey respondents," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 64, pp. 184–195, 2019.

[30] M. Omae, T. Ogitsu, N. Honma, and K. Usami, "Automatic driving control for passing through intersection without stopping," *International Journal of Intelligent Transportation Systems Research*, vol. 8, no. 3, pp. 201–210, 2010.

[31] B. V. Arem, C. J. G. V. Driel, and R. Visser, "The impact of cooperative adaptive cruise control on traffic-flow characteristics," *IEEE Transactions on Intelligent Transportation Systems*, vol. 7, no. 4, pp. 429–436, 2006.

[32] M. A. S. Kamal, J. Imura, A. Ohata, T. Hayakawa, and K. Aihara, "Control of traffic signals in a model predictive control framework," *IFAC Proceedings Volumes*, vol. 45, no. 24, pp. 221–226, 2012.

[33] M. Treiber, A. Hennecke, and D. Helbing, "Congested traffic states in empirical observations and microscopic simulations," *Physical Review*, vol. 62, no. 2, pp. 1805–1824, 2000.

[34] P. Diakaki, D. Kotsialos, V. Wang, A. Kotsialos, and Y. Wang, "Review of road traffic control strategies," *Proceedings of the IEEE*, vol. 91, no. 12, pp. 2041-2042, 2003.

[35] B. Si, M. Zhong, and Z. Gao, "Link resistance function of urban mixed traffic network," *Journal of Transportation Systems Engineering and Information Technology*, vol. 8, no. 1, pp. 68–73, 2008.

[36] G. Sharon and P. Stone, "A protocol for mixed autonomous and human-operated vehicles at intersections," in *Proceedings of the International Conference on Autonomous Agents and Multiagent Systems*, pp. 151–167, Springer, Berlin, Germany, November 2017.

[37] E. Jeong, C. Oh, and S. Lee, "Is vehicle automation enough to prevent crashes? role of traffic operations in automated driving environments for traffic safety," *Accident Analysis & Prevention*, vol. 104, pp. 115–124, 2017.

[38] L. Booth, R. Norman, and S. Pettigrew, "The potential implications of autonomous vehicles for active transport," *Journal of Transport & Health*, vol. 15, Article ID 100623, 2019.

[39] M. A. S. Kamal, J.-i. Imura, T. Hayakawa, A. Ohata, and K. Aihara, "A vehicle-intersection coordination scheme for smooth flows of traffic without using traffic lights," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 3, pp. 1136–1147, 2015.

[40] T.-C. Au, S. Zhang, and P. Stone, "Autonomous intersection management for semi-autonomous vehicles," *Handbook of transportation*, pp. 88–104, 2015.

[41] U. Montanaro, S. Dixit, S. Fallah et al., "Towards Connected Autonomous Driving: Review of Use-Cases," *Vehicle System Dynamics*, vol. 57, pp. 1–36, 2018.

[42] A. Uno, T. Sakaguchi, and S. Tsugawa, "A merging control algorithm based on inter-vehicle communication," in *Proceedings of the 1999 IEEE/IEEJ/JSAI International Conference on Intelligent Transportation Systems (Cat. No.99TH8383)*, pp. 783–787, IEEE, Tokyo, Japan, October 1999.

[43] K. Dresner and P. Stone, "Traffic intersections of the future," *Proceedings of the national conference on artificial intelligence*, vol. 21, AAAI Press; MIT Press, Washington, D.C, U.S.A, July 1999.

[44] V. Milanés, J. Pérez, E. Onieva, and C. González, "Controller for urban intersections based on wireless communications and fuzzy logic," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 1, pp. 243–248, 2010.

[45] T. Litman, *Autonomous Vehicle Implementation Predictions*, Victoria Transport Policy Institute Victoria, Victoria, Canada, 2017.

[46] J. M. Anderson, K. Nidhi, K. D. Stanley, P. Sorensen, C. Samaras, and O. A. Oluwatola, *Autonomous Vehicle Technology: A Guide for Policymakers*, Rand Corporation, Santa Monica, CA, U.S.A, 2014.

[47] S. A. Seshia, D. Sadigh, and S. S. Sastry, "Towards Verified Artificial Intelligence," 2016, https://arxiv.org/abs/1606.08514.

[48] R. Claes, T. Holvoet, and D. Weyns, "A decentralized approach for anticipatory vehicle routing using delegate multiagent systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 2, pp. 364–373, 2011.

[49] K. Dresner and P. Stone, "A multiagent approach to autonomous intersection management," *Journal of Artificial Intelligence Research*, vol. 31, pp. 591–656, 2008.

[50] Q. Zeng, C. Wu, L. Peng, and H. Li, "Novel vehicle crash risk detection based on vehicular sensory system," in *Proceedings of the Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), 2015 IEEE*, pp. 622–626, IEEE, Chongqing, China, December 2015.

[51] J. Eguchi and H. Koike, "Discrimination of an approaching vehicle at an intersection using a monocular camera," in *Proceedings of the Intelligent Vehicles Symposium, 2007 IEEE*, pp. 618–623, IEEE, Istanbul, Turkey, June 2007.

[52] M. C. P. Ferreira, O. Tonguz, R. J. Fernandes, H. M. F. DaConceicao, and W. Viriyasitavat, "Methods and systems for coordinating vehicular traffic using in-vehicle virtual traffic control signals enabled by vehicle-to-vehicle communications," US8972159B2, 2015.

[53] S. Knorn, A. Donaire, J. C. Agüero, and R. H. Middleton, "Passivity-based control for multi-vehicle systems subject to string constraints," *Automatica*, vol. 50, no. 12, pp. 3224–3230, 2014.

[54] D. Schrank, T. Lomax, and B. Eisele, *Urban Mobility Report*, Texas Transportation Institute, Texas, TX, U.S.A, 2012.

[55] W. Zhao, D. Ngoduy, S. Shepherd, R. Liu, and M. Papageorgiou, "A platoon based cooperative eco-driving model for mixed automated and human-driven vehicles at a signalised intersection," *Transportation Research Part C: Emerging Technologies*, vol. 95, pp. 802–821, 2018.

[56] B. Friedrich, "The effect of autonomous vehicles on traffic," in *Autonomous Driving*, pp. 317–334, Springer, Berlin, Germany, 2016.

[57] M. L. Maitre and A. Prorok, "Effects of Controller Heterogeneity on Autonomous Vehicle Traffic," in *Proceedings of the 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)*, Rhodes, Greece, September 2020.

[58] P. Droździel, S. Tarkowski, I. Rybicka, and R. Wrona, "Drivers' reaction time research in the conditions in the real traffic," *Open Engineering*, vol. 10, no. 1, pp. 35–47, 2020.

[59] R. Liao, "Smart mobility: challenges and trends," *Toward Sustainable And Economic Smart Mobility: Shaping The Future Of Smart Cities*, vol. 10, p. 1, 2020.

[60] L. C. Bento, R. Parafita, and U. Nunes, "Intelligent traffic management at intersections supported by v2v and v2i communications," in *Proceedings of the 2012 15th International IEEE Conference on Intelligent Transportation Systems*, pp. 1495–1502, IEEE, Anchorage, AK, USA, September 2012.

[61] A. Naiem, M. Reda, M. El-Beltagy, and I. El-Khodary, "An agent based approach for modeling traffic flow," in *Proceedings of the 2010 The 7th International Conference on Informatics and Systems (INFOS)*, pp. 1–6, IEEE, Cairo ,Egypt, March 2010.

[62] H. Fujii, H. Uchida, and S. Yoshimura, "Agent-based simulation framework for mixed traffic of cars, pedestrians and trams," *Transportation Research Part C: Emerging Technologies*, vol. 85, pp. 234–248, 2017.

[63] I. Tchappi Haman, V. C. Kamla, S. Galland, and J. C. Kamgang, "Towards an multilevel agent-based model for traffic simulation," *Procedia Computer Science*, vol. 109, pp. 887–892, 2017.

[64] B. N. Matcha, S. N. Namasivayam, M. Hosseini Fouladi, K. C. Ng, S. Sivanesan, and S. Y. Eh Noum, "Simulation strategies for mixed traffic conditions: a review of car-following models and simulation frameworks," *Journal of Engineering*, vol. 2020, Article ID 8231930, 22 pages, 2020.

[65] A. K. Budhkar and A. K. Maurya, "Multiple-leader vehicle-following behavior in heterogeneous weak lane discipline traffic," *Transportation in developing economies*, vol. 3, no. 2, p. 20, 2017.

[66] T. V. Mathew, C. R. Munigety, and A. Bajpai, "Strip-based approach for the simulation of mixed traffic conditions," *Journal of Computing in Civil Engineering*, vol. 29, no. 5, Article ID 04014069, 2015.

[67] J. Guo, S. Cheng, and Y. Liu, "Merging and diverging impact on mixed traffic of regular and autonomous vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 3, pp. 1639–1649, 2021.

[68] M. A. S. Kamal, J.-i. Imura, A. Ohata, T. Hayakawa, and K. Aihara, "Coordination of automated vehicles at a traffic-lightless intersection," in *Proceedings of the Intelligent Transportation Systems-(ITSC), 2013 16th International IEEE Conference on*, pp. 922–927, IEEE, The Hague, Netherlands, October 2013.

[69] J. Ploeg, A. F. A. Serrarens, and G. J. Heijenk, "Connect & drive: design and evaluation of cooperative adaptive cruise control for congestion reduction," *Journal of Modern Transportation*, vol. 19, no. 3, pp. 207–213, 2011.

[70] S. Gong and L. Du, "Cooperative platoon control for a mixed traffic flow including human drive vehicles and connected and autonomous vehicles," *Transportation Research Part B: Methodological*, vol. 116, pp. 25–61, 2018.

[71] E. Chan, P. Gilhead, P. Jelinek, P. Krejci, and T. Robinson, "Cooperative control of sartre automated platoon vehicles," in *Proceedings of the 19th ITS World CongressERTICO-ITS EuropeEuropean CommissionITS AmericaITS Asia-Pacific*, Vienna, Austria, October 2012.

[72] Y. Zhou, S. Ahn, M. Chitturi, and D. A. Noyce, "Rolling horizon stochastic optimal control strategy for acc and cacc under uncertainty," *Transportation Research Part C: Emerging Technologies*, vol. 83, pp. 61–76, 2017.

[73] D. Swaroop, J. K. Hedrick, C. C. Chien, and P. Ioannou, "A comparision of spacing and headway control laws for automatically controlled vehicles1," *Vehicle System Dynamics*, vol. 23, no. 1, pp. 597–625, 1994.

[74] B. Khondaker and L. Kattan, "Variable speed limit: a microscopic analysis in a connected vehicle environment," *Transportation Research Part C: Emerging Technologies*, vol. 58, pp. 146–159, 2015.

[75] Y. Feng, K. L. Head, S. Khoshmagham, and M. Zamanipour, "A real-time adaptive signal control in a connected vehicle environment," *Transportation Research Part C: Emerging Technologies*, vol. 55, pp. 460–473, 2015.

[76] M. Wang, W. Daamen, S. P. Hoogendoorn, and B. van Arem, "Rolling horizon control framework for driver assistance systems. part ii: cooperative sensing and cooperative control," *Transportation Research Part C: Emerging Technologies*, vol. 40, pp. 290–311, 2014.

[77] N. Raju, S. Arkatkar, S. Easa, and G. Joshi, "Customizing the following behavior models to mimic the weak lane based mixed traffic conditions," *Transportation Business: Transport Dynamics*, vol. 10, no. 1, pp. 20–47, 2021.

[78] L. Guo, P. Ge, D. Sun, and Y. Qiao, "Adaptive cruise control based on model predictive control with constraints softening," *Applied Sciences*, vol. 10, no. 5, p. 1635, 2020.

[79] Y. Theodoridis, J. R. O. Silva, and M. A. Nascimento, "On the generation of spatiotemporal datasets," in *Proceedings of the International Symposium on Spatial Databases*, pp. 147–164, Springer, Hong Kong, China, July 1999.

[80] D. Pfoser and Y. Theodoridis, "Generating semantics-based trajectories of moving objects," *Computers, Environment and Urban Systems*, vol. 27, no. 3, pp. 243–263, 2003.

[81] T. Tzouramanis, M. Vassilakopoulos, and Y. Manolopoulos, "On the generation of time-evolving regional data," *GeoInformatica*, vol. 6, no. 3, pp. 207–231, 2002.

[82] N. Li, *Large-scale Realistic Macro-Simulation of Vehicle Movement on Road Networks*, Royal Institute of Technology, Stockholm, Sweden, 2013.

[83] R. Akcelik, "Gap-acceptance modelling by traffic signal analogy," *Traffic Engineering and Control*, vol. 35, no. 9, pp. 498–501, 1994.

[84] S. Teply, M. I. A. Henaidy, and J. D. Hunt, "Gap Acceptance Behaviour-Aggregate and Logit Perspectives: Part 1," *Traffic engineering & control*, vol. 38, 1997.

[85] R. Akçelik, "A review of gap-acceptance capacity models," in *Proceedings of the 29th Conference of Australian Institutes of Transport Research (CAITR 2007)*, pp. 5–7, University of South Australia, Adelaide, Australia, December 2007.

[86] A. Kesting, M. Treiber, and D. Helbing, "Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity," *Philosophical Transactions of the Royal Society A: Mathematical, Physical & Engineering Sciences*, vol. 368, no. 1928, pp. 4585–4605, 2010.