Integration of Autonomous and Human-Driven Cars
Review Meeting

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1 Status Overview

In the following, I describe the advances made in the last review period (from June 2018 to March 2019). During this period, my program was suspended for two months due to health challenges followed by a change of supervisor in December 2018.

However, as there were substantial changes since the change of my supervisor, the work conducted in this period describes my current status – the previous effort was overhauled.

1.1 Research Progress

After my review meeting of 25/05/18, steps were taken to address the feedback from the review committee – nine items were raised by the committee (see Appendix A).

The following progress was made:

(a) Clarification of the research goal: We define research strategies and implementation steps starting with the development of a physical model of traffic simulator

(b) Definition of a methodological research approach: Preliminary experimental research was conducted with a randomly moving vehicle that forms a baseline for our research.

(c) Background research: We developed a 10-page document summarizing the traffic intersection management techniques with their pros and cons

(d) Model creation: a car motion model was developed based on physics principles.

(e) Simulator prototype: A Python3 prototype has been developed. Is uses the *continuous simulation* approach approximated with discrete time steps. While still premature, it showcases how to build an environment of intersections, uses a simplified model, and provides debugging output to understand the behaviour of cars using Scalable Vector Graphics (SVG) reporters combined with other functions.

1.2 Personal Advances

RRPD Courses: I have attended several RRPD courses since the beginning of my Ph.D. program. Table 1 shows a list of those RRPD courses I attended with dates and those once already booked for in this current academic session.

Technical skills Since the last review period, I have improved my technical competences by training on:

- Python3 for programming
- LaTeX for typesetting

Table 1: List of RRDP courses Taken

Course title	Date
An Essential Guide to Critical Academic Writing	2018/10/25
Ensuring confirmation of registration	2018/11/06
How to avoid plagiarism	2018/11/14
How to write a paper in the physical sciences	2019/03/27
Statistical modelling and graphics using R	2019/01/17
How to summarize your research in 3 minutes	2019/03/08
Academic teaching Mentoring	On-going

- Overleaf for sharing documents
- A Linux Desktop for development
- Inkscape for drawing scalable vector diagrams
- Git for version management

I'm now using the aforementioned tools to improve my productivity.

Other activities At the beginning of April, I gave my first presentation about my research as part of the Open Source AI workshop[1]. Preparing and giving a technical presentation about my research was a rewarding experience.

1.3 Personal Reflection

While reflecting on my experience in the course of doing this research, I came to realize that though it is very challenging but interesting once one starts producing results which are a reflection of the expected outputs. The process needs resilience and enjoyable at least in the subject area. However, I am passionate about learning things that concern to my major and future career to be able to contribute a novelty in the sector. This informs why I came into this process optimistic to find something new. Though I originally have an idea in traffic management, after spending some time researching about the current state of the art, I can now say I have something new to add which is futuristic.

2 Research Approach

Pricing of road-spacetime and slot reservations for vehicles is proposed. Airplanes use landing slots pricing to avoid conflict, what if AVs and HVs did the same thing in addition to platooning [17, 7, 23, 43, 8]. Figures 1 and 2 represent the intersection area for the scheme and vehicle reservation tiles respectively

2.1 Research goals

Our research main goals are summarized as follows:

- To model a road junction so as to investigate a strategy for safety and to improve traffic flow when a mix of autonomous and human-driven vehicles are there
- Develop and integrate two traffic models of HVs and AVs into one scheme for mix traffic.
- Investigate the performance of the method based on the percentage mix of HVs and AVs to serve as a guide for the transition period.

[1] `https://ossg.bcs.org/blog/event/open-source-ai-april-2019/`

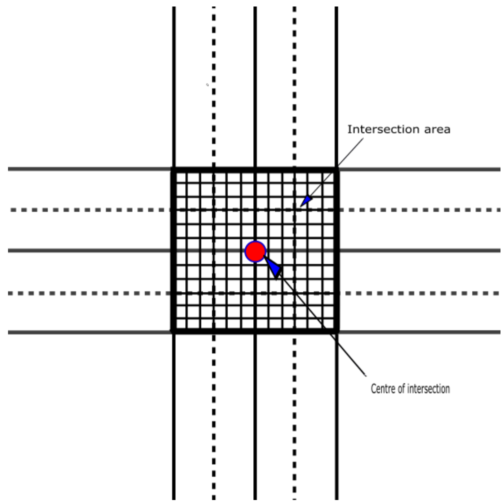

Figure 1: Intersection area

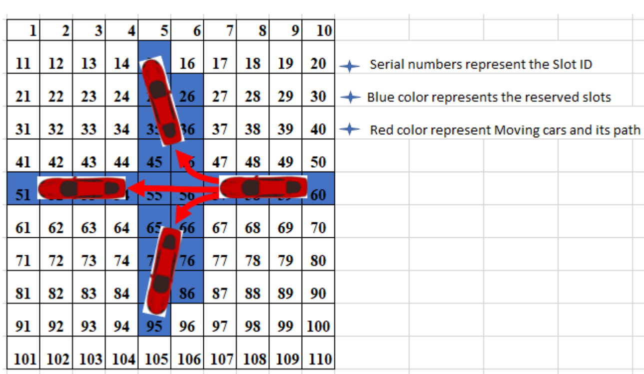

Figure 2: Reservation slot

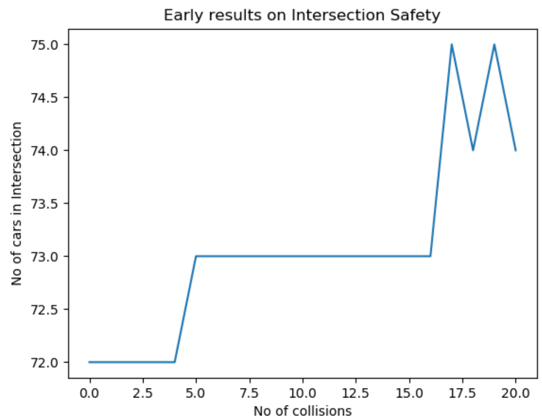

Figure 3: Graph of no of cars versus no of crashes

2.2 Research Considerations

- To analyse such a hybrid traffic scenario, we model HVs with the light, while the AVs are controlled by an MPC.
- The car dynamics was developed using the Newton law of Physics
- The main constraint for safety is the cross-collision point but the continuous time simulator will check for collisions every time step (e.g., 50 ms)
- Full behavioural freedom was granted to the human-driven vehicle
- The car position, trajectory, speed, time is modelled. We considered the parameters that define the operation of each vehicle category with existing traffic infrastructure.

3 Early Results

A first test was conducted to showcase the use of the simulator and to demonstrate the extraction of metrics from it. In this primitive scenario, cars were randomly moving within the intersection. Figure 3 shows a plot of the number of vehicle collisions against the number of vehicles in an intersection, at each time interval the number of cars in the intersection was taken in relation to the number of collisions. From here we will categorize the cars based on HV and AV, add a behavioural feature like - obstacle maneuvering and other feature, and review its safety and efficiency.

4 Research Plan

Research plan and time table for the next 6 months is as shown in figure 4

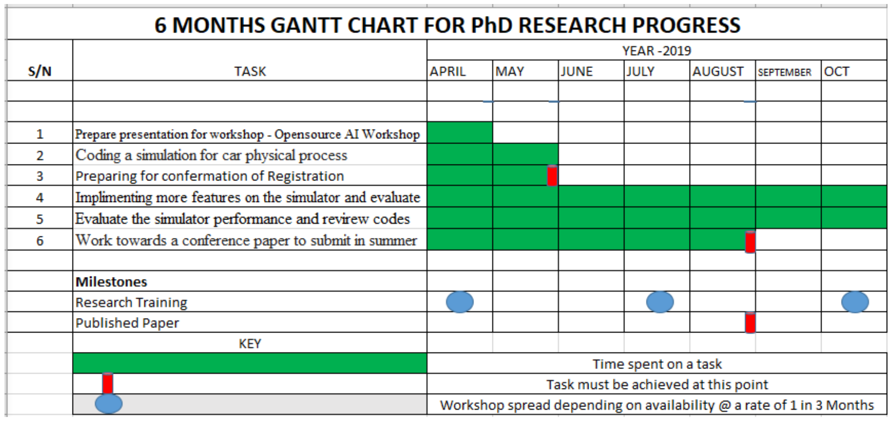

Figure 4: Research Plan and Time Table for the Next 6 Months

The following is an excerpt of the various created documents; it serves the purpose of providing the reviewers with a deeper background and clarifies the current research approach.

5 Background

The current research direction on establishing intersection safety mostly focuses on the situation where all vehicles are fully autonomous. However conventional vehicles are human-driven and will need to transition through regimes featuring a varying proportion of human-driven and autonomous vehicles ratio before realizing such a fully autonomous future [27, 42]. Based on the foregoing, we need to address the safety issues in a hybrid system for the coexistence of human and autonomous vehicles as represented in fig 5. The update from incidents involving autonomous vehicles has already highlighted the need to research directed towards the safety of autonomous vehicles co-existing with human-driven vehicles[28, 49, 31, 32, 33, 52, 29, 40, 47, 19]. The transition to the autonomous driving system has generated various expectations ranging from the decrease in traffic accidents/incidence, decrease in traffic congestion, roads comfort, less emission, less fuel consumption to a shortage of drivers. Within this envisaged transition period of coexistence of human-driven and autonomous vehicles, there is a need for a robust technology to be put in place to drive the process. Under these conditions, it will not be too feasible for the human car drivers to predict the movements of an autonomous car and vice versa.

There has been an established worry over the road traffic control system due to constant traffic congestion caused by increased population and urbanization. However, it has become hard for traffic controllers to provide safe and efficient traffic movement on the streets at the same time. The interconnections of different road paths make intersections, where the possibilities of vehicle collision are critical without good control measures [16, 15]. The Efficient use of the existing road infrastructure by innovative intersection management and control is a feasible solution for the cities where further construction and expansion of roads are difficult. Conventional vehicles have road traffic intersection control measures of using traffic light system, while the driver-less vehicles access road facilities via vehicle-vehicle and vehicle-infrastructure communication, while Human-driven vehicles involve driver-to-road infrastructures communication. The introduction of new technology is not automatic, and the current technology will be replaced by news one gradually, the integration of driver-less vehicle movement parameters with that of the human-driven vehicle to midwife the smooth transition to a fully automated or smart city is necessary. The Gradual transformation to a fully automated road transport system can seamlessly be achieved by integrating the attributes of automated vehicles into the human-driven

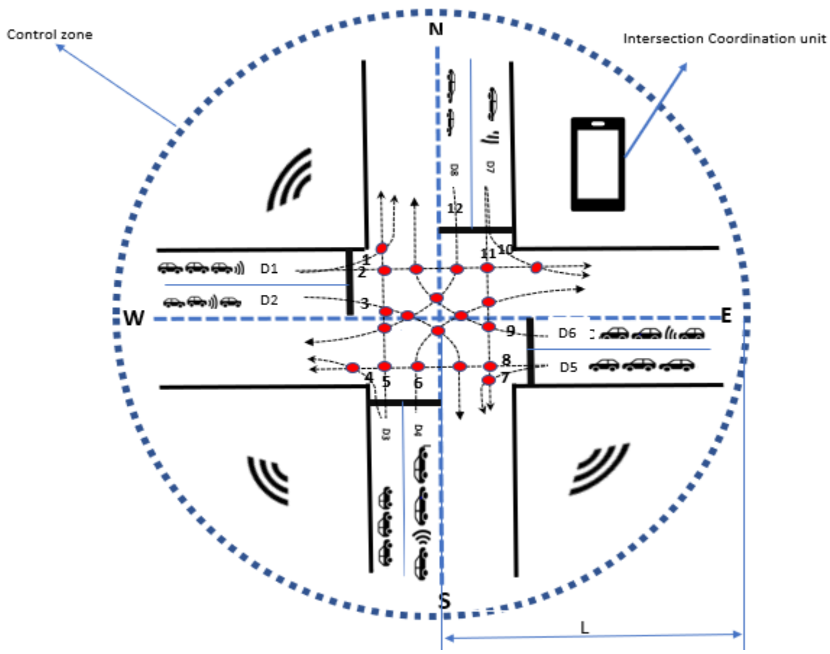

Figure 5: Crossroad intersection with double lanes

vehicles bearing in mind the human driver's attribute on road (tracking user's behaviour) which is stochastic in nature.
An early approach to automation in vehicles started with the Automated Highway System (AHS) research program[18, 18, 32, 48, 4], it was focused on the improvement of the capacity and the safety of the highway traffics. The advent of automated vehicles led to the birth of vehicle-to-vehicle and vehicle-to-infrastructure communication which inadvertently led to road intersection settings without traffic lights but has smooth and efficient flows of traffic with good safety measures. There is no doubt in saying that connected and automated vehicles (CAVs) have the potential to improve safety by reducing and mitigating traffic accident with seamless flow of traffic and good safety measures [41, 40, 29, 1].

5.1 Classification of Techniques for Traffic Management

Based on the current state of the art in vehicle technology and road traffic management as it relates to human-driven and driver-less vehicles, we have two main methods to controlling traffic flow within an intersection, this includes:

- **Traffic signal light**: This consists of the installation of signal lights that control traffic streams by using different light indicators. Its primary aim is to prevent simultaneous movement of two or more incompatible traffic streams by assigning and canceling the right-of-way to a particular traffic stream [38, 46, 21, 44, 39].
- **V2V and V2I Communication**: This involves a traffic intersection control scheme without lights, in this case, autonomous or semi-autonomous vehicle accesses an intersection using vehicle to vehicle (V2V) or vehicle-to-infrastructure (V2I) communication means [22, 14, 5, 36, 45].

However, we categorize the above two methods of implementing a traffic scheme into two distinct strategies based on the two underpinning factors: centralized and decentralized approaches.

5.1.1 Centralized approach

In the centralized method as reflected in table 1, there is at least one factor in the traffic scheduling characteristics or features that are globally decided for all vehicles in the scheme by a single central controller. When a central decision is made for at least one of the factors, it is called a centralized approach [35, 30, 3, 42].

5.1.2 Decentralized approach

In this category, all the vehicles are treated as autonomous agents but use the interaction between (vehicle-to-vehicle and vehicle-to-infrastructure) to maximize efficiency in communication and control. In this case however, each individual agent (vehicle) obtains information from other vehicles and or road-side infrastructure to enhance performance criteria like safety, efficiency and travel time before access sing the intersection [9, 12, 51, 13, 16, 24].
The correlation used in intersection control with the underpinning technologies with the evaluation of its performance matrix is as shown in table 2. Each matrix cell defines the performance index of various methods and also identifies which characteristics are to balance. This matrix presents a detailed picture for consideration in the development of a robust hybrid-based system with some degree of safety, performance, costing and adaptability.

The classification categories are based on the below column headers:

- **Method**: the control or strategy to orchestrate the traffic flow, i.e., the rules deciding which car may drive or has to wait?
- **Vehicle Type**: For autonomous vehicle (AV) and or human-driven vehicle (HV): the type of vehicle it is controlling: Hv is a human-driven vehicle while Av refers to autonomous vehicles
- **Performance index**: This is a measure of intersection efficiency: where +, ++ means good and best performance respectively.
- **Communication means** Signal, vehicle to vehicle (V2V) or vehicle to vehicle to infrastructure (V2I). This represents the means of intercommunication where signal, V2V and Vi means traffic light signal, vehicle to vehicle and vehicle to infrastructural communication respectively.
- **Fairness**: This feature takes care of the waiting time among vehicles in which case, the principle of FIFO is obeyed at the point of intersection less there is a priority request from an emergency vehicle.
- **Safety**: the safety of the control in avoiding conflict of the vehicle or accident is very important
- **Scalability**: This is the capability or potentials of a system or to be expanded to be able to address more complex traffic control situation with a different type of road network and size
- **Cost**: This is the cost of implementation.
- **Complexity**: This is described as the amount of time it takes to run an algorithm, therefore the time this has to do with how complex the control can be implemented at real time and how complex the errors can be controlled.

Table 2 and 3 shows a matrix of classification used to quantify the quality of each feature in relation to a traffic management strategy, it shows the statistical impact of the on the column header item. The signs: 0, -, +, −, and ++ are used in this order to show statistical impact levels of non-impact, negative impact, positive impact, major negative impact, and major positive impact respectively.

Table 2: Categorization based on Centralized Intersection Control

Method	Vehicle Type	Communication	Performance	Fairness	Safety	Scalability	Cost	Complexity
Fuzzy-based	AV	V2V	++	++	++	++	+	−
Automatic merge control	AV	V2V and V2I	+	++	++	+	−−	+
Vehicle platooning	A	V2V and V2I	+	+	+	++	+	−−
	H	Signal	+	++	+	++	−	+
Cooperative adaptive cruise control	AV	V2V	+	+	+	++	++	+
Game theory-based intersection control	AV	Signal	+	++	++	+	+	−
Genetic Algorithm	AV	Signal	+	++	++	+	++	+
Optimization approach	AV (CVIC)	V2V and V2I	+	++	+	++	++	−
	HV (MPC)	V2V and V2I	++	++	++	+	++	−
	AV (Multi-agents)	signal	+	++	+	+	−	−
Safe velocity and acceleration	HV and AV	V2V	+	++	++	++	++	++
Buffer-assignment based coordinated	AV	V2V and V2I	+	++	++	++	++	++

Table 3: Categorization based on Decentralized Intersection Control

Method	Vehicle Type	Communication	Performance	Fairness	Safety	Scalability	Cost	Complexity
Job scheduling	AV	Signal	+	+	++	+	−	−
Optimization 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 slot with HV and AV	AV and HV	Signal,V2I and V2V	−−					
Virtual platooning	AV	V2V	++	++	++	+	+	−
Space-time slot reservation	AV and HV	Signal,V2I and V2V	**	**	++	**	**	+

6 Model Design

To analyse such hybrid traffic scenario with reference to figures 1 and 2 , we model HVs with navigation freedom and a worst-case scenario using a traffic light systems while the autonomous vehicle which can obey a stringent rule is centrally controlled using an intersection control unit with a strict respond to instruction at real time. In the design, it is important to consider the parameters that define the operation of each category of the vehicle without much deviation from the existing traffic infrastructure.
However, the differences between HVs and AVs can be summarized under the following four heading:

- **Communication**: Autonomous vehicles are associated with a two-way communication system while human drivers are one way
- **Control Efficiency**: Autonomous observe a set of predefined rules, while human-driven vehicles have freedom. [31].
- **Complexity in the set of rules**: Autonomous vehicles are protocol-based design(movement), while human nature control in HVs.
- **Response Time**:AVs response to instructions (emergency situations or braking) are automatic while HVs response time is 2.3 seconds[34].This delay can be dangerous in an emergency.

6.1 Vehicle Dynamics Model

The model of underlying vehicle dynamics is purely based on the principle of Newton's laws of Physics. The model describes the following forces:

- Road-tire friction monitoring systems
- Acceleration
- Deceleration
- Force at a Curve

6.2 Frictional force

The frictional force exerted on the tire of a vehicle "Fr" is the product the coefficient of static friction "μ", the mass "m" and the acceleration due to gravity "g"

$$\mathrm{Fr} = \mu \cdot m \cdot g \ (in\ Newtons) \tag{1}$$

6.3 Vehicle Acceleration

The acceleration "a" of a vehicle is determined by the components of net force "F" and the car's mass "m"

$$F = m \cdot a \ (in\ Newtons) \tag{2}$$

Therefore

$$a = \frac{F}{m} \left(in\ \frac{meters}{seconds^2} \right) \tag{3}$$

6.4 Vehicle Deceleration

Deceleration which is the opposite of acceleration or otherwise called negative acceleration: The deceleration force is due to the breking force generated between the tire and the road surface. This force is a product of the coefficient of friction "μHf" and the normal force 'Fn' With reference to equation 2,

$$\text{Fr} = \mu Hf \cdot Fn = uHf \cdot g \cdot m \ (in\ Newtons) \tag{4}$$

$$\text{deceleration: } a = -uHf \cdot g \left(in\ \frac{meters}{seconds^2}\right) \tag{5}$$

6.5 Force at a Curve

The centripetal force "Fpetal" is acting on the vehicle towards the centre direction of the curve at an intersection. This is the force that acts on a vehicle moving in a circular path At this stage, keeps speed constant, assume no over-steering, "r" is the radius of the curve, the tangential velocity "v", the vehicle mas "m"

$$\text{Fpedal} = m \cdot v^2/r \ (in\ Newtons) \tag{6}$$

$$\text{To avoid slipping out of the curve, solve for } Fr >= FPedal \ (in\ Newtons) \tag{7}$$

$$v <= sqrt(uHf \cdot g \cdot).\ (in\ meter\ per\ second) \tag{8}$$

7 Ethical issues associated with the integration of HV and AV

the ethical challenges associated with AVs are summarized as shown below:

- **Privacy Issues**: Running on sophisticated and advanced onboard computing systems, its communication standards are open for hacking [2, 10]
- **Morality issues** - the dilemma of taking a decision, for example Self trolley problem [37, 11]
- **Safety Issues** ISO 26262 specify the safety standard for road vehicles, what of AVs? google car test 1milion Kilometre, is this ok? [26, 20, 25, 6]
- **Trust-** How trustworthy are the data source for navigation and route calculation are? [50]
- **Transparency-** Transparency is a prerequisite for ethical engagement in AVs, while respecting copyright, corporate secrets, security
- **Reliability-** What if there is no network of the sensor(s) fail? Possibility for having a threshold to determine car reliability
- **Responsibility and Accountability-** in case of accident or incident, how does one determine responsibility [29, 1]
- **Quality Assurance Process-** What is the overall quality and lifetime of components, quality control measures for transparent software engineering process

8 Some Open Source and Interface for AVs

There is some open source interface platform for autonomous vehicle development, they include:

- Apollo - simulator engine

- Autoware - open city driving in 3D maps
- EB robinos and EB robinos Predictor Elektrobit - combine software's together
- NVIDIA® DriveWorks - Software kits -goes from detection to localization to planning to visualization.
- OpenPilot - controls brake and steering system

References

[1] Rusul Abduljabbar, Hussein Dia, Sohani Liyanage, and Saeed Bagloee. Applications of artificial intelligence in transport: An overview. *Sustainability*, 11(1):189, 2019.

[2] Mani Amoozadeh, Arun Raghuramu, Chen-Nee Chuah, Dipak Ghosal, H Michael Zhang, Jeff Rowe, and Karl Levitt. Security vulnerabilities of connected vehicle streams and their impact on cooperative driving. *IEEE Communications Magazine*, 53(6):126–132, 2015.

[3] James M Anderson, Kalra Nidhi, Karlyn D Stanley, Paul Sorensen, Constantine Samaras, and Oluwatobi A Oluwatola. *Autonomous vehicle technology: A guide for policymakers.* Rand Corporation, 2014.

[4] Stefan Annell, Alexander Gratner, and Lars Svensson. Probabilistic collision estimation system for autonomous vehicles. In *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, pages 473–478. IEEE, 2016.

[5] Tsz-Chiu Au, Shun Zhang, and Peter Stone. Autonomous intersection management for semi-autonomous vehicles. *Handbook of transportation*, pages 88–104, 2015.

[6] John Birch, Roger Rivett, Ibrahim Habli, Ben Bradshaw, John Botham, Dave Higham, Peter Jesty, Helen Monkhouse, and Robert Palin. Safety cases and their role in iso 26262 functional safety assessment. In *International Conference on Computer Safety, Reliability, and Security*, pages 154–165. Springer, 2013.

[7] Simeon Craig Calvert, TH A Van Den Broek, and Martijn van Noort. Modelling cooperative driving in congestion shockwaves on a freeway network. In *Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on*, pages 614–619. IEEE, 2011.

[8] Eric Chan, Peter Gilhead, Pavel Jelinek, Petr Krejci, and Tom Robinson. Cooperative control of sartre automated platoon vehicles. In *19th ITS World CongressERTICO-ITS EuropeEuropean CommissionITS AmericaITS Asia-Pacific*, 2012.

[9] Rutger Claes, Tom Holvoet, and Danny Weyns. A decentralized approach for anticipatory vehicle routing using delegate multiagent systems. *IEEE Transactions on Intelligent Transportation Systems*, 12(2):364–373, 2011.

[10] Lisa Collingwood. Privacy implications and liability issues of autonomous vehicles. *Information & Communications Technology Law*, 26(1):32–45, 2017.

[11] Ezio Di Nucci. Self-sacrifice and the trolley problem. *Philosophical Psychology*, 26(5):662–672, 2013.

[12] Kurt Dresner and Peter Stone. A multiagent approach to autonomous intersection management. *Journal of artificial intelligence research*, 31:591–656, 2008.

[13] Junji Eguchi and Hiroyuki Koike. Discrimination of an approaching vehicle at an intersection using a monocular camera. In *Intelligent Vehicles Symposium, 2007 IEEE*, pages 618–623. IEEE, 2007.

[14] David Fajardo, Tsz-Chiu Au, S Travis Waller, Peter Stone, and David Yang. Automated intersection control: Performance of future innovation versus current traffic signal control. *Transportation Research Record*, 2259(1):223–232, 2011.

[15] Yiheng Feng, K Larry Head, Shayan Khoshmagham, and Mehdi Zamanipour. A real-time adaptive signal control in a connected vehicle environment. *Transportation Research Part C: Emerging Technologies*, 55:460–473, 2015.

[16] Michel Celestino Paiva Ferreira, Ozan Tonguz, Ricardo Jorge Fernandes, Hugo Marcelo Fernandes DaConceicao, and Wantanee Viriyasitavat. Methods and systems for coordinating vehicular traffic using in-vehicle virtual traffic control signals enabled by vehicle-to-vehicle communications, March 3 2015. US Patent 8,972,159.

[17] Siyuan Gong and Lili Du. Cooperative platoon control for a mixed traffic flow including human drive vehicles and connected and autonomous vehicles. *Transportation research part B: methodological*, 116:25–61, 2018.

[18] Roberto Horowitz and Pravin Varaiya. Control design of an automated highway system. *Proceedings of the IEEE*, 88(7):913–925, 2000.

[19] Xiaowei Huang, Marta Kwiatkowska, Sen Wang, and Min Wu. Safety verification of deep neural networks. In *International Conference on Computer Aided Verification*, pages 3–29. Springer, 2017.

[20] Peter Kafka. The automotive standard iso 26262, the innovative driver for enhanced safety assessment & technology for motor cars. *Procedia Engineering*, 45:2–10, 2012.

[21] MAS Kamal, Jun-ichi Imura, Akira Ohata, Tomohisa Hayakawa, and Kazuyuki Aihara. Control of traffic signals in a model predictive control framework. *IFAC Proceedings Volumes*, 45(24):221–226, 2012.

[22] Md Abdus Samad Kamal, Jun-ichi Imura, Tomohisa Hayakawa, Akira Ohata, and Kazuyuki Aihara. A vehicle-intersection coordination scheme for smooth flows of traffic without using traffic lights. *IEEE Trans. Intelligent Transportation Systems*, 16(3):1136–1147, 2015.

[23] Bidoura Khondaker and Lina Kattan. Variable speed limit: A microscopic analysis in a connected vehicle environment. *Transportation Research Part C: Emerging Technologies*, 58:146–159, 2015.

[24] Steffi Knorn, Alejandro Donaire, Juan C Agüero, and Richard H Middleton. Passivity-based control for multi-vehicle systems subject to string constraints. *Automatica*, 50(12):3224–3230, 2014.

[25] Philip Koopman and Michael Wagner. Challenges in autonomous vehicle testing and validation. *SAE International Journal of Transportation Safety*, 4(1):15–24, 2016.

[26] Philip Koopman and Michael Wagner. Autonomous vehicle safety: An interdisciplinary challenge. *IEEE Intelligent Transportation Systems Magazine*, 9(1):90–96, 2017.

[27] Akisue Kuramoto, Mohammad A Aldibaja, Ryo Yanase, Junya Kameyama, Keisuke Yoneda, and Naoki Suganuma. Mono-camera based 3d object tracking strategy for autonomous vehicles. In *2018 IEEE Intelligent Vehicles Symposium (IV)*, pages 459–464. IEEE, 2018.

[28] Scott Le Vine, Alireza Zolfaghari, and John Polak. Autonomous cars: The tension between occupant experience and intersection capacity. *Transportation Research Part C: Emerging Technologies*, 52:1–14, 2015.

[29] Sheng-Hao Lin and Tsung-Yi Ho. Autonomous vehicle routing in multiple intersections. In *Proceedings of the 24th Asia and South Pacific Design Automation Conference*, pages 585–590. ACM, 2019.

[30] Todd Litman. *Autonomous vehicle implementation predictions*. Victoria Transport Policy Institute Victoria, Canada, 2017.

[31] Xi Liu, Ping-Chun Hsieh, and PR Kumar. Safe intersection management for mixed transportation systems with human-driven and autonomous vehicles. In *2018 56th Annual Allerton Conference on Communication, Control, and Computing (Allerton)*, pages 834–841. IEEE, 2018.

[32] Xiao-Yun Lu, Han-Shue Tan, Steven E Shladover, and J Karl Hedrick. Automated vehicle merging maneuver implementation for ahs. *Vehicle System Dynamics*, 41(2):85–107, 2004.

[33] Jiaqi Ma, Xiaopeng Li, Fang Zhou, Jia Hu, and B Brian Park. Parsimonious shooting heuristic for trajectory design of connected automated traffic part ii: computational issues and optimization. *Transportation Research Part B: Methodological*, 95:421–441, 2017.

[34] Daniel V McGehee, Elizabeth N Mazzae, and GH Scott Baldwin. Driver reaction time in crash avoidance research: validation of a driving simulator study on a test track. In *Proceedings of the human factors and ergonomics society annual meeting*, volume 44, pages 3–320. SAGE Publications Sage CA: Los Angeles, CA, 2000.

[35] Vicente Milanés, Joshué Pérez, Enrique Onieva, and Carlos González. Controller for urban intersections based on wireless communications and fuzzy logic. *IEEE Transactions on Intelligent Transportation Systems*, 11(1):243–248, 2010.

[36] Umberto Montanaro, Shilp Dixit, Saber Fallah, Mehrdad Dianati, Alan Stevens, David Oxtoby, and Alexandros Mouzakitis. Towards connected autonomous driving: review of use-cases. *Vehicle System Dynamics*, pages 1–36, 2018.

[37] Sven Nyholm and Jilles Smids. The ethics of accident-algorithms for self-driving cars: An applied trolley problem? *Ethical theory and moral practice*, 19(5):1275–1289, 2016.

[38] Manabu Omae, Takeki Ogitsu, Noritsugu Honma, and Keisuke Usami. Automatic driving control for passing through intersection without stopping. *International Journal of Intelligent Transportation Systems Research*, 8(3):201–210, 2010.

[39] Markos Papageorgiou, Christina Diakaki, Vaya Dinopoulou, Apostolos Kotsialos, and Yibing Wang. Review of road traffic control strategies. *Proceedings of the IEEE*, 91(12):2043–2067, 2003.

[40] Jackeline Rios-Torres and Andreas 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*, 18(5):1066–1077, 2017.

[41] David Schrank, Bill Eisele, and Tim Lomax. Tti's 2012 urban mobility report. *Texas A&M Transportation Institute. The Texas A&M University System*, 4, 2012.

[42] Sanjit A Seshia, Dorsa Sadigh, and S Shankar Sastry. Towards verified artificial intelligence. *arXiv preprint arXiv:1606.08514*, 2016.

[43] DVAHG Swaroop, J Karl Hedrick, CC Chien, and P Ioannou. A comparision of spacing and headway control laws for automatically controlled vehicles1. *Vehicle system dynamics*, 23(1):597–625, 1994.

[44] Martin Treiber, Ansgar Hennecke, and Dirk Helbing. Congested traffic states in empirical observations and microscopic simulations. *Physical review E*, 62(2):1805, 2000.

[45] Atsuya Uno, Takeshi Sakaguchi, and Sadayuki Tsugawa. A merging control algorithm based on inter-vehicle communication. In *Intelligent Transportation Systems, 1999. Proceedings. 1999 IEEE/IEEJ/JSAI International Conference on*, pages 783–787. IEEE, 1999.

[46] Bart Van Arem, Cornelie JG Van Driel, and Ruben Visser. The impact of cooperative adaptive cruise control on traffic-flow characteristics. *IEEE Transactions on Intelligent Transportation Systems*, 7(4):429–436, 2006.

[47] Mascha Van der Voort, Mark S Dougherty, and Martin van Maarseveen. A prototype fuel-efficiency support tool. *Transportation Research Part C: Emerging Technologies*, 9(4):279–296, 2001.

[48] Juan José Besa Vial, William E Devanny, David Eppstein, and Michael T Goodrich. Scheduling autonomous vehicle platoons through an unregulated intersection. *arXiv preprint arXiv:1609.04512*, 2016.

[49] Jian-Qiang Wang, Shengbo Eben Li, Yang Zheng, and Xiao-Yun Lu. Longitudinal collision mitigation via coordinated braking of multiple vehicles using model predictive control. *Integrated Computer-Aided Engineering*, 22(2):171–185, 2015.

[50] Chen Yan, Wenyuan Xu, and Jianhao Liu. Can you trust autonomous vehicles: Contactless attacks against sensors of self-driving vehicle. *DEF CON*, 24, 2016.

[51] Qingdong Zeng, Chaozhong Wu, Liqun Peng, and Haoran Li. Novel vehicle crash risk detection based on vehicular sensory system. In *Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), 2015 IEEE*, pages 622–626. IEEE, 2015.

[52] Weiming Zhao, Ronghui Liu, and Dong Ngoduy. A bilevel programming model for autonomous intersection control and trajectory planning. *Transportmetrica A: Transport Science*, pages 1–25, 2019.