Evaluation of Car-Following Model for Mixed Autonomous and Human Driven Vehicles on Road Facilities.

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ABSTRACT

Driverless cars are emerging slowly but bear the opportunity to improve the traffic system efficiency and user comfort. For the near future, a mix of human-driven and driver-less vehicle co- existence is inevitable. The quest to integrate autonomous and human-driven vehicles has created numerous critical questions in the road traffic system: How can autonomous and human- driven vehicles co-exist efficiently? What are the prospects of breaching the existing car-following model widely adopted to control the longitudinal movement of vehicles and control the driver's maintenance of a safe distance? There is no doubt, that the emergence of autonomous vehicles and their integration is altering the existing traffic theories and the idea behind the car-following model. Currently, researchers are working hard to efficiently describe the physics behind the traffic flow theory of car-following models in mixed traffic. This work investigated a homogeneous car-following model sensitivity with varying human drivers' reaction time in mixed traffic. The ability to predict the optimal vehicle response time in a platoon to the behaviour of its predecessor is vital in predicting the effect a change in the driving environment of mixed traffic has on traffic flow. The major complexities surrounding the car-following model in a mixed traffic flow environment are how the traffic participants share the road intersection space and the car-following behavior of human-driven vehicles. Investigation in microscopic traffic flow describes the way a single car be- haves and then introduces the impact another car has on a car's behavior to address the mixed traffic flow. The traffic speed performance under the different traffic conditions suggests that the proposed mixed traffic car-following model outperforms the existing car-following model for human-driven vehicles with an average of 22.59mph. There is a significant throughput improvement in a mixed traffic environment when the distance headway of autonomous vehicles is adjusted to support the research hypothesis.

Keywords: 2-dimensional traffic control, car-following, mix-traffic co-operation level, speed harmonization, intersection capacity utilization, vehicle queue.

INTRODUCTION

Recently, autonomous vehicles have been looked at as analternative way to solve road traffic problems. fig. 1 represent a fully automated 4-way intersection with all the autonomous vehicle road infrastructure where the red dotes represents the vehicle collision points and the wireless network sign represent communications between the vehicles and the road infrastructures. The emergence of autonomous vehicles (AV) inadvertently makes the co-existence of human-driven vehicles (HV) and autonomous vehicles are inevitable. AV will not solve all the HV inefficiencies in a mixed traffic setting but will help a great deal as there are myriad possibilities. A car-following model has been developed with particular reference to the weak discipline of lane-based driving. The theory is based on the discomfort caused by lateral friction between vehicles. The movement of the following vehiclewas formulated as a function of the off-centre effects of its leader(s). The main idea of this model is that a vehicle will maintain a minimum space and time gap between it and the vehicle that precedes it. Thus, under congested conditions, if the leading car changes its speed, the following vehicle will also change the speed at a point in time-space along the trafficwave speed,-w.

Following the emergence of autonomous vehicles, mixed traffic problems have attracted researchers to develop many related technologies to find solutions associated with the autonomous vehicle integration process. Significant road in- frastructure enhancement such as road-vehicle communication needs to be upgraded to accommodate autonomous vehicle

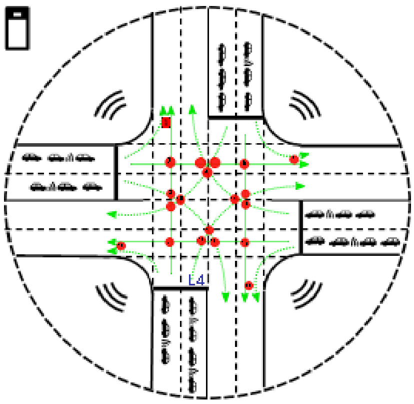

Fig. 1: A 4-way road intersection with double lanes

integration and future traffic growth. Traffic flow theories describe the traffic flow variables of volume, density, and speed which correlate with city traffic. Traffic management methods like the car-following model aim to increase traffic peak capacity and ensure a more efficient and smooth flow of traffic. However, the compelling benefits of autonomous vehicles may require prohibiting human-driven vehicles on certain roadways because of the challenges surrounding AVs and HVs co-existence. AV will not solve all the HV ineffi- ciencies in a mixed traffic setting but will help a great deal as there are myriad possibilities. The current study by [AT24] predicts growth of more than tenfold in the global autonomous vehicle market worth 54.23billionin2019to556.67 billion by 2026. Undoubtedly, the co-existence of human-driven and autonomous vehicles will complicate this situation if there is no reliable, safe, and efficient integration framework in place. Over the years, research on traffic management has been on the increase [KR18, FK15]. This increase in traffic research is due to the advancements in car technology, an increase in pop- ulation growth, with a corresponding increase in the number of cars on the road, without the right complement of road infrastructure and traffic management techniques[LAS+19, BBKHK18]. Based on different car behaviours associated with mix-traffic, autonomous vehicle integration will increase delay without an efficient traffic control scheme, which will cause the under-utilisation of the benefits of autonomous vehicles. A flawed traffic management scheme has been identified as the root cause of traffic gridlock along the roads.

Research Question sec:question AVs are evolving; while HVs are not to be eradicated any time soon, it is therefore ev- ident that AVs and HVs co-existence for a while is inevitable.

This paper investigates the efficiency of mixed traffic flow in a car-following model using traffic theories and compares it with the homogenous traffic system. Several issues are still the focus of research in the integration of human-driven and autonomous vehicles. Some of these challenges include the following

Mix-driving requires many complex social interactions with an expected impact on traffic; how do we deal with the investigation?

The worry surrounding autonomous vehicle integration has been growing, and the need to design an efficient car-following method and regulations for its co-existenceis vital.

Review of the state of the art

The review of the state of the art in classification of car- following models is based on their applicable background and structure [AHL21], [WST+23], [ZJM+24]. By considering driving behavior and specific model parameters, we identify the advantages and limitations of each microscopic simulation model in terms of accuracy and continuity. We also discuss model calibration methods, stability analysis, and the impact of complex traffic environmental behaviour on the car-following process. The current literature confirms that typical constraints in the car-following model is its rigidity to longitudinal vehicle dynamics of safe- distance, average speed, and acceleration/de- celeration rate. Most existing traffic models are only suitable for describing a homogeneous traffic environment using a firm lane behaviour. As a result, an in-depth analysis of vehicle lateral and longitudinal movements are needed to assess driver behaviour in a heterogeneous traffic flow system. Currently, no widely used traffic theory could exhaustively simulate a car-following 2-dimensional mix-traffic flow involving a lateral and longitudinal behavioural model because of the intricate human driving behavioural pattern involved.Traffic

control strategies are employed to ensure the safety of life, efficient flow of traffic, increase road capacity, reduction of delay/congestion, and a general effort to ameliorate problems resulting from traffics. A good traffic management strategy represents the most visible end-results to manage the long- awaited mixed traffic scenario involving human-driven and autonomous vehicles. Traffic management strategies are con- cerned with planning, arrangement, guidance, and control of traffic services needed to efficiently move vehicles within a road system. It aims at the safe and seamless traffic movement and preserving and improving quality of life and the local environment. Algorithms of traffic management have helped in defining an efficient and safe traffic flow. Generally, routing forecasting data are used to estimate the effect of traffic performance. Car-following model help in managing collisions and improve the safety of the traffic flow scheme. This research deals with the flow aspect of real-time traffic, which involves controlling flow strategies in a group of vehicles. This research area is directed towards preventing congestionand increasing flow efficiency along the road and at traffic intersections. There is currently extensive research going on in the area of mix-traffic control methods. However, this underpinned the integration of autonomous vehicles. [MJ17], provided an overall research direction in the mix-traffic control system, covering a mix-traffic flow control, intelligent trans-portation system, and traffic coordination scheme in urban areas motorway networks. Currently, there exists a wide gap between hypothesis and practicability in this area of mixed traffic. The attempt by [HLS16] focused on addressing safety assistance and the integration process. Research in a mix- traffic flow environment has been investigated, though with its challenges because of car behaviours. In microscopic traffic modelling, the conduct among individual vehicles and the road intersections are modelled independently.

More often than not, traffic ideally observes enough distance urban and suburban roads network for safety reasons. When driving on a good dry road, one can keep approximately 1 metre (1 yard) for every one mile per hour of your speed. The 2-second rule applies irrespective of the vehicle's speed since the distance between the following and the leading vehicle will naturally extend the faster travel. However, a car moving at 30 mph, will be 30 metres away from the vehicle in its front, sufficient to encompass the propose comprehensive stopping distance published in the UK transport authority [ta20]. The 2-seconds rule is a technique used by drivers to calculate their safe following distance, enabling them to control or stop their vehicle any time the vehicle directly ahead of it stop for an emergency. Besides, this 2-seconds rule is not a guide to the safe stopping distance of the vehicle; instead, it is a more useful guide to drivers' reaction times. However, the speed limits requirement of different city roads guides the rate of vehicle motion. This limit is usually indicated on the traffic signs with the permitted speed range for each route. The UK High way code specifies a maximum of 30mph for city roads, 60mph on main single-carriageway roads, and 70mph on dual carriageways and motorways.

The scenario of mixing traffic behaviours in a single flow model brings a mountain of complex variables into consid- eration, lies the elements of human and machine co-existence: in mixed traffic flow at a road intersection, each vehicle type are expected to behave in line with its default design/operation, have a very minimal behavioural deviation and maintain the essential objectives of traffics, which is to safely reach its target destination or goal in the shortest possible time. With traffic flow parameters, the behavioural pattern of vehicles could be evaluated reasonably to suggest that the co-existence of human and autonomous vehicles is possible. In doing this, developing a mix-traffic flow model is the first step towards shaping a more sophisticated traffic management strategy to midwife the transition period seamlessly. Mix-traffic flow man-agement creates room for vehicle co-existing by negotiating with other vehicle types and traffic participants who have a different behavioural pattern based on agreed set down rule to avoid a collision. The platooning model of traffic management strategy is used to optimise the traffic flow. Besides, the method of varying the safe distance between autonomous and human-driven vehicles is also deployed to enhance the optimal efficiency of the traffic. [ZNS+18] proposed a real- time co-operative eco-driving scheme for AV and HV mixed- vehicles using platoon. According to [ZNS+18], the lead vehicle receives timing and phase signal information through (V2I) communication, while the preceding vehicle on the reference platoon communicates via V2V.

METHODOLOGY

There exist several mathematical models that describes car following behavior under a wide range of conditions which are based on the stimulus–response framework that was first developed at the General Motors research laboratories [SZ14]. The framework the proposed model assumes that mixed vehicles responds to a given stimulus with varying inter- vehicle distance and safe distance according to the following relationship: response= vehicle type × stimulus. Over the years, various researchers [Rot92] on car following models have looked at vehicles of the same type.

The road model Figure 2 outlines a single lane merging road system with its physical properties. Mix traffic involves cars with a different behavioural pattern but the same road system; how can the co-existence work without heavily impacting traffic flow efficiency? In this situation, fig. 2 represent a merging T-intersection at an angle of 45° which is between node 8 and 12 is being considered for cars sharing space to test the hypothesis. For clarity the model in fig. 2 represent a theoretical T-junction for easy of implementation. This is a scenario where cars are coming from a separate road and will merge into a priority road at a common node between them and cannot always tell by their distance from each other if they are likely to collide. They consider that they might eventually collide in a situation where they are heading towards the same destination. Naturally, the major problem will arise from human-controlled vehicles because they do not possess the features of being self-aware of their environment as their behaviour is stochastic and more prone to prediction errors. The proposed model considered the combination of the two traffic management strategies of a centralised and decentralised approach. In the centralised strategy, drivers and vehicles communicate with a central controller and the traffic signal to assign right-of-way access priority to the intersection. On the other hand, in the decentralized strategy, drivers and vehicles communicate and negotiate for right-of-way access priority. Several research investigation works have been done in the area of the impact of autonomous cars on the traffic flow at the intersection [DR18]. [HZ18] proposes the Optimisation of traffic intersection using connected and autonomous vehicles. Also, [CSAL19] considered the impact of autonomous cars on traffic with consideration of two-vehicle types, which are distinguished by their maximum velocities; slow (V_s) and fast (V_f), which denotes the fraction of the slow and fast vehicles respectively.

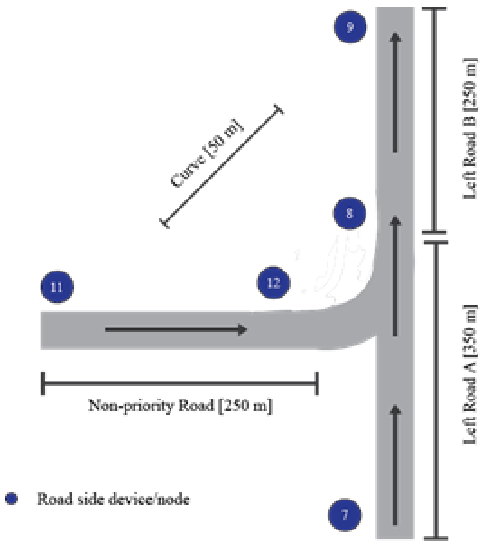

Fig. 2: Merging road model

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The developed Mathematical relationships model describes the two types of vehicle mixed behaviour to the occupation time with the traffic flow in a merging single lane road system. A proposal is made for a mix-traffic model at a merging T-junction with a priority road section, in which case, we have a vehicle mix of human-driven and driver- less cars accessing the intersection simultaneously. Figure 2 is the proposed model of a one-way merging T-junction with a priority road section and dimensions of the nodes considered. The mix-vehicles on the two-road system with start nodes (7 and 11) have a common destination or target at node 9. The vehicle emerges from the two roads segment at node 8 and joins the priority road. The fundamental work of intersection is to direct vehicle trajectories from start to target. The driving behavioural difference and the dynamic headway are taken into account. Hence, driving behaviour is classified into two typical types: the aggressive driving style for humans and the gentle driving for autonomous vehicles, respectively. The equations obtained were used to estimate the critical safe and inter- vehicle distances for aggressive driving(HV). The queuing distance is calculated using an existing method of clearing behaviour approach according to [DA18]. It is also shown that the estimation of the safe distance is more realistic if reaction time and the aggressive behaviour of drivers are considered simultaneously.

Correspondingly, the safe distance, car-following and pla- tooning rules are used to optimise the traffic model. The proposed mix traffic model considers the position and dynamic headway of the leading and preceding vehicles, in this case, both vehicles are on the current lane or will share a common node upon merging, thereby making use of safe distance and car-following model. Based on the preceding, the following protocols of the central controller determines the traffic flow schedule under the below model underpinning protocols:

- The car movement priority is assigned to the road be- tween nodes 7, 8 and 9 fig. 2.
- If the merging point (node 8) in fig. 2 of the road system experiences vehicle arrivals at the same time, then the priority to cross the merging point is given to the road with a Human-driven vehicle in front.
- If both roads have the same vehicle types at the front, the priority road takes precedence.

Design of the Road Model

sec:design The length of the road is determined by the addition of all route lengths present in the model by calculating the assumed distance from one node to another. The length of the routes of the roads are calculated thus:

We assume that if the route is horizontally straight, like node

1 2 4 5 of the road system then the route length is the difference of their x coordinates:

5(x)˘1(x) (1)

While if the route is vertically straight: Therefore, the length of the road is calculated thus:

l_{road} = (1˘2˘4˘5) + (11˘12˘14˘15) + (7˘6˘8˘9) + (17˘16˘18˘19) + (12˘8) + (2˘18) + (16˘4) + (6˘14) + (12˘16) + (2˘6) + (8˘4)

$l_{road} = 600 + 600 + 600 + 600 + 49.5 + 106.1 +$

$49.5 + 106.1 + 106.1 + 49.5 + 106.1$

Therefore: $l_{road} = 2972.9$m (approximately)

$l_{car} = 4.5$m (Average)

$v = 10$m/s

$n_{cars} = l_{road}/(S + l_{car})$ (2)

Where

$safe_{distance}$, S is 5m for AVs,

S is 7m for HVs during platooning and

S is 3m after merging. The after merging time is when the cars are on straight road and maintain a steady velocity.

Vehicle Model

There are two (2) types of vehicles being considered:

1) Autonomous Vehicles (AVs) with intelligent transporta- tion systems (ITSs) features. These ITSs come in the im- plementation of technologies like sensors and the Internet of Things.
2) Human Driven Vehicles (HVs) with no intelligent trans- portation system, but makes use of a human driver who engages their sense of sight and hearing to watch for traffic signals from traffic signalling devices.

Interaction between HV and AV: The AV is modelled with a gentle driving style where the car is responsible for avoiding all obstacles and mitigates its movement through the environment. The AV driving system has the following features as implemented:

- High precision in obstacle avoidance and manoeuvring, thereby controlling the velocity and acceleration seam- lessly
- The AV has a safe distance 0f 3 seconds.While the HV driving was implemented as a conventional system of driving with features as listed below.
- The human drivers' response to a stimulus is about 6 seconds when compared to the AV, which is a real-time
- The HV has a safe distance 0f 5 seconds.
- The braking distance for HD is higher than that AV, but all are subject to the car's current speed.

Because of these distinct differences between the AVs and HVs, there will be challenges in implementing a safe distance model that produces collision-free traffic flow due to the different vehicle behaviours. Human drivers are unpredictable with stochastic behaviour, less precise, and more prone to mistakes. [vWB20] observed that human drivers respond to unforeseen events in about 6 seconds, while autonomously driven vehicles respond close to real-time, the distance to be kept between autonomous vehicles will be:

$$s_r = v \cdot t_r \qquad (3)$$

While that for human-driven vehicles will be:

$$s_r = v \cdot t_r + 6 \qquad (4)$$

Where 6 seconds is the reaction time for human drivers according to [ZKRB17], [ĐF09].

The developed model combined the microscopic and macro- scopic vehicle level of vehicle modelling to address the longitudinal and lateral mixed-vehicle behaviour process. [MNHF+20], observed that the roadway and traffic impact driving behaviour features while the 2-dimensional behaviour of heterogeneous vehicles impacts the intersection capacity. This condition makes the driving behaviour control vehicles longitudinal and lateral manoeuvre at the merging points. This bi-directional behavioural feature is sophisticated when compared with the car-following model for homogeneous traffic behaviour, giving rise to abreast careful guide, filtering, tailgating, and co-existence. Therefore, the need for a rigorous investigation of the traffic parameters at the microscopic level to assess the traffic behaviour and model an all-inclusive numerical prototype.

The mix-traffic simulation strategies are subdivided into two controlling routines or approaches:

Longitudinal Control for Car Following model: One of the fundamental features of the car-following model is that vehicles observe an average spacing, "S,"(m) that one vehicle would follow another at a given speed, "V"(mi/hr). This parameter is of interest in accessing the throughput of the Car-following model. The aver- age speed-spacing relation in Equation (5) proposed by [Rot92] deals with the longitudinal features of the road and has a relationship with the single-lane road capacity 'C'(veh/hr) estimation in the form:

$$C = (100)\frac{V}{S} \quad (5)$$

Where the constant 100 represent the default optimal capacity of the intersection.

However, the average spacing relations could be repre- sented as:

$$S = \alpha + \beta V + \gamma V^2 \quad (6)$$

Where

α = vehicle length, L

β = the reaction time, T

γ = the reciprocal of the average maximum deceleration of a following vehicle to provide enough space for safety.

Lateral control of vehicle impacts macroscopic and mi- croscopic behaviours on a car-following model. The lateral control causes a lateral interference in a car- following model designed to impact its management only on the longitudinal pattern [MGSG19]. The essence of the lateral behaviour in this AVHVcontol model is to address the driver behaviour characteristics in a mixed vehicle environment. The AVHV control introduces the coupling model between lateral and longitudinal vehicle dynamics through velocity v_x control process and the front wheel steering angle λ_i derived from the steering angle β_v. The relationship between the vehicle velocity v, the longitudinal velocity components v_x, and the vehicle's side slip angle θ is represented in Equation (7)

$$v_x = v \cdot \cos\theta \quad (7)$$

In addition, the steering angle θ of the vehicle front wheel λ_i the angle of the steering wheel, β_v and steering ration i_u is represented in Equation (8).

$$\lambda_i = \frac{\beta_v}{iu} \quad (8)$$

A mix of these two approaches is vital to modelling mix-traffic flow simulations at road intersections to manage longitudinal and lateral driving behaviour effectively. The longitudinal car- following model used the optimal velocity function to relax the equilibrium value of the gap between vehicles. Besides, there is still high acceleration and deceleration problems after a vehicle cuts in front, but the intelligent Driver Model addressed this problem. The lateral model uses the technique of maintain- ing the safe distance braking process to decide the possibility, necessity, and desirability of lateral control of vehicles. The lateral approach model is addressed on a simplified decision- making process using acceleration according to [KTH07].

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Algorithm 1: Car Behaviour Algorithm- Collision free method

```
Data: Default Gentle behaviour of AV, Aggressiveness
      in human drivers psychology (quantified by
      random values)
Result: AVs and HVs Behaviour
for Every HV : do
    Assign aggressiveness with the following attributes;
    Randomised Reaction time ;
    Randomised Safe distance (in time);
    if The Vehicle is AV then
        Maintain the constant Reaction time;
        Maintain the constant Safe distance (in time);
    end
    if AV and HV having the same expected arrival
     time (EAT),comes into conflict to share an
     available road space (eg RN, traffic light or CCP)
     then
        // (apply priority
        considerations);
        Assign priority to HVs to move;
        Decelerate the AV;
        Then move the next Car (AV);
        if the two Vehicle has diferent expected arrival
         time (EAT) then
            move the vehicle with the shortest EAT
             first ;
        end
        At Intersection;
        AV is guided by the Vehicle to Vehicle and to
         infrastructural communication;
        HV is guided by the traffic light control;
        The CU sync the 2 control methods
    end
    if Emergency situation occurs then
        The AV drives defensively by applying
         deceleration/acceleration as necessary ;
    end
end
```

Vehicle Queue

Queue estimates the time vehicle spent waiting for another vehicle to access the intersection first before having the right of way. Depending on the intersection-specific conditions and at the city's discretion, it is queuing analyses for transporta- tion system plan, transportation planning rule (TPR) may be required for operational analysis. Traffic congestion is often as-sociated with stop-and-go traffic, slower speeds, longer travel times, and increased vehicular queuing as characteristics. This can be quantified by the number of vehicles waiting for vehicles around any intersection. It is the cumulative effect of an intersection over travel time. The vehicle delay time analysed for the three intersection control strategies using the time difference between the average vehicle occupancy.

Car Following Model With Safe Distance

The car-following model maintains the behaviour pattern of the leading vehicle. The characteristics pattern of the model analyses Figure 3 shows how a human being reacts in a traffic situation, represented in drivers' longitudinal behaviour following a leading vehicle and maintaining a safe gap in between vehicle groups.

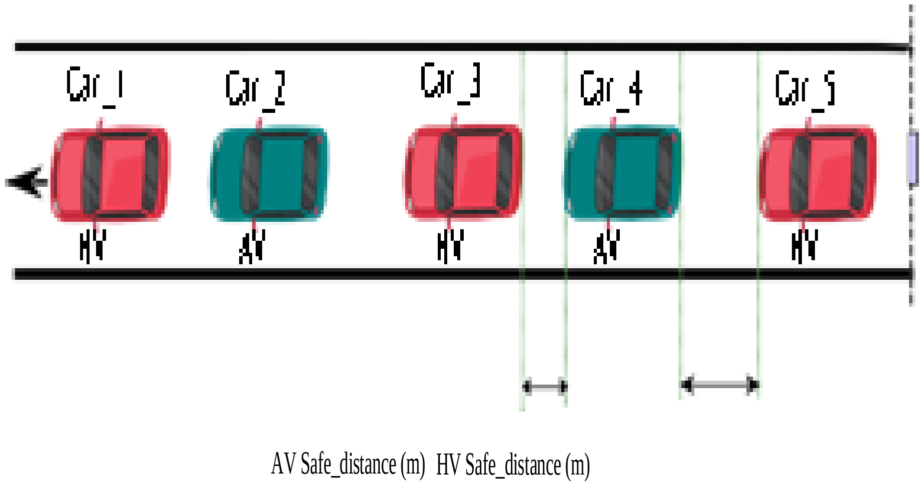

Fig. 3: Car following model with safe distance

The driving behaviour does not altogether depend on the leader in a car-following model, but it depends on the imme- diate vehicle's optimal velocity in front. This model does not consider lane changing and overtaking scenarios as that will involve lateral behaviour. The car-following model behaviour could be described in detail using the below three points:

- The leading vehicle can accelerate to its desired speed because there is no vehicle to influence its speed.
- The leading vehicle's speed primarily determines the following vehicle state because drivers try to maintain a reasonable interval of space or time.
- The braking process involves the use of varying degrees of braking force to avoid the collision

Conditions for safe distance is dependent enumerate

The braking manoeuvre is always executed with constant de- celeration b. There is no distinction between comfortable and maximum deceleration.

There is a constant " $\text{Reaction}_{\text{time}}$" t_r of 0.3 sec for Avs and a randomised $\text{reaction}_{\text{time}}$ of 0.3 to 1.7sec for HVs.

For safety reasons, all vehicle must maintain a constant gap.

We propose a new mathematical model with aggressive factors and adjustable inter-vehicle distance to describe the hybrid vehicle moving behaviour in which the vehicle platoon used to balance the traffic flow. This model deals with the concept that a driver recognises and follows a lead vehicle at a lower speed. According to [Gip81], [AR18], [Mat09], [ZZ18], the potential to follow and estimate the vehicle response to its predecessor's behaviour in a traffic stream is essential in evaluating what impact the changes to the driving condition will have on traffic flow. The car that follows the leader concept is dependent on the below two assumptions:

- The collision avoidance approach demands that a driver must maintain a safe distance from other vehicles on the road.
- The vehicle speed is directly proportional to the spacing between the vehicles.

Let δs^{t} represent the distance available for $(n + 1)^{th}$ vehicle,

δx_{safe} represent the safe distance

v_{n+1} and v^t_a represents velocities

Therefore, the gap required for safety is given by

$$\delta s^{t}_{n+1} = \delta x_{safe} + T \cdot v^{t}_{n+1} \qquad (9)$$

Where:

T = sensitivity coefficient.

However Equation (9) above could be expressed as:

$x_n - x^{t}_{a+1} = \delta x_{safe} + T \cdot vt_{a+1}$ (10)

When the above equation is differentiated with respect to time t:

$$v^{t}_{n} - v^{t}_{n+1} = I \cdot a^{t}_{n+1} \qquad (11)$$

$$a^{t}_{n+1} = \frac{1}{T} \cdot [v^{t}_{n} - v^{t}_{n+1}] \qquad (12)$$

From the model prototype, the chosen random values of (0.3 to 1.7) for the human drivers' safe distance based on the UK transport authority [ta20] According to the sensitivity coefficient term resulting from generations of models, we have

$$a^{t}_{n+1} = \left[\frac{\alpha_{l,se} (v^{t}_{n})^{m}}{x^{t}_{n} - (x^{t}_{n+1})^{l}}\right][v^{t}_{n} - v^{t}_{n+1}] \qquad (13)$$

Where l = headway

s_e = speed exponent

α =sensitivity coefficient

Figure 4 is a background description of the vehicle's safe distance as suggested by the UK Highway Code. The baseline of the method suggests that a human-driven vehicle moving at 30mph will take approximately 23 metres for the braking and stopping the process. This is not the case with the autonomous vehicle with about 0.1 seconds of thinking distance. This stopping distance s is a component of the thinking distance (the time it takes for a driver to activate brakes and time involved in covering distance before the applied), and from the time brake effect the car speed by initiating the deceleration process. Also involved within the braking distance is the stopping time (time/distance it takes the car to come to a stop).

According to [LLL+16], in the field of driving behaviour, many researchers have devoted themselves to modelling driv- ing behaviour, analysing conflict mechanisms, and improving traffic safety. All values are based on the S.I units of metres, seconds, and kilograms. Consideration is based on distinguish- ing between conservative driving and optimistic driving style to help in the prediction of the car motion: In conservative driving, a car must be able to decelerate to a complete stop when the car in front stops suddenly or completely like in a crash-like scenario, it is the worst-case scenario. In this case, the distance gap to the leading vehicle should not become smaller than a minimum gap of 30m [Ler06], while in the optimistic driving style, it is assumed that the car in front

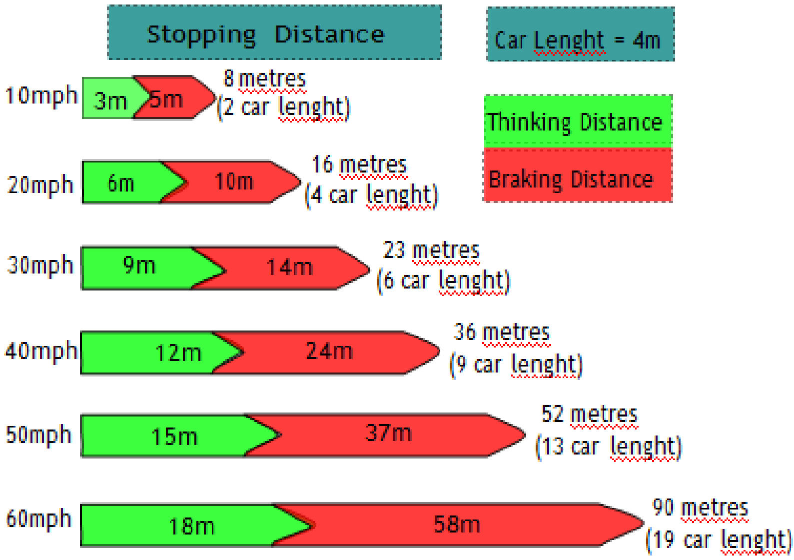

Fig. 4: Safe Distance Description for HV

brakes as well, and the safe distance takes care of the situation. During reaction time, the car moves by:

$$s_r = v \cdot t_r \qquad (14)$$

However, based on the above assumptions, the safe distance between vehicles is set to be a constant for the AVs and varies for the HVs. The safe distance values are measured in seconds, effectively describing the distance related to the current car speed. Condition 1 implies that the braking distance that the leading vehicle needs to come to a complete stop is given by

$$s = \frac{v_1^2}{2 \cdot a} \qquad (15)$$

From condition 2 it follows that to come to a complete stop, the driver of the considered vehicle needs not only braking distance $\frac{v^2}{2b}$, but also an additional reaction distance vδt travelled during the reaction time (the time to decode and execute the breaking instruction needed).

Consequently, the stopping distance is given by

$$\delta x = v\delta t + \frac{v^2}{2 \cdot b} \qquad (16)$$

Finally, condition 3 is satisfied if the gap 's' exceeds the required minimum final value of 0 by considering the stopping distance.

$$\delta x = \delta t + \frac{v^2}{2b} - \frac{v_1^2}{2 \cdot b} \qquad (17)$$

The speed 'v' for which the equal sign holds (the highest possible speed) defines the "safe speed"

$$v_{safe}(s, v_1) = b \cdot \delta t + \sqrt{b^2 \delta t^2 + 2 \cdot (s - s_0)} \quad (18)$$

What happens in a situation where the car in front applies an automatic break? You must have time (reaction time) to apply an automatic brake to avoid collision with the available space and stop. If v = 40 m/s on the motorway, then 20 m distance to start braking time is ideal using the 2 secs rule proposed by [SZHW15].

If the distance between the lead vehicle and the next is greater than the calculated value of y, the merging AV decides to enter the intersection.

III- 0a For AV

$$y = v \cdot t \quad (19)$$

Where

- t[s] = Transit time of the T-junction
- v[km/h]= velocity of coming vehicle

y can be related to the intersection capacity estimates by

$$c = v \cdot y \quad (20)$$

and

$$y = l_{car} + t_{reaction} \cdot v + a \cdot v^2 \cdot t \quad (21)$$

Where

- l_{car} = vehicle length
- t = reaction time
- a= deceleration rate
- v = speed

Going by the above analysis equations, the inter-vehicle distance for the different car categories can be driven as:

III-0b For HV

$$y = v \cdot (t + 1.8) \quad (22)$$

Where the constant 1.8 is the inter vehicle time of transit for HV

However, considering the human anxiety due to AV by adding a stopping distance d for safety.

We have

$$y = v \cdot t \cdot d \quad (23)$$

where d is the safe distance.

The stopping, braking and reaction time were enumerated for clarity

$$s_s = v_0 \cdot t_l + \frac{v_0^2}{2} \cdot a_F \quad (24)$$

From fig. 6, using the first in - first out approach, the first human vehicle is followed by the first autonomous vehicle and, so on, based on the first to arrive, has the right of way. Also, note the similarities in the plots, where aggressive cars 1 and 2 approaching a curve have a similar velocity pattern to gentle cars 1 and 2 that slow down to keep a safe distance.

Model validation

The developed model satisfies the criterion that the model parameters should correspond to realistic characteristics of the driver-less and human-driven vehicle. The testing of traffic theories when reasonable values are assigned to the parameters to show that the model is able to mimic the behaviour of real AV and HV is conducted. The advanced traffic simulator measures the distinct delays related to supervising traffic through an intersection and using other defined performance assessment metrics for each strategy. According to [DS04], with autonomous vehicle features like cruise control, au- tonomous steering, and GPS-based route planning, the mixed- traffic coordination in a multi-agent behaviour and mechanism will increase the performance of human-driven vehicles. The process of executing the test and validation involved using small experiments to demonstrate that the mathematical model is well approximated and the resulting car behaviour matches our expectations. The simulation process testing made use of different traffic intersection scenarios.

- Testing scenario1: straight(lateral) movement.
- Testing scenario2: straight-curve-straight movement of vehicles.
- Testing with the 3-way intersection system. For a real

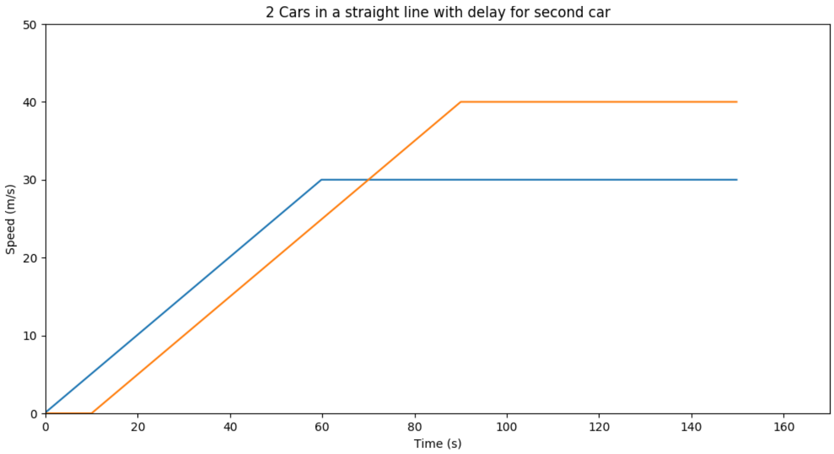

Fig. 5: Two cars straight movement model

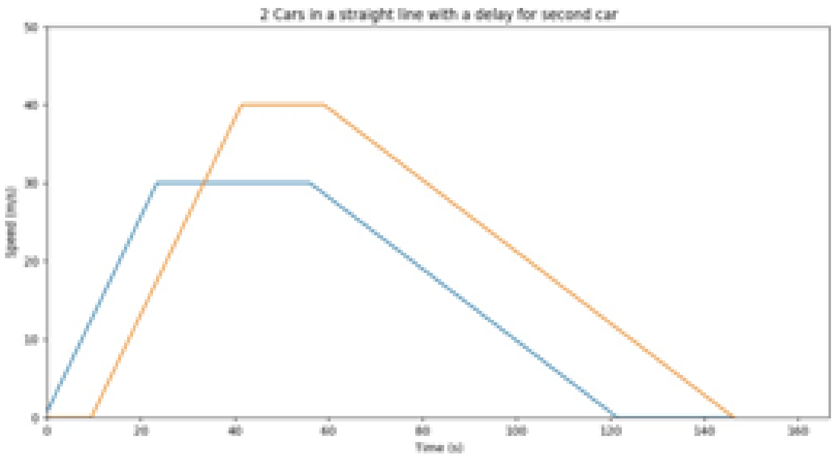

Fig. 6: Two cars straight movement model with braking

traffic system behaviour and better control on the param- eters of the experiments given the dimensions of the road stated in the Figure 2, the following parameter values were used:

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- V_{max} = 10m/s (maximum velocity)
- A_{max} = 9.9m/s^2 (maximum acceleration)
- D_{max} =9.9m/s^2 (maximum declaration) –
- M_{Car} = 1200kg (mass of car)
- F_m = 2200N (moving force)
- F_b = 1200N (braking force).
- C = 100 cars (intersection capacity)

IV-B Traffic Flow ModelThe traffic state

$$q = k.v_t \qquad (25)$$

(where q = volume, v = speed and k = density)

$$v_k = V_f - \frac{v_f}{k_{max}} \cdot k = v_f(1 - \frac{k}{k_{max}}) \qquad (26)$$

where v_f = free flow speed k_{max} = max traffic density from equation 1 and 2 , we have :

$$q_k = v_f \cdot (\frac{k - k^2}{k_{max}}) \qquad (27)$$

Traffic Flow Procedure itemize

- Autonomous and Human-driven vehicles are filled out, let's say HVs is on-road A and AVs, on-road B for simplicity. Road A is a straight road, and the HVs proceed without making any turns or bends.
- While road B merges or joins road A midway at node 8 after a curve and at an intersection.
- The AVs on approaching the curve, slow down con- siderably and, depending on how close they are to the intersection node 8, get a sense of how far the other car (HV) might be from the nearest RVC server or node.
- More importantly, the RVC server judges how far away both vehicles are from each other.
- The RVC then uses this information to grant RN to vehicle. It signals the AV to decelerate, keep moving or halt and displays a traffic signal for the human driver in the HV that prompts them to move or slow down or halt.
- As a result of this, other cars behind the car that slows down while communicating with an RVC node or due to traffic or while arriving at an intersection will also slow down to obey the safe-distance model by judging how far they are from the car ahead of them (which is where Inter-Vehicle Communication applies).

At this point, two vehicles from different roads obey the merging algorithm rule before fusing together and forming a platoon.

Vehicle movement algorithm

However, looking ahead on how the cars will decide on their movement to the target, each vehicle has a defined route by identifying all the node-id along its trajectory or path between the start node and the destination node, then analysing each of the nodes within each identified route according to a metric function value calculated for each identified route. The metric function may include parameters associated with each of the road nodes in the system, including a node-to-node distance parameter, traffic movement rules, crossing time, straight and curve movement model.

Algorithm 2: Car Movement Algorithm

function *Start to destination node movement*;
Assign vehicle type upon entering the intersection zone ;
for *Car movement is equal true* **do**
  $Car_{speed} = car_{velocity}$ multiply by the $car_{magnitude}$;
  $car_{velocity}$ on x_{axis} = speed multiply by cosine *theta*;
  $car_{velocity}$ on y_{axis} = speed multiply by *sin* ϑ.
  for *Car movement is equal to False:* **do**
    Decelerate by initialising the acceleration to zero;
    Stop
  end
  $car_{acceleration}$ on x_{axis} = 0.0;
  $car_{acceleration}$ on y_{axis} = 0.0;
  $Car_{speed} = car_{velocity}$ multiply by the $car_{magnitude}$;
  $car_{velocity}$ on x_{axis} = speed multiply by cosineϑ;
  $car_{velocity}$ on y_{axis} = speed multiply by $sin\vartheta$;
  for *All the next node is a Road node* **do**
    if node is a valid RoadNode object;
    check edges and append connected nodes to destination list;
    append this node to destination lists of connected node;
    Decelerate the car by multiplying the acceleration by 0;
    Stop
  end
end

During Platooning, the safe distance is maintained at 5m for AVs and 7m for HVs respectively.

For AVs: $n_{cars} = 2972.9/(5 + 4.5)$

$n_{cars} = 312.93$(approx.)

Therefore, $n_{cars} = 312$ cars for AVs

For HVs: $n_{cars} = 2972.9/(7 + 4.5)$

$n_{cars} = 258.51$ (approx)

Therefore, $n_{cars} = 258$ for HVs

Based on the above calculations, the road capacity for the different category of cars are calculated as follow:

- capacity for AVs = 396 cars
- capacity for HVs = 312 cars of the road

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The vehicle describes a curved circular path perfectly when the front wheels turn at an angle 'θ', while the car maintains a constant speed. For optimal performance, keep the car speed constant while the physics of turning is simulated at low speed and high speed. Car wheels can sometimes have a velocity not aligned with the wheel orientation, and this is because, at high speed, one observes that the wheel can be heading in one direction while the car body is still moving in another direction. This means a velocity component is at a right angle to the wheel, which generates frictions.

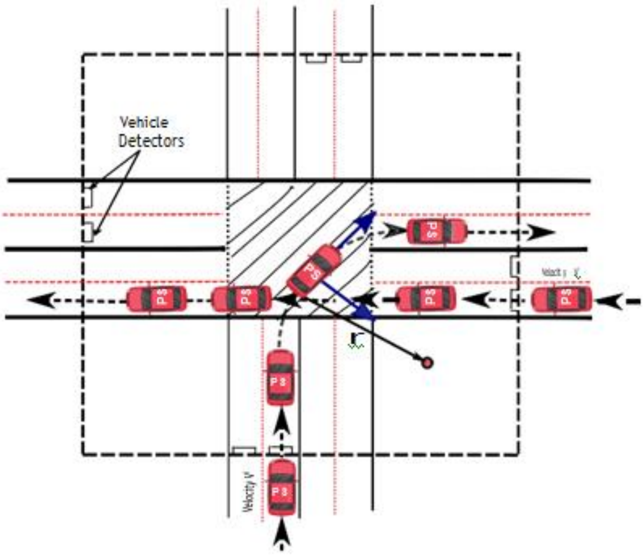

Fig. 7: Model of curved vehicle movement

capacity = max traffic volume equation $q = k.v_t$ density

$$k = \frac{1}{vT_h + L} \quad (28)$$

HA equation $C_h = q_{max} = \frac{v}{vT_h+L}$

IV-A0a VA

$$C_a = \frac{v}{vT_a + L} \quad (29)$$

When HV and AV are combined togethe, one will be able o generate the expected impact of AV on HV when implemented on a graph with varying parameters.

$$\frac{C_a}{C_h} = \frac{vT_h + L}{vT_a + L} \quad (30)$$

For traffic mix, n represent Av capacity cm is now dependent on nn represent the ratio of AV integrated into the road.

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$$cm = \frac{v}{nvTa + (1-n)vT_h + Lpkw} \quad (31)$$

Considering an additional distance by AV to a vehicle steered by HV to avoid harassment of drivers

$$cm = \frac{1}{n^2vTaa + n(1-n)vT_{ah} + (1-n)vT_{hx} + L} \quad (32)$$

Road traffic capacity estimation approach enumerate Shortening of headway between Av Speed of the vehicle group. The higher the speed at a constant density, the higher the traffic volume

Experiments

Collision Avoidance with Save Distance (CAwSD) Control Method

The collision avoidance techniques describe how the inter- action between traffics and the road system is represented as a chain of conflict points. There is no requirement for a phase assignment or cycle time compared with the traffic light control method. At each time, traffic arriving at the intersection check to know if there is another traffic sharing the collision points along its trajectory. The vehicle arriving parameters of position, speed, time are used to calculate which vehicle would be given way to the collision point in a real traffic situation. On arrival at the intersection, conflicting vehicles cannot enter the intersection simultaneously when they share the same collision point but can move concurrently on intersection as it provides that they do not share the same collision point simultaneously. This method takes an analytical approach by calculating the probability of traffics arriving at a conflict pointsimultaneously and the subsequent delay. When vehicles are sharing the same collision point from a different route, they might eventually collide. Naturally, the major problem will arise from human-controlled vehicles as their behaviour is stochastic, and they are more prone to errors in prediction. Consideration is based on two types of vehicles which varies in their maximum velocities; slow (V_s) and fast (V_f) which denotes the fraction of the slow and fast vehicles, respectively.

Reservation Nodes (RN) Control Method

This RN technique described as proposed is a reservation- based algorithm that schedules the vehicles' entrances into the intersection space by reserving a collision cell to one particular vehicle every instance. The process of using the intersection collision point is based on a request, and reservations are made based on a predefined protocol before vehicles can pass. This efficient schedule is formulated to calculate the vehicle's relative speed to the reservation cell and assign the cell a

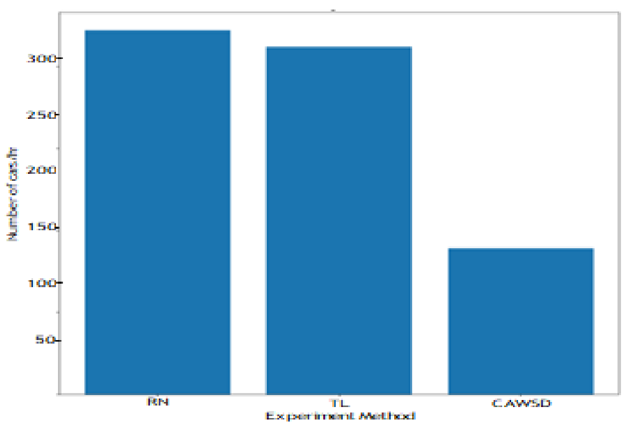

Fig. 8: 50% Capacity

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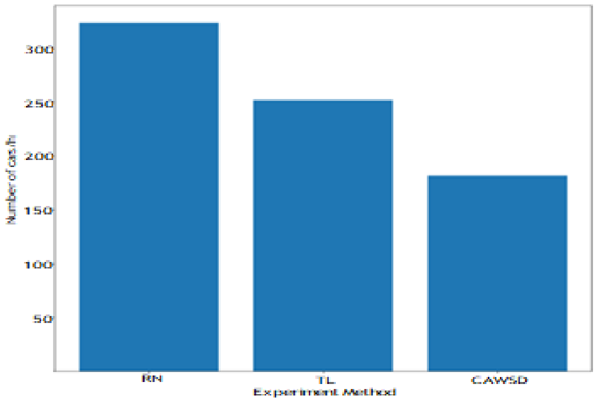

Fig. 9: 100% Capacity

vehicle sequence. Car's distances to other cars before it is calculated and the minimum distance to the reservation node is found. After this, the environment's central collision avoidance system signals the car to brake, decelerate, and, if not, to keep going. The safe vehicle distance, reaction time, and relative distance model are proposed to maximise the delay and reduce the probability of accidents at cross collision points. This traffic management strategy is a decentralised strategy where drivers and vehicles communicate and negotiate for access to the cross collision point based on their relative distance and access priority to the intersection.

RESULT DISCUSSION AND EVALUATION

To test the hypothesis, which states that vehicles move more efficiently when the road intersection cells are reserved. With the adjustment of the Avs inter-vehicle distance, the perfor- mance of HVs increases, and the vehicle's occupation time in- creases with an increase in the ratio of human-driven vehicles in a car-following model. An analysis of variance in the time analysis of different ratio simulation tests is conducted fig. 11 which gives statistics for the variation in time occupancy with vehicle mix ratio. This is due to the difference in the behavioural aspects of human-driven and driver-less cars.

Stability:

In the contest of this thesis, traffic flow stability as represented in Figure 12 is analysed with the number of traffic braking in response to the volume for the different control methods under the same condition. The traffic flow efficiency at road intersections depends partly on traffic flow stability which is analysed with the number of braking associated with a control method. The traffic stability could be accessed from the uniformity of the flow speed. It is a state where all cars move with an identical safe distance and optimal velocity. A speed fluctuation impacts the vehicle flow stability when in motion. It is observed that the different traffic control methods are associated with different stability levels. The vehicle safe distance process involves deceleration and acceleration, which causes a perturbation in the stability of the overall flow.

Discussions

The proposed methodology for analysing the impact of mixing AVs and HVs will help determine the integration pattern of an autonomous vehicle for the mixed vehicle transition period. In addition, traffic engineers can use the models developed in this study to estimate the capacity of a road intersection in a mixed-traffic environment. This investigation discovered that autonomous vehicles are much safer, time-efficient, and help decongest roads. It is evident from Figure 9 that inter- section efficiency increases with an increase in the ratio of an autonomous vehicle. This is because AVs combine and interpret their surroundings' sensory data to identify appropri- ate navigation paths, obstacles, and appropriate signage. The

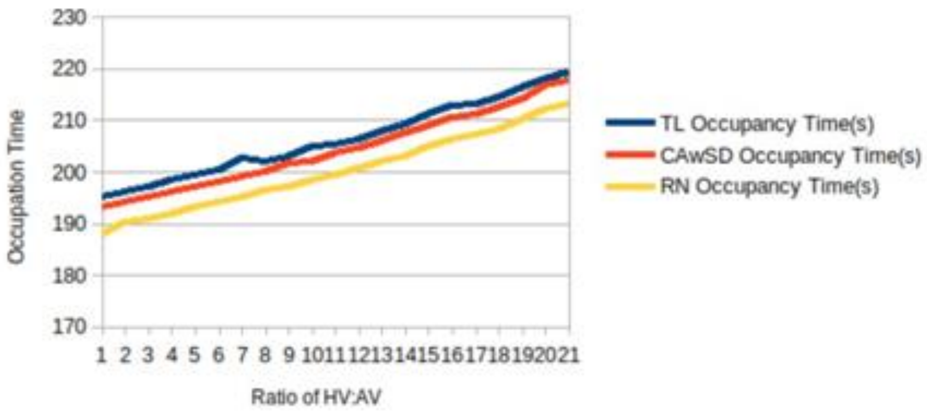

Fig. 10: Vehicle Occupancy Matrix

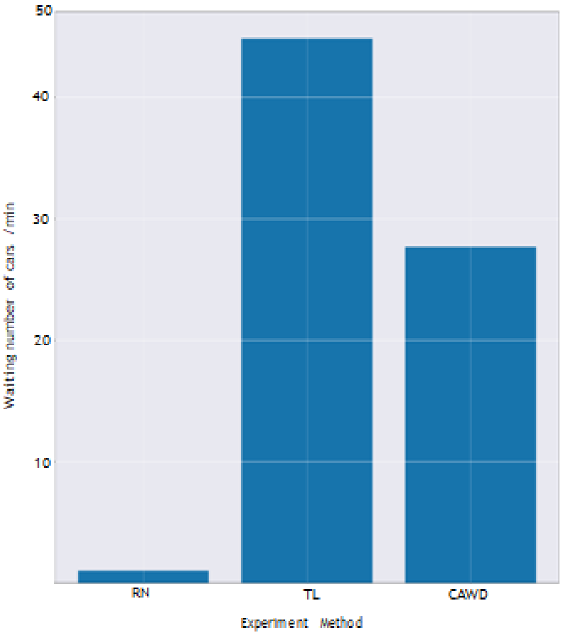

Fig. 11: Travel time delay

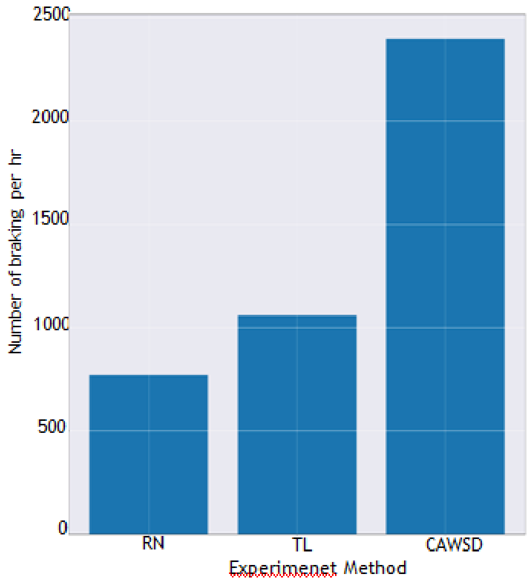

Fig. 12: The Number of Braking Occurred

measure of intersection efficiency is conducted using traffic parameters performance metrics relating to throughput and delay. The Performance for different traffic control strategies is analysed using different parameter values based on simulations to see the effect of their values on the system's throughput performance.

The values of the vehicle mixed ratio were increased in every simulation to establish the impact of the ration variation to guide the integration pattern. The Performance of different ratio cases is analysed and compared under the three traffic control methods. This trend makes the HV benefit inefficiency from the AV in a co-existence scenario.

Contributions to Knowledge

In the cause of this work, some new knowledge based on the previously available knowledge has been created. They include

- Guide to mixing traffic integration pattern
- Describe 2-D mix-traffic behaviour effectively
- Increases HVs performance when AV inter-vehicle dis- tance is adjusted
- A speed harmonisation method for mixed traffic
- Serves as a mixed driving behaviour model

CONCLUSION

The novelty of the cell reservation method is that it tackles vehicle collision by assigning individual vehicles sequentially to the intersection reservation cells; secondly, by addressing a 2-dimensional traffic flow problem in heterogeneous traffic using an existing 1-dimensional car-following model compen- sating for unexpected changes in human-driven vehicles. The algorithm controls the mix-traffic variable speed bottleneck to smooth the traffic flow effectively. Using the acceptance safe distance model, this proposed model entails interpolating human-driven and autonomous vehicles' behaviour with inter- vehicle distance adjustment. The above strategy has been implemented on the developed model and calibrated with realistic parameters, vehicle distribution, and vehicle ratio mixes. The concept of the cell reservation method appears to be efficient as it centrally synchronises both AH and HV parameters simultaneously. The feature of real-time traffic parameter sharing in AV makes predicting vehicle velocities in managing traffic possible. This work provides scientific support for the integration plan of autonomous vehicles and a mixed traffic control system. It will improve mixed-traffic efficiency, mitigate traffic congestion at road intersections, and provide technical support for future research in traffic control systems. A mix of human-driven and automated vehicles is gradually becoming the norm around the world. The large- scale advancement and application of new technologies in vehicle and traffic management will greatly promote urban traffic control systems and support a full-scale intelligent transportation system.

The effect of driverless cars on human-driven cars at a merging road intersection using inter-vehicle distance has been investigated using the cell reservation method. The vehicle occupation time was observed at a merging road, and mixed mathematical relations relating to occupation time of different vehicle types were developed. From our findings, a vehicle ratio occupancy pattern was developed to serve as a valuable tool for evaluating the integration process of autonomous cars on the road. The key conclusions arising out of this study were:

1) Traffic flow efficiency increases when road intersection cells are reserved.
2) It has been established that the integration of autonomous cars on the road will positively impact the efficiency of human-driven cars.
3) The vehicle occupancy time depends on the traffic mixed ratio.

Summary

Related traffic technologies have been developed to support the autonomous vehicle integration process, which is essen- tial for effectively utilizing autonomous vehicles' benefits. A Mathematical model describes the two types of vehicle mixed behaviour to the occupation time with the traffic flow in a merging T-junction. It has been observed that the vehicle occupation time in a mixed traffic flow increases with a higher ratio of an autonomous vehicle. Also, the throughput increases by adjusting the inter-vehicle distance. The proposed method- ology will be helpful to determine the integration pattern of an autonomous vehicle for the mixed vehicle transition period. Also, the models developed in this research can be used by traffic engineers to estimate the capacity of a merging road intersection in a mixed traffic environment. The investigation discovered that autonomous cars are much safer, time-efficient, and helps de-congest roads. The work done so far represents steps towards a system of safe and efficient mixed traffic management schemes to aid in implementing a mixed traffic integration environment. It is an essential goal as reliance on these autonomous cars is ever increasing, the objectives of this project have been identified, and autonomous cars have come to stay and co-exist with human-driven cars inevitably. Towards this end, a promising method of managing traffic mix is realisable. The generated experimental results promise to produce a traffic schedule that will sustain state-of-the-art mixed traffic environment management.

The results obtained are based on an intersection capacity of 100 cars with a varying ratio mixed of autonomous and human-driven cars. Looking at the result in **??**, it is observed that the obtained result shows that an increase in the ratios of autonomous cars is inversely proportional to a decrease in the simulation time, and this supports the research hypothesis. Hence, we conclude that the intersection efficiency increases with the increase in the ratio of autonomous cars to human- driven cars, which shows that autonomous cars improve traffic efficiency. We have examined the potential impact of integrating autonomous cars to co-exist with human-driven cars on the road. Our assessment was carried out under parameters that are in consonance with the realistic operating environment of the city traffic flow system. Modern traffic lights use real-time event-driven control models but are designed to model a homogeneous traffic system. However, the AVHV control model supports a traffic schedule with a traffic signal light to control HVs and wireless communications for controlling AVs. This control method involves the dynamic representation of a mixed-traffic system at road intersections to help plan, design, and operate traffic systems moving it through time.

The research direction taken was the utilization of reservation cells to improve the traffic flow performance. By reserving any of the 12 intersection reservation cells for a vehicle at every instance, the traffic flow throughput increases better than when using traffic lights or collision avoidance methods. The obtained results demonstrate that the cell reservation strategy has about 18.2% performance margin.

Future Research Direction

Car-following model appears to be an efficient and cost-effective method of improving mixed traffic performance for autonomous vehicle emergence. The following significant areas need some research improvement from future researchers:

- The combined effect of all safe distance and reaction time distribution issues makes it tough to estimate the critical distance headway in a mixed environment.
- Because of the combined effect of all safe distance and reaction time distribution issues, determining the critical and efficient safe distance in a mixed environment is challenging and needs to be investigated.
- Mixed traffic fundamental models such as drivers' behavior and social force models could be integrated into car-following models to efficiently address the behavioural challenges of human and autonomous vehicle co-existence.
- The mixed traffic situations necessitate a re-look into the factors that influence the safe distance behaviour in a car-following model.
- Consideration of varying vehicle lengths to reflect the actual city traffic situation is essential for feature research direction.

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