

Review Paper

A Comprehensive Review of Red-Light Violation Warnings and Green Light Optimal-Speed Advisory Systems in V2X-Enabled CAVs

Santhosh Krishnan Venkata¹✉, Sandesh Raghupathyr Rao Sreesha²

¹Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, 576104, India

²Manipal Institute of Technology Bengaluru, Manipal Academy of Higher Education, Manipal, 576104, India

✉ santhosh.kv@manipal.edu

🌐 <https://doi.org/10.31603/ae.14868>

Published by Automotive Laboratory of Universitas Muhammadiyah Magelang

Abstract

Article Info

Submitted:

21/09/2025

Revised:

08/04/2026

Accepted:

14/05/2026

Online first:

12/06/2026

The advancement of connected autonomous vehicle (CAV) technologies has significantly accelerated the development and deployment of vehicle-to-everything (V2X) communication systems, which are essential for enhancing traffic connectivity and safety. Among the prominent applications, red-light violation warning (RLVW) and green light optimal speed advisory (GLOSA) systems have emerged as key innovations, drawing interdisciplinary interest from computer science, intelligent transport systems (ITS), civil engineering, and electronics. The RLVW system uses CAV capabilities to monitor and analyse driver braking behavior in response to traffic signal changes, aiming to reduce red-light violations and improve intersection safety. In contrast, the GLOSA system offers speed recommendations and estimates time to the next green signal, thereby contributing to reduced fuel consumption, lower CO₂ emissions, and enhanced driving efficiency. Both systems rely on signal phase and timing (SPaT) and map data message (MAP) protocols to transmit real-time traffic signal information and intersection geometry from roadside units (RSUs) to on-board units (OBUs). This paper presents a comprehensive review of the operational principles, benefits, and limitations of RLVW and GLOSA systems and identifies key research gaps that warrant further investigation to support the future evolution of V2X-enabled traffic management solutions.

Keywords: Connected autonomous vehicles; Red-Light Violation Warning (RLVW); Green Light Optimal Speed Advisory (GLOSA); Signal Phase and Timing (SPaT); Map Data Message (MAP)

1. Introduction

According to a recent report from the World Health Organization (WHO), the number of annual traffic accidents has increased from 1.13 million in 2018 to 1.19 million in 2023 [1], and these accidents are anticipated to increase annually. Modern vehicles are equipped with new technologies such as airbags, antilock braking systems, advanced driving assist systems (ADASs), etc., that form support systems for these vehicles. These fatalities can occur on roads or at signalized intersections, resulting not only in injuries or deaths but also in the economic growth of the country.

Over the years, the automotive industry has focused on innovating new products that focus on safety and nonsafety issues. One of the prominent solutions includes providing connectivity between vehicles via suitable communication technology, named connected vehicles (CVs), which reshapes the automotive industry. Among the CVs, vehicles exchange information with other vehicles on the road or with their surroundings, termed Vehicle-to-Vehicle communication (V2V) or infrastructure known as Vehicle-to-Infrastructure (V2I), which provides better vehicle awareness and hence condenses road fatalities and traffic jam at signal intersections for better driving experience [2], [3].



This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Many researchers have explored CVs along with enabling technologies, challenges and opportunities, thus bringing one step closer to widespread adoption. Additionally, given the lack of standards between various brands of sensors and their technology, the communication medium is yet another challenge to integrate [4]. Lu et al. discussed challenges and alternative wireless communication technologies for safe and secure V2X applications considering intravehicular communication, protocols for dedicated short-range communication and the use of internet connectivity for intervehicle communications [5]. The authors of [6] reviewed architecture, enabling technologies, applications and challenges in terms of privacy, scalability and extensibility for CV technology.

Enhanced driving experience, with the use of the latest sensors and their technologies deployed within vehicles, has paved the way for numerous applications related to traffic management, safety and nonsafety, such as infotainment systems. However, with recent advancements in sensors and their technologies embedded within vehicles, numerous challenges still exist, such as smart parking of vehicles; reverse warning; V2X safety, such as the Red Light Violation Warning System (RLVW), Green Light Optimal Speed Advisory (GLOSA), Curve Speed Warning (CSW), stop warning, impact warning, speed/work zone warning, Emergency Electronic Brake Lights (EEBL), forward collision warning (FCW), intersection movement assist (IMA), left turn assist (LTA), blind spot/lane change warning (BSW/LCW), not passing warning (DNPW), and turning the vehicle right in front of the bus warning. V2X systems can generally be categorized in terms of road safety, traffic performance, and security [7]. **Table 1** shows that different V2X applications, particularly V2V applications, focus primarily on road safety, traffic performance and security. Furthermore, communication for different V2X applications can be categorized into periodic messaging, event-driven messages, bidirectional applications and, finally, RSU-transmitted messages.

Periodic communication for V2V applications requires recurrent communication between vehicles. Some notable applications include cooperative collision warning, where vehicles receive wireless messages on the basis of the

motion/movement of neighboring vehicles [8], [9]. Collective perception (CP) allows us to share environmental sensor data comprising surrounding traffic and road environments to improve accuracy and safety and reduce latency [10]. In the next application, intersection moving assist (IMA) provides warning messages to vehicles by analysing the position, velocity and trajectory of other vehicles and preventing them from entering intersections because of high collision during poor visibility [11]. Blind spot warning (BSW) or lane-changing assistance (LCA) warning drivers when they want to change lanes [12]. Another safe application is slow stationary vehicle warning (SSVW), which is primarily used in V2X applications to reduce accidents due to slow or stationary vehicles [13]. Cooperative glare reduction (CGR) in V2X reduces the difficulty in observing the vehicle headlamp light, which comes from the opposite direction [14]. A prominent application is Left Turn Assist or Right Turn Assist, an application that alerts the driver, as they attempt an uncontrolled left or right turn in traffic, thus avoiding crashes [15]. In recent years, traffic regulations have been most common. RLVW is an application that alerts vehicle drivers approaching a signalized intersection so that they are likely to enter the signalized intersection after the light turns red [16]. Conversely, the GLOSA provides speed recommendations for vehicles entering a signalized intersection [17].

The same V2V-based periodic messaging can be used to enhance traffic performance by adjusting the vehicle speed automatically to maintain the distance between other vehicles on the road [18]. This application is termed cooperative adaptive cruise control (CACC) [18]. Another application, vehicle platooning (VP), contributes to vehicle performance in terms of reducing fuel consumption and reducing carbon. In the VP, two or more vehicles move in close proximity to each other via dedicated vehicle communication technology [19], [20]. Finally, the same periodic messaging can be extended to detect stolen vehicles by providing alerts to vehicle drivers [21].

The next communication is based on V2V event-driven messages, where messages, such as emergency braking, stationary vehicle warning (SVW) or lane merging, are sent to vehicles driven only when an event occurs. In emergency electronic

Table 1. Different communications and categories of V2X applications [22]

Communication	Category	V2X applications
V2V based on periodic messaging	Road safety	• Cooperative collision Warning (CCW), • Collective perception (CP), • Intersection Moving Assist (IMA), • Blind Spot Warning (BSW)/Lane changing assist (LCA), • Slow Stationary Vehicle Warning, (SSVW), • Cooperative Glare Reduction (CGR), • Left Turn Assist (LTA) • Red Light Violation Warning (RLVW), • Green Light Optimal Speed Advisory (GLOSA)
	Traffic performance	• Cooperative Adaptive Cruise Control (CACC), • Vehicle Platooning
	Security	• Stolen Vehicle Alert (SVA)
V2V based on event Driven Message	Road safety	• Emergency Electronic Brake Light (EEBL) • Stationary vehicle Warning (SVM) • Road Condition Warning (RCW) • Traffic Queue/traffic jam ahead warning • Cooperative Lane Merging (CLM)
	Traffic performance	• Vehicle Platooning (VP)
Bidirectional Comm.	Road safety	• See through (both messages and Video)
	Security	• Instant Messaging (IM)
V2I based on periodic messages	Road safety	• Curve Speed Warning (CSW)
V2I based on events driven messages	Road Safety	• Collision warning based on Infrastructure • Presence of Vulnerable Road Users (VRU) • Traffic jams related to infrastructure (TJRI) • Warning related to road condition • Road Work Warning (RWW)
	Traffic performance	• Emergency Vehicle Preemption (EVP)
V2P based on periodic messages	Road Safety	• Pedestrian Collision warning to vehicles and vice versa (PCW)
RSU- transmitted messages	Road safety	• RSU- Broadcasting • RSU- traffic control server
V2N bidirectional Comm.	Security	• Remote Driving (RD) • Other applications

brake light (EEBL) [23], [24], vehicles apply self-generated brakes depending on the surrounding traffic to avoid accidents. Similarly, when warning of a stationary vehicle, the vehicle warns about possible accidents that could occur if stationary vehicles stand on the road [13]. Other applications include road condition warnings [25], traffic queue/traffic jam-ahead warnings [26], [27] and cooperative lane merging [28], [29]. The VP can also work on event messaging [30], [31], [32]. Furthermore, bidirectional communication that allows information to be exchanged between two vehicles or between vehicles and infrastructure is needed. One such notable application is video [33], [34] and instant messaging [31].

Another type of communication is V2I communication, which is based on periodic messaging and differs in that the RSU regularly transmits messages to nearby vehicles. One such application is curved speed warnings [12], where vehicles receive alert messages about approaching curves. In the case of V2I-based event-driven methods, the RSU or the vehicle sends messages only when a specific event, for example, detects vulnerable road users (VRUs), such as motorcyclists or individuals with disabilities [35]. Some of the other applications in this category are collision warnings based on infrastructure, which receive warnings about approaching collisions related to infrastructure [36] or traffic jams related to infrastructure [37]; warning related to road conditions [38]; and road work warnings [21]. In

V2P scenarios that use periodic communication, pedestrians and vehicles can exchange messages to prevent collisions [39], [40]. RSUs can also broadcast such information to widen coverage or send it to traffic management systems for further action [41], [42]. V2N communication enables two-way data transfer for applications such as remote vehicle operation [14], real-time map updates, and downloads [7]. V2V bidirectional communication, on the other hand, is typically used for direct point-to-point interactions.

The main goal of this work is to summarize and review the previous technical contributions related to RLVW and GLOSA. The potential benefits of using RLVW and GLOSA in practical scenarios, which focus mainly on carbon emissions, reductions in fuel consumption, and safety, are discussed in this work. The simulation, field tests and key findings are also tabulated. The rest of the section is organized as follows: Section II discusses the experimental investigations carried out for RLVW systems; Section III highlights the research insights of the GLOSA; Section IV focuses on SPaT and MAP messages and their importance for CAV technology; and finally, Section V concludes with limitations and research gaps.

2. Red Light Violation Warning (RLVW)

Red-light violation warning (RLVW) applications focus primarily on connected autonomous vehicles (CAVs) when they approach traffic signalized intersections to receive signal timing and geometry information. To accomplish this, the speed and acceleration of vehicles can be used along with the signal timing and geometry information to regulate whether the vehicle can enter the instrumented signal intersection in violation of a traffic signal; under such conditions, an RLVW should be enabled in vehicles if a violation is likely to occur. Conversely, the RLVW application developed should assist vehicle drivers by providing a warning message at their infotainment system when they violate a red light at the signalized intersection. To ensure this, the vehicle requires information from infrastructure, signalized intersection geometry, and road and weather conditions in real time, and sensors that are embedded in the vehicle are used to check

whether the vehicle will need to stop when the signal changes to red. The information from vehicles to the infrastructure is communicated to other vehicles in the form of a signal phase and timing (SPaT) format.

However, when the RLVW application is embedded in vehicles, some of the latent challenges that require focus, for example, drivers need early assistance to help them avoid entering signalized intersections in the case of red signals, which allows drivers to avoid probable conflicts between vehicles or pedestrians in cross walks by assisting them during the start of red signals. Furthermore, RLVW applications should reduce collisions at intersections and allow them to change their driving behaviors, thereby creating a safer driving environment. As drivers become more accustomed to safer driving environments, their behavior may change, resulting in a less active role in driving defensively. On the other hand, ignoring potential alert or warning information can also be a modified behavior that would compromise the safety benefits expected from the application. The alert or warning information can be haptic, visual, or audio messages or a combination of these and should not distract drivers. A warning or alert can be presented to drivers in a stipulated time frame, allowing them to safely stop near signalized intersections by reducing the vehicle speed.

With all these challenges, RLVW has distinct goals that need to be addressed. The primary intention of the RLVW application is to reduce its usage when the driver unintentionally tries to enter the intersection when the traffic signal is red or changes to red, for example, when the driver is distracted or unfamiliar with the intersection. This information is provided on time to vehicle drivers to ensure safe driving and braking operations. Finally, drivers can be assisted with braking through optional assisted or full braking operations. The goals should also aim to reduce any conflicts between other vehicles and pedestrians at the signalized intersection.

A signalized intersection with vehicles approaching it is shown in [Figure 1](#). Lines A1 and A2 are used to represent distances near intersections and depend on factors such as vehicle

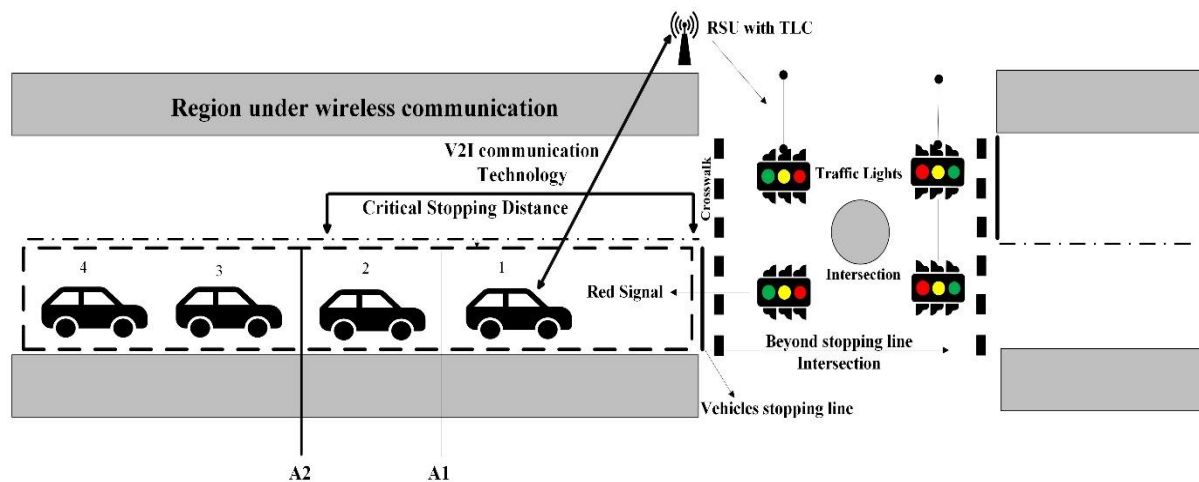


Figure 1. RLVW intersection indicating the critical stopping distance and intersection

speed. In addition to these two lines, there is a critical stopping distance (CSD), which is the distance from the intersection that allows vehicles to stop safely. The CSD depends on numerous factors, such as perception/reaction time, actual vehicle speed, deceleration properties, and roadway grade. As shown in [Figure 1](#), as the traffic signal changes to yellow, vehicles moving at the same speed beyond the A1 region continue to pass through the intersection before the red signal begins. Here, only Vehicle 1 is allowed to pass through the intersection. Conversely, Vehicles 2, 3 and 4 do not pass through the intersection, even though they continue to move at the same speed. However, another important factor to consider here is that vehicles moving at the same speed upstream of A2 will not pass the stop line before the start of the red interval.

Furthermore, one can categorize [Figure 1](#) into four different scenarios. To understand these scenarios, certain prerequisites remain essential before RLVW application can be implemented. The RLVW application should be enabled when the vehicles start and continue to be in enabled condition until the vehicle is stopped. The option for enabling the RLVW application should depend on driver preference either to opt-in or opt-out. An indication to the vehicle driver may be initiated in the case of RLVW error. In scenario 1, [\[16\]](#) when the traffic signal changes from a green signal to a yellow signal, the vehicle(s) past the A1 region will pass through the signalized intersection under such conditions, and the vehicle will not receive RLVW notification. In this case, if the current traffic signal is yellow, the RLVW

application uses the remaining yellow time to calculate whether it can pass the stop line. Conversely, if the current traffic signal remains green, RLVW uses the remaining green signal time along with the yellow signal time interval to determine the time for the red signal interval. Under certain conditions, the vehicle driver will not receive RLVW notification if there is a dynamic change or manual change in the traffic signal or a change in the timing of the traffic signal or any other technical issues that may vary at each intersection.

In scenario 2 [\[43\]](#), where the traffic signal changes from a green signal to a yellow signal, the vehicles will pass the stop line but not the intersection. Drivers who receive a notification during the green traffic signal are expected to reduce their vehicle speed and safely manoeuvre before the stop line. Under these conditions, RLVW calculates the total time by considering the time remaining for the green and yellow traffic signals, which is used to determine the beginning of the red interval. Furthermore, if a driver receives a notification at the start of a yellow traffic signal, a brake should be applied to safely stop the vehicle before it stops. Similarly, RLVW calculates the remaining yellow traffic signal time interval that allows vehicles to pass through intervals. In both cases, if vehicles stop before the yellow traffic signal ends and vehicles continue to move at the same speed, the RLVW will estimate whether vehicles will pass through the intersection before the onset of the red signal. RLVW sends appropriate notifications to drivers if vehicles are likely to not pass through the intersection. The vehicle drivers may not receive

notifications or lack notifications, allowing vehicles to safely manoeuvre before stopping.

In scenario 3, when the current traffic signal is yellow, RLVW uses the remaining yellow traffic time to calculate whether vehicles can safely pass the stop line before the start of the red interval; subsequently, vehicles should apply for braking. Similarly, when the current traffic signal is green, RLVW uses the remaining green signal time along with the yellow time interval to find the total time required for vehicles to stop before the stop line at the onset of the red interval. Under these conditions, vehicles should reduce their speed to stop safely. In addition to these two conditions, the RLVW application sends notifications to vehicle drivers when the vehicles cannot cross the stop line before the traffic signal changes to red. Finally, in scenario 4, if the vehicle is approaching the A2 region and if the current traffic signal is red, the vehicle will slow down and safely stop near the stop line and receive an RLVW notification. Under certain conditions, the vehicle driver does not receive any notification when the red traffic signal ends, and the signal indication is green before the vehicle stops near the stop line.

If the vehicles are approaching or within the critical stopping distance (CSD) and the current traffic signal is red, the vehicle drivers can apply a brake for a safe stop near the stop line. On the other hand, if drivers are ahead of the CSD and if the current traffic signal is red, vehicles should begin to reduce speed for safe stops near the stop line. Any change from a red signal to a green signal will allow vehicles to continue to pass through the intersection. Thus, CSD allows vehicle drivers to make proper decisions in association with traffic signals. The timing and method of notification depend on the OEMs, and the RLVW notification should be sent to drivers with enough time so that the vehicle drivers react to the notification before any action is initiated. Although a lack of notification does not indicate safe operation, vehicle drivers are responsible for operating their vehicles in a safe environment.

In recent developments, Lu et al. proposed real-time applications that can be implemented related to road safety and easy transportation by using promising facilities, such as location-dependent services and providing internet inside vehicles for connected vehicles (CVs) [5]. Currently, CVs use wireless communication, such

as DSRC and cellular V2X, to exchange information between vehicles and infrastructure. These technologies, in combination with on-board units (OBUs) installed in vehicles and RSUs near traffic intersections that can control traffic signals, streetlights, etc., make CV technology promising. These CV technologies can be used to increase awareness of traffic by exchanging data with their surrounding vehicles, thus helping reduce fatalities, traffic congestion and safe driving [44]. With the same CV technology in association with V2I communication, vehicle drivers can be alerted to possible red light violation warnings.

In [45], the authors developed a predictive model to predict red light running (RLR) within the framework of CVs. They also proposed a dynamic all red extension (DARE) framework for CV via radar sensors. The proposed system enables us to classify RLR and non-RLR vehicles. Furthermore, Chen et al. [46] studied the RLR behavior of non-CVs on the basis of the same radar data. The authors in [47] developed an algorithm to provide possible alerts for vehicle drivers about lane changes and speed to reduce accidents. The VISSIM simulator was examined to prevent RLR, thereby confirming the effectiveness of the system. The limitations of this work include the failure to consider changes in weather conditions. In [48], an algorithm to detect the approaching traffic light status, red light running (RLR), was developed. The system employs basic safety messages (BSMs) received through V2I communication. The RSU controlling the traffic light ensures the possibility of vehicles being in the RLR zone. The method uses a CARLA simulator to establish V2I communication between vehicles and infrastructure to display the traffic light status, and red-light warnings to vehicle drivers are displayed. Recent developments have allowed some simulators that can be used in RLVW applications, including PreScan [49], CarSim [50], SUMO [51], and VISSIM [52]. Table 2 shows the merits and De values of some of the popular simulators used. A reduction in RLR violations can be seen by sending a notification to vehicle drivers 1 s in advance about possible signal changes at signalized intersections [53].

Furthermore, the RSU communicates to the vehicles approaching the signalized intersections about the upcoming traffic signal and warns them.

Table 2. Merits and demerits of simulators

Simulator	Merits	Demerits
PreScan	• Suited for ADAS & autonomous vehicle simulation • Supports sensor fusion for safety validation	• Increased cost • Suited for only small traffic environment
CarSim	• Real time simulation for vehicle dynamics • Good for control system validation	• Not suitable for traffic-level studies • Limited multivehicle interaction
SUMO	• Customizable open-source simulator for large-scale traffic simulation • Supports GLOSA, V2Xcommunication	• Low vehicle dynamics realism • Limits sensor-level simulation
VISSIM	• microscopic traffic simulation integrating driver behavior models • best suited for traffic level simulation	• Expensive • Integration complexity • Less detailed vehicle dynamics

The experimental results allowed 93 participants to accommodate the simulation environment. The RLVWs were received much earlier, thus providing them with enough time to apply brakes to stop near the signalized intersection. Approximately 40% of the participants could not stop at red lights, and 55% of the vehicles stopped safely near the signalized intersection when the RLVW was received by drivers [54]. Two different V2I applications, namely, RLVW and GLOSA, were evaluated for their effectiveness. RLVW is generally more effective in terms of safety, as it avoids red light violations and collisions between vehicles, whereas GLOSA is more effectively used for reducing fuel and improving traffic flow. The evaluation involved implementing both applications in hardware-in-the-loop (HIL) simulators, which utilized components such as those deployed at actual intersections, such as roadside units (RSUs) and traffic signal cabinets. The final validation was conducted through on-road testing in real-world scenarios. Additionally, the HIL simulator was employed to assess the RLVW application under conditions of semiautomated signal control in a connected vehicle (CV) environment. A recently introduced concept, the assured green period (AGP), was proposed to provide definitive end times for green signal intervals [55]. Extending further, the authors of [56] improved the mobility and safety when the presence of AGP with proper signal coordination significantly increased the number of vehicles by 36% in the green phase with an 11-s offset. While the incorporation of AGP has improved RLVW performance in CV applications, it has also been associated with an increase in the number of vehicle stops and approach delays [57].

Another study evaluated the safety benefits of an RLVW system, a connected vehicle (CV)-based vehicle-to-infrastructure (V2I) application, at signalized intersections via simulation. The calibrated simulation results demonstrated that the RLVW system could improve intersection safety by up to 50.7% when deployed at a 100% utilization rate [58]. To further assess the system's performance, field tests were conducted. In [59], antennas were installed along roadside transmitted signal phase and timing (SPaT) information to approaching vehicles before the signal transitioned to yellow. The onboard unit (OBU) within the vehicles received this information and activated a dilemma zone warning system, issuing alerts to help prevent potential red-light violations by encouraging timely stops.

Similarly, another field study involved the design of both visual and audible warnings for vehicles entering the dilemma zone. Experimental evaluations were performed for vehicles moving at speeds ranging from 20 km/h to 60 km/h, where the OBU successfully received and processed warning messages at all tested speeds, except for vehicles travelling at 50 km/h, where the system failed to act effectively. The reasons for failure can be technical latency, reaction time, communication range or other factors that need to be investigated. Finally, in another study, the authors developed an RLVW algorithm by considering the safe stopping distance and CSD. With the necessary sensor system and RSU, the developed system can safely remove the RLV for vehicles [60] and avoid possible accidents near intersections to develop such systems, and the local system needs to deploy V2X systems near signalized intersections [61]. The authors of the

present work conducted experimental simulations considering two scenarios for RLVW systems [16].

3. Optimal Green Light Speed

In the automotive domain, Green Light Optimal Speed Light Advisory (GLOSA) uses connected vehicle technology to assist vehicle drivers in optimizing their speed along with other factors, such as vehicle position, combined with the calculation speed required to safely pass through the signalized intersection. GLOSA enables smoother traffic flow and improves efficiency by avoiding unnecessary acceleration/deceleration; it also provides an option to display remaining green time on the dashboard of vehicles to mitigate stress among vehicle drivers.

With these real-time recommendations, the application of the GLOSA in vehicles offers notable benefits, such as a reduction in fuel consumption, carbon emissions and travel time [62], [63], [64]. The traffic light is controlled by RSUs that communicate the information through Vehicle-to-Infrastructure (V2I) via standard wireless communication technologies, such as DSRC or 5G or 6G [65], which are messaged to CAVs and CVs technology within their communication range. Consider the scenario mentioned in Figure 2a. when vehicles V4 and V5 approach the signalized intersection. The traffic light controller controls traffic signals at the intersection and provides speed advice on the dashboard of vehicles. In Figure 2b, Vehicle 1 approaches the signalized intersection; with the help of the map data message (MAP), the GLOSA

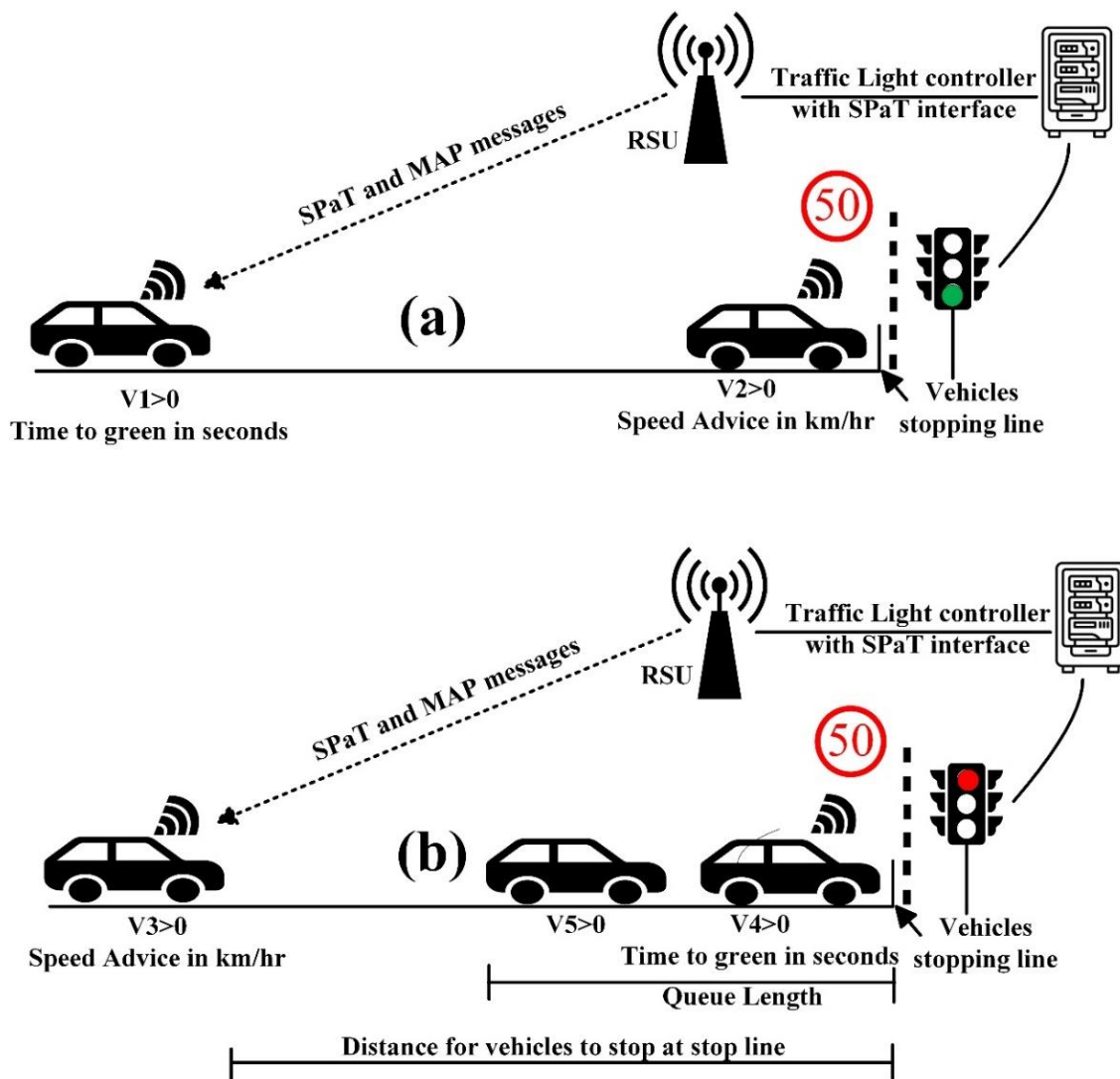


Figure 2. (a) Communication initiated when the current signal is green; (b) Communication initiated when the current signal is red

application calculates that if vehicles can pass through a signalized intersection when the traffic signal is green. Similarly, Vehicle 2 stops at the signalized intersection, and the remaining time required for the next traffic signal, i.e., the green signal, is calculated and transmitted to the vehicles. In both cases, the speed advice or time for the green signal is displayed on the dashboard. The GLOSA system combines traffic signal information along with the current position of the traffic signal to provide vehicle speed recommendations, which assist the current position of vehicles in passing through the signalized intersection. With the GLOSA, vehicles can reduce vehicle stops, fuel consumption and carbon emissions. Table 3 shows the proposed GLOSA application algorithm.

3.1. Related works—Simulation

In recent years, interest in GLOSA systems has increased across diverse research domains in the field of computer science engineering, and civil

and transportation engineering research on GLOSAs has led to a wide variety of solutions for real-time problems, considering simulations and experimental field studies. This section summarizes the GLOSA systems considering only simulations. Table 4 shows the related works for GLOSA simulation along with key findings and the objectives of each work.

3.2. GLOSA-Experimental Field tests and their findings

The field test in the GLOSA is carried out to evaluate the behavior of vehicles in real time via traffic signal information to compute speed advisory or time for green lights that help them stop at red lights. The primary goal of the GLOSA is to help improve traffic flow and reduce fuel and CO emissions and delays. The technical evaluation of the GLOSA is carried out considering the SPaT/MAP latency, message frequency and packet loss from the RSU to the OBU and vice versa. The other category includes

Table 3. Proposed algorithm for GLOSA application

1.	Start GLOSA Application
2.	Search the Traffic light controller using suitable communication technology
3.	Is the TLC detected Yes- go to step 4, NO- go to step 2
4.	<i>Get the MAP message</i>
5.	<i>Estimate the vehicle distance from signalized intersection</i>
6.	<i>Calculate the queue length at current moment</i>
7.	<i>Determine the SPaT message to find the current traffic signal</i>
8.	If (traffic signal =Green)
9.	<i>Estimate the remaining time from present instant to end of green signal and calculate the arrival time.</i>
10.	If (arrival time < green signal)
11.	Vehicle is expected to arrive at current green signal
12.	else
13.	Calculate the speed advice to arrive at current green phase
14.	Display it in vehicle dashboard
15.	If the speed value is in between range and between minimum and maximum value
16.	<i>Send speed advisory message</i>
17.	else
18.	<i>Calculate the advisory speed to arrive at next green signal</i>
19.	elseif (traffic signal =red)
20.	<i>Estimate the remaining time from present instant to end of green signal and calculate the arrival time.</i>
21.	If (arrival time < red signal)
22.	Vehicle is expected to arrive at green signal
23.	else
24.	Vehicle is not arriving at green signal
25.	Calculate the speed advice to arrive at current green phase
26.	Display it in vehicle dashboard
27.	If the speed value is in between range is between minimum and maximum value
28.	<i>Send speed advisory message</i>
29.	else
30.	Exit GLOSA application.

Table 4. Related works—GLOSA simulation

Ref	Testing objective	Simulator/traffic representation	Type of Engine	Key findings
[63]	Vehicle performance and traffic flow	VISSIM	Gasoline and Diesel	- Reduction in fuel consumption by up to 22% for single vehicles in traffic light. - Information distance refers to range in meters typically 500 m to 600 m where the vehicles receive information about traffic lights.
[66]	Vehicle performances	No traffic	Gasoline	- Developed arterial velocity planning algorithms that give dynamic speed values for vehicle drivers. - Reduction in acceleration/deceleration rates thereby safeguarding vehicles not exceeding speed limits along 10 empty intersection signalized corridor.
[67]	Effects on traffic	SUMO	Gasoline	- An increase in GLOSA penetration rate can lead to 80% decrease in stop time and upto 7% of reduction of fuel consumption. - The vehicle should maintain at least 300 m for successful activation. - The simulation was carried out with pre assumption
[68]	Vehicle performance and traffic flow	SUMO	Gasoline	- The main aim was to use simulation model for GLOSA application - Drivers are likely to anticipate a traffic light turning red if they have been approaching it for an extended period. As a result, they may begin adjusting their speed in advance, even before the light changes — a behavior that is not yet represented in existing traffic simulations.
[69]	Vehicle performance	Traffic representation	Gasoline	- To investigate the effects of different speed limits and weather - and travel time savings of 32 percent.
[70]	Traffic flow	SUMO	Gasoline	With GLOSA, CO2 emissions and fuel consumption could be decrease by up to 11.5% for less traffic and continue to deteriorate for denser traffic.
[71]	Traffic flow	VISSIM	Gasoline	- The GLOSA system was implemented for predictable fixed time signal and unpredictable actuated coordinated signal using VISSIM simulator. - Small improvements in fuel consumption, while the average delay for stopped vehicles showed a significant reduction.
[72]	Vehicle performances	No traffic	Gasoline	Proposed multisegmented GLOSA system along with genetic algorithm for speed optimization allowing drivers to receive speed advisory for each segment of traffic signals.
[73]	Vehicle performances	No traffic	Gasoline	Reduction in fuel consumption up to 69.3% and saves travel time by 12.2% in free flow traffic conditions by imbibing Augmented Lagrangian Genetic Algorithm (AGLA) for searching optimized speed curve.
[74]	Vehicle performances	Custom Simulator	Gasoline	The eco driving support system was evaluated using simulator under no traffic conditions using different driving situations like traffic light approach, curves and stop signs in both urban and rural scenario.
[75]	Vehicle performance and traffic flow	VISSIM	Gasoline and diesel	- The objective of this work is to avoid unnecessary accelerations/deaccelerations and delays for two different applications, namely, infrastructure based, and vehicle based. - Under typical driving conditions ~15.5% of travel time and 2.9 and 9.3% for CO2 emissions.

Ref	Testing objective	Simulator/traffic representation	Type of Engine	Key findings
[76]	Traffic flow	Custom simulator	--	• Recommends sharing SPaT messages in advance from the traffic intersection location. • Driver adjusts the speed values when they approach trajectory. • Proposes the effects the Model Predictive Control on traffic.
[77]	Traffic flow	Paramics	Gasoline	• In this work, CAV is equipped with Speed Advisory System on arterial traffic in micro simulations. • A reduction in fuel consumption can be observed.
[78]	Vehicle performances	Aimsum	Electric	• This work highlights a method for energy consumption when the vehicles travel in signalized intersections, considering the portions of traffic light green phase.
[79]	Vehicle platoon performance	Custom simulator	Gasoline	• Developed algorithm for minimizing the vehicles delay by 30-50% • Vehicle speed was limited to 20 kmph and required testing to be done in more realistic simulator.
[80]	Traffic flow	VISSIM	Gasoline	• Investigated GLOSA strategy for vehicles at formed intersection by simulating, considering the parameters like waiting time, queue length and number of stops for further reduction.
[81]	Traffic flow	Custom simulator	Gasoline	• Performance of GLOSA system is evaluated considering distance between vehicle and next closet traffic signal, making it active. • Earlier activation of GLOSA in vehicles can be effective, particularly when the traffic signal is red.
[82]	Traffic flow	Custom simulator	Gasoline	• Addressed driver advisory system to assist vehicle drivers to study the impact of traffic flow. • The performance of system was evaluated addressing travel time, fuel consumption, and carbon dioxide (CO₂) emissions of vehicles entering and exiting an artificial traffic intersection.
[83]	Traffic flow	SUMO	Gasoline	• Provides comparisons on different GLOSA algorithms focusing on minimization of fuel usage, emissions and/or delay and identifying the potential research gaps
[84]	Traffic flow,	SUMO	Gasoline	• Provides experimental investigation for CAV using V2X technology to improve traffic flow and reduce emissions at signalized intersections. More penetration yields less emission, travel time and wait time.
[85]	Vehicle Performance	No traffic	Diesel	• Investigated the use of traffic light signals that affects fuel consumption for vehicle travelling along 1 km distance. • Three different scenarios were considered that using TLS showcased reduction in fuel consumption of approximately 7.5% to 12% and NO_x emission by 13% to 32%.
[86]	Traffic flow	VISSIM	--	• This study evaluates the GLOSA system using a microscopic traffic simulation in VISSIM, simulating full connected vehicle penetration and comparing it to conventional vehicles on a bidirectional road with signalized intersections. • Results show that GLOSA significantly improves traffic flow, reducing average delays by over 83% and waiting times by up to 28 s under varying traffic densities
[87]	Vehicle Performance	No traffic	Electric	• Proposed a new dynamic GLOSA control algorithm for Sustainable development goals and allowed energy reduction up to 35%.

Ref	Testing objective	Simulator/traffic representation	Type of Engine	Key findings
[88]	Vehicle performances	Real time tests	Gasoline	Conducted experimental simulation and field tests to evaluate the performance GLOSA system with assumptions like link length, traffic demand.
[89]	Traffic flow, Vehicle performance	Integrated simulating Environment	Electric	- Proposed Integrating simulation environment that uses GLOSA system considering traffic flow and vehicle dynamics. - A subtle energy reduction of approximately 5% can be witnessed.
[90]	Vehicle performance	SUMO	Gasoline	This work demonstrated, Efficient Path planning GLOSA and Dijkstra greedy algorithm for proposing fastest path for driver.
[91]	Traffic flow	--	--	Discussed detailed framework for urban C-ITS GLOSA system.
[92]	Traffic flow	SUMO	Diesel	- The study tested vehicle-specific GLOSA parameters and restricting GLOSA to passenger vehicles, finding no significant performance differences. - Issues mainly arise from unconnected vehicles reacting to connected ones, especially in mixed traffic conditions.
[93]	Traffic flow	Aimsum	--	- Developed an algorithm, to identify the potential limitations in existing GLOSA literature. - Without GLOSA, the crash rate increases and with GLOSA crash rate decreases.
[17]	Traffic flow	VISSIM	--	- Developed a solution for vehicle traversing the regular traffic light, by implementing dynamic road infrastructure and adjusting traffic light. - Reduction in vehicle speed from 40 km/hr to 30 km/hr can reduce the traffic.
[94]	Vehicle performance	SUMO	Gasoline	Reduction of 24 – 40% in the emissions of CO₂, CO, HC and NO_x as well as a, across a split grade junction
[95]	Vehicle performance	VISSIM+MOVES	Gasoline and diesel	- This work presents and integrated framework using VISSIM and MOVES simulator to evaluate the impact of GLOSA for V2I applications. - A custom algorithm-built showcase reduction rate in volume for CO, NO_x, PM_{2.5} and PM₁₀ can be up to 30.5%, 49.5%, 51.09% and 51.2%.
[96]	Vehicle performance	SUMO	Gasoline and Diesel	This work examines different vehicle emission models, traffic and C-Its simulation to reduce vehicle emissions (20-30%).
[22]	Vehicle Performance+ traffic Flow	SUMO	Gasoline and Diesel	- Fuzzy Logic (FL) based GLOSA system reduces 26% of emissions and adaptive FL GLOSA systems reduces 47% total emission, thus outperforming compared to conventional GLOSA system. - Contributed 36% of energy consumption and emissions compared to GLOSA and V2I system and 47% reduction when combined with adaptive traffic lights with FL-GLOSA
[97]	Vehicle Performance+ traffic Flow	--	--	- Introduces Reinforcement Learning based GLOSA to provide a tradeoff between energy consumption and travel efficiency among CAVs. - A reduction in energy consumption upto 24.8% can witnessed with an increase in communication range (300 m)

driver behavior, which focuses on metrics such as compliance; average stops; average speed; mobility, such as travel time, delay and vehicle stop frequency; and system reliability, such as communication-up time and prediction drift. All these performance parameters are studied to increase driver comfort and stop casualties. To conduct field tests and evaluate the performance parameters, components such as the RSU, OBU, communication technology, HMI and data loggers are essential.

Xia et al. [64] carried out a GLOSA field test by using 4G LTE for a BMW test vehicle at a signalized intersection to determine the changes in fuel consumption. Two different types of tests were constructed on the basis of speed recommendations, and their findings revealed a 13.6% reduction in fuel consumption in real time compared with 14% in the simulation environment. Furthermore, a decrease in fuel consumption of up to 17.4% can be achieved by eco-speed control applications. The GLOSA system is activated 250 m from the signalized intersections, allowing a decrease in travel time of up to 8.4% [98]. The authors in [99] developed a new connected vehicle eco-approach and departure application to conduct field tests to evaluate the metrics in the environmental category. A reduction of 7% in CO, 13% in NO_x and 18% in HC was reported, leading to a significant reduction in emissions from vehicles.

The technical evaluation of GLOSA systems was implemented via IEEE 802.11a, which allows the transmission of traffic light information to vehicles. The experimental evaluations validated fair information transmission between distances of 95 m and 420 m via line-of-sight conditions [100]. Bernais et al. proposed a hybrid communication system for GLOSA applications that is based on cellular communication technologies. The average transmission reached 300 m in their experimental validations. The transmission range of SPaT and MAP messages depends on environmental factors and configurations [101], [102], [103]. Another work that focuses on implementing IEEE 802.11p communication technology has a reasonable communication range of received SPaT messages in vehicles ranging from 300 m to 500 m. Experimental complications arise within side roads and the induction of traffic lights [104]. With the same IEEE 802.11p-based GLOSA system, which provides information about performance

metrics, total end-to-end delays between 330 ms and 640 ms can be achieved [105]. The authors extended their work [105] and reached a message delivery ratio (MDR) of 50%, which caused IEEE 802.11p to remain unstable for single hop systems [106], and proposed multihop systems. Extending further, the same authors proposed. Two-hop dissemination uses 200 traffic lights that exchange information approximately 35% of the time in challenging environments [107]. This study associated short-range (ITS-G5) and long-range (LTE Uu) communication for the GLOSA using data from three smart traffic lights and reported that LTE Uu has better coverage and efficiency, particularly for individual vehicle targeting [103]. This work is the first to propose HIL simulator testing for two V2I applications, namely, RLVW and the GLOSA. In the latter case, the GLOSA system has an optimal speed advisory, which allows vehicles to pass through green light and combines with the RLVW system, which is carried out for road testing and interpretation [105].

An analysis of the simulated and experimental field tests for the GLOSA is shown in Figure 3. The figure shows that a fuel reduction of 22% can be observed with the simulation. However, much more research is needed for field tests, as most of the time, simulation and field test results vary. Furthermore, with respect to the field test results, a fuel reduction of 17.4% can be achieved compared with the constrained environment. Conversely, enabling the GLOSA systems in vehicles will provide necessary speed advice or time to access a green signal, thus improving safety, reducing fuel, minimizing stops near signalized intersections and ultimately decreasing acceleration/deceleration. Summarizing the work carried out for RLVW and GLOSA, a significant reduction in fuel, CO₂ emission, and traffic delay was demonstrated. Table 5 shows an analysis of the GLOSA system in terms of fuel reduction, travel time and performance.

4. SPaT and MAP messages

In connected autonomous vehicle (CAV) technology and intelligent transport systems (ITS), the signal phase and timing (SPaT) and map data message (MAP) [99], [105], [106] are essential for enabling vehicles to understand and communicate with traffic signals. For RLVW and

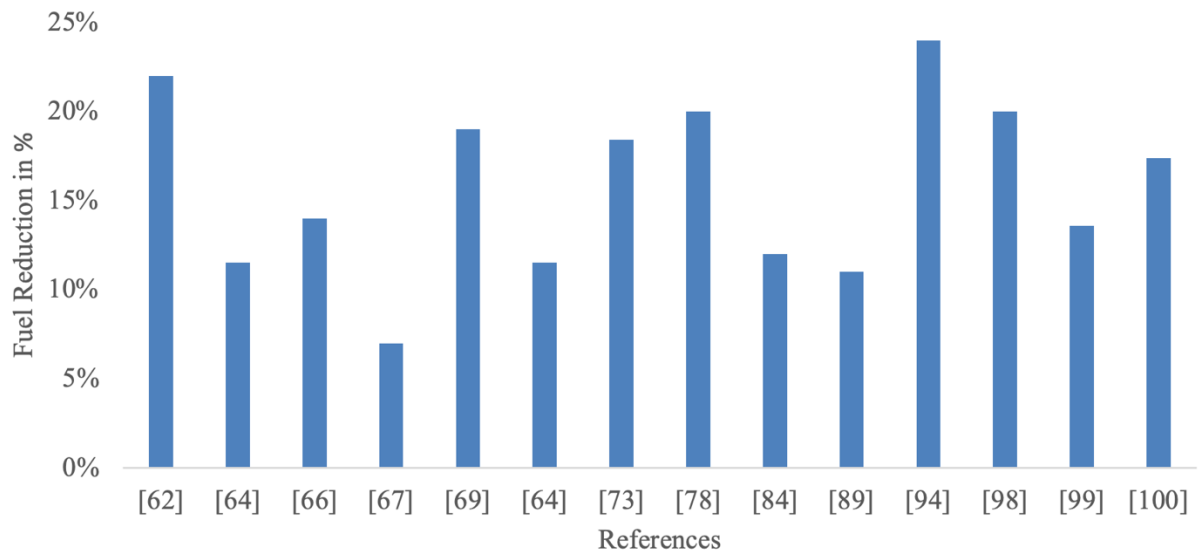


Figure 3. Analysis of simulated and experimental field test results obtained for fuel reduction in the GLOSA

Table 5. Performance parameters of the GLOSA system

Sl.no	Criteria	Ref	Description
1	Vehicle Emission	[75] [85] [94] [96] [99]	2.9 and 9.3% for CO ₂ emissions. NO _x emission by 13% to 32%. 24 – 40% in the emissions of CO ₂ , CO, HC and NO _x vehicle emissions (20-30%). 7% of CO and 13% of No _x and 18% of HC
2	Travel time	[67] [73] [75] [90]	80% reduction in stop time saves travel time by 12.2% 15.5% of travel time travel time of 20% can be achieved.
3	Delay and wait time	[86]	reducing average delays by over 83% and wait times by up to 28 seconds
4	Energy reduction	[87]	energy reduction up to 35%.

GLOSA applications, SPaT remains crucial for providing real-time traffic signal information, the timing of the next phase change, and the intersection geometry and identifiers. However, SPaT messages are always accompanied by MAP messages, which provide geographic layouts of traffic intersections that determine vehicle movement in lanes. Typically, the SPaT message is broadcast by the RSU and received by the OBU in vehicles [108]. SPaT offers numerous benefits for vehicles related to safety, such as warning drivers about possible red-light violations, a competence that can optimize vehicle speed (GLOSA), and eco-driving, which contributes to a reduction in fuel consumption and emissions and importance, which requires vehicles for signal priority.

Conversely, the MAP provides information about the physical geometry and layout of traffic intersections with vehicles. The MAP allows

vehicles to know where they are and path to navigate safely at the signalized intersection. Unlike SPaT, MAP also offers benefits such as lane awareness, which helps drivers know the lane in which they are travelling, avoids collisions, enhances efficiency and contributes to V2X integration. The MAP and SPaT together contribute to CAV applications. For RLVW, the MAP allows the vehicles to check its lane and links to the traffic signal group. SPaT indicates whether the traffic signal is currently red or turning red, and finally, the vehicles use its speed and current location to stop safely at the intersection, the failure of which RLVW is alerted. Similarly, for the GLOSA application, vehicles also determine the current location via the MAP, which helps them calculate the distance from the signalized intersection. The SPaT provides information about the traffic signal, which allows the vehicle speed needed to reach the signalized intersection

before the traffic signal turns green and is recommended to the driver. Furthermore, the MAP is used to match the vehicles in the lane according to their location on the road, followed by matching the lane with the vehicles to determine the phase group number. SPaT information for vehicles consolidates the event state comprising the current state of the traffic light; for example, the green, red and minimum end times are the minimum times in which the current phase changes. The RSU sends this information to the OBU for further action [55].

To communicate effectively between the RSU and OBU in the RLVW and GLOSA, the V2X system should follow the technical standards specified by the Society of Automotive Engineers (SAE-International). The RLVW and GLOSA systems follow SAE-J2735, which allows a standard communication framework for V2X communication [109]. The signal and phase timings obtained from SAE J2735 allow us to tabulate the traffic signal for a 4-mile road containing six intersections and develop a statistical method to evaluate its performance. This work also highlights the importance of SAE J2735 for V2X applications [110]. SAEs J2735 and IEEE 1609 are standards developed from US standards, and other standards, such as ETSI ITS-G5 [111] by European standards and ISO 19091 [112], are some of the global standards that allow SPaT and MAP messages for effective V2X transmission.

5. Conclusion

Recent advancements in connected autonomous vehicles (CAVs), which combine red light violation warning (RLVW) and green light optimized speed advisory (GLOSA) systems, have led to significant advancements in ITSs. The improvements in V2I communication influence real-time traffic signal data, which helps vehicle drivers improve decision-making. Recent developments in RLVW systems will improve safety for vehicle drivers through alerting or intervention when red light violation occurs, thus reducing the number of collisions at intersections and avoiding violations to improve safety.

However, from the available literature, some important factors remain missing or need more focus. First, reliable, low-latency and efficient communication protocols need to be standardized

for data exchange. Privacy and cybersecurity need more attention to safeguard vehicle data during communication. To date, the experimental results have focused more on simulations, and real-world validations involving the performance of more field tests in mixed traffic environments, especially in urban traffic scenarios, are needed. These two systems must consider driver behavior, sensor accuracy, and sudden changes in environmental conditions. In the future, applications of AI and machine learning can improve the performance of the system.

Artificial intelligence can be used to predict red light violations more precisely; edge computing can be applied for faster processing of traffic signal data near intersections. On the other hand, AI can be used for GLOSA systems that help adapt to unexpected changes in signal timing. Other factors, such as privacy in data sharing, can employ blockchain mechanisms. Educating the public about RLVW and the GLOSA is also necessary. International collaboration helps standardize the intersection geometry, safe acceleration and global adoption of CAVs among different manufacturing segments. All the aspects discussed require researchers to work in collaboration, increasing the safety of vehicles driving on roads.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

Funding

No funding information from the authors.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Generative AI statement

The author(s) declare that no generative AI or AI-assisted technologies were used in the preparation of this manuscript.

Additional information

No additional information from the authors.

References

- [1] World Health Organization, "Global Status Report on Road Safety 2023: Summary," Geneva, Switzerland, 2023.
- [2] AVIN, "Opportunities for Connected Vehicles beyond Transportation," Toronto, 2019.
- [3] R. S. Sandesh, P. Mohanty, and S. K. Venkata, "Wi-Fi-Based Information Flow Topology for Effective Vehicle Platooning: Experimental Analysis and Implementation," *World Electric Vehicle Journal*, vol. 16, no. 2, p. 105, Feb. 2025, doi: 10.3390/wevj16020105.
- [4] J. Guerrero-Ibáñez, S. Zeadally, and J. Contreras-Castillo, "Sensor Technologies for Intelligent Transportation Systems," *Sensors*, vol. 18, no. 4, p. 1212, Apr. 2018, doi: 10.3390/s18041212.
- [5] N. Lu, N. Cheng, N. Zhang, X. Shen, and J. W. Mark, "Connected Vehicles: Solutions and Challenges," *IEEE Internet of Things Journal*, vol. 1, no. 4, pp. 289–299, Aug. 2014, doi: 10.1109/JIOT.2014.2327587.
- [6] J. E. Siegel, D. C. Erb, and S. E. Sarma, "A Survey of the Connected Vehicle Landscape—Architectures, Enabling Technologies, Applications, and Development Areas," *IEEE Transactions on Intelligent Transportation Systems*, vol. 19, no. 8, pp. 2391–2406, Aug. 2018, doi: 10.1109/TITS.2017.2749459.
- [7] I. Soto, M. Calderon, O. Amador, and M. Urueña, "A survey on road safety and traffic efficiency vehicular applications based on C-V2X technologies," *Vehicular Communications*, vol. 33, p. 100428, Jan. 2022, doi: 10.1016/j.vehcom.2021.100428.
- [8] S. Mignardi, C. Buratti, A. Bazzi, and R. Verdone, "Trajectories and Resource Management of Flying Base Stations for C-V2X," *Sensors*, vol. 19, no. 4, p. 811, Feb. 2019, doi: 10.3390/s19040811.
- [9] F. A. Schiegg, N. Brahmi, and I. Llatser, "Analytical Performance Evaluation of the Collective Perception Service in C-V2X Mode 4 Networks," in *2019 IEEE Intelligent Transportation Systems Conference (ITSC)*, IEEE, Oct. 2019, pp. 181–188. doi: 10.1109/ITSC.2019.8917214.
- [10] T. Hirai and T. Murase, "Performance Evaluations of PC5-based Cellular-V2X Mode 4 for Feasibility Analysis of Driver Assistance Systems with Crash Warning," *Sensors*, vol. 20, no. 10, p. 2950, May 2020, doi: 10.3390/s20102950.
- [11] G. Olenscki, O. Dokur, and S. Katkoori, "Intersection Movement Assist and Lane Change Assist V2V Warnings with DSRC-based Basic Safety Messages," in *2022 IEEE International Symposium on Smart Electronic Systems (iSES)*, IEEE, Dec. 2022, pp. 718–723. doi: 10.1109/iSES54909.2022.00160.
- [12] Y. Ali, Z. Zheng, and M. M. Haque, "Modelling lane-changing execution behaviour in a connected environment: A grouped random parameters with heterogeneity-in-means approach," *Communications in Transportation Research*, vol. 1, p. 100009, Dec. 2021, doi: 10.1016/j.commtr.2021.100009.
- [13] O. Dokur, G. Olenscki, and S. Katkoori, "Slow Moving Vehicle, Do Not Pass, and Stationary Vehicle V2V Warnings Based on DSRC Basic Safety Messages," in *2022 IEEE International Symposium on Smart Electronic Systems (iSES)*, IEEE, Dec. 2022, pp. 694–699. doi: 10.1109/iSES54909.2022.00154.
- [14] T. Steiner, K. Roscher, and J. Jiru, "Cooperative glare reduction using V2V radio technology," in *2013 IEEE 5th International Symposium on Wireless Vehicular Communications (WiVeC)*, IEEE, Jun. 2013, pp. 1–5. doi: 10.1109/wivec.2013.6698231.
- [15] M. Arafat, M. Hadi, M. A. Raihan, M. S. Iqbal, and M. T. Tariq, "Benefits of connected vehicle signalized left-turn assist: Simulation-based study," *Transportation Engineering*, vol. 4, p. 100065, Jun. 2021, doi: 10.1016/j.treng.2021.100065.
- [16] S. R S and S. KV, "'Scenario-1: Vehicle in Platooning will Pass the Intersection', Experimental Analysis and Implementation," in *2024 IEEE 4th International Conference on Sustainable Energy and Future Electric Transportation (SEFET)*, IEEE, Jul. 2024, pp. 1–6. doi: 10.1109/SEFET61574.2024.10718123.

- [17] Y. K. Jawad and M. Nitulescu, "Controlling Traffic Congestion in a Residential Area via GLOSA Development," *Applied Sciences*, vol. 14, no. 4, p. 1474, Feb. 2024, doi: 10.3390/app14041474.
- [18] Z. Wang, G. Wu, and M. J. Barth, "A Review on Cooperative Adaptive Cruise Control (CACC) Systems: Architectures, Controls, and Applications," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, IEEE, Nov. 2018, pp. 2884–2891. doi: 10.1109/ITSC.2018.8569947.
- [19] R. Geng, H. Ren, and J. Yan, "User Satisfaction-Aware Resource Allocation for 5G Green Vehicle Platooning," in *2019 International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)*, IEEE, Jul. 2019, pp. 868–873. doi: 10.1109/iThings/GreenCom/CPSCom/SmartData.2019.00156.
- [20] A. Lekidis and F. Bouali, "C-V2X network slicing framework for 5G-enabled vehicle platooning applications," in *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring)*, IEEE, Apr. 2021, pp. 1–7. doi: 10.1109/VTC2021-Spring51267.2021.9448769.
- [21] M. Gupta, J. Benson, F. Patwa, and R. Sandhu, "Secure V2V and V2I Communication in Intelligent Transportation Using Cloudlets," *IEEE Transactions on Services Computing*, vol. 15, no. 4, pp. 1912–1925, Jul. 2022, doi: 10.1109/TSC.2020.3025993.
- [22] T. Othmani, S. Boubaker, F. Rehim, and S. El Alimi, "Fuzzy logic green light optimal speed advisory approach: traffic, energy consumption and emissions optimization," *International Journal of Environmental Science and Technology*, vol. 23, no. 2, p. 106, Feb. 2026, doi: 10.1007/s13762-025-06901-8.
- [23] J. Speiran, E. Shakshuki, H. Malik, and A. Yasar, "Preliminary Results of EEBL System for the Smartphone VANET," *Procedia Computer Science*, vol. 220, pp. 372–381, 2023, doi: 10.1016/j.procs.2023.03.048.
- [24] F. Poli *et al.*, "Evaluation of C-V2X Sidelink for Cooperative Lane Merging in a Cross-Border Highway Scenario," in *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring)*, IEEE, Apr. 2021, pp. 1–5. doi: 10.1109/VTC2021-Spring51267.2021.9448998.
- [25] M. Teke and F. Duran, "The design and implementation of road condition warning system for drivers," *Measurement and Control*, vol. 52, no. 7–8, pp. 985–994, Sep. 2019, doi: 10.1177/0020294019858088.
- [26] F. Romeo, C. Campolo, A. Molinaro, and A. O. Berthet, "Asynchronous Traffic on the Sidelink of 5G V2X," in *2020 IEEE International Conference on Communications Workshops (ICC Workshops)*, IEEE, Jun. 2020, pp. 1–6. doi: 10.1109/ICCWorkshops49005.2020.9145466.
- [27] G. Hernandez-Oregon *et al.*, "Performance Analysis of V2V and V2I LiFi Communication Systems in Traffic Lights," *Wireless Communications and Mobile Computing*, vol. 2019, no. 1, pp. 1–12, Aug. 2019, doi: 10.1155/2019/4279683.
- [28] K. Sun, X. Zhao, and X. Wu, "A cooperative lane change model for connected and autonomous vehicles on two lanes highway by considering the traffic efficiency on both lanes," *Transportation Research Interdisciplinary Perspectives*, vol. 9, p. 100310, Mar. 2021, doi: 10.1016/j.trip.2021.100310.
- [29] J. Zheng, L. Ma, and W. Zhang, "Promotion of cooperative lane changes by use of emotional vehicle-to-vehicle communication," *Applied Ergonomics*, vol. 102, p. 103742, Jul. 2022, doi: 10.1016/j.apergo.2022.103742.
- [30] R. Wang, J. Wu, and J. Yan, "Resource Allocation for D2D-Enabled Communications in Vehicle Platooning," *IEEE Access*, vol. 6, pp. 50526–50537, 2018, doi: 10.1109/ACCESS.2018.2868839.
- [31] A. Balador, A. Bazzi, U. Hernandez-Jayo, I. de la Iglesia, and H. Ahmadvand, "A survey on vehicular communication for cooperative truck platooning application," *Vehicular Communications*, vol. 35, p. 100460, Jun. 2022, doi: 10.1016/j.vehcom.2022.100460.

- 10.1016/j.vehcom.2022.100460.
- [32] R. S. Sandesh and K. Santhosh, "Vehicle Platooning-System design, Objectives, Simulation and Field testing," in *2024 International Conference on Automation and Computation (AUTOCOM)*, IEEE, Mar. 2024, pp. 529–533. doi: 10.1109/AUTOCOM60220.2024.10486092.
- [33] C. Perfecto, J. Del Ser, M. Bennis, and M. N. Bilbao, "Beyond WYSIWYG: Sharing contextual sensing data through mmWave V2V communications," in *2017 European Conference on Networks and Communications (EuCNC)*, IEEE, Jun. 2017, pp. 1–6. doi: 10.1109/EuCNC.2017.7980726.
- [34] M. Kutila, P. Pyykonen, Q. Huang, W. Deng, W. Lei, and E. Pollakis, "C-V2X Supported Automated Driving," in *2019 IEEE International Conference on Communications Workshops (ICC Workshops)*, IEEE, May 2019, pp. 1–5. doi: 10.1109/ICCW.2019.8756871.
- [35] X. Lv, Z. Xiao, J. Fang, Q. Li, F. Lei, and G. Sun, "On safety design of vehicle for protection of vulnerable road users: A review," *Thin-Walled Structures*, vol. 182, p. 109990, Jan. 2023, doi: 10.1016/j.tws.2022.109990.
- [36] Y. Huang, Y. Wang, X. Yan, X. Li, K. Duan, and Q. Xue, "Using a V2V- and V2I-based collision warning system to improve vehicle interaction at unsignalized intersections," *Journal of Safety Research*, vol. 83, pp. 282–293, Dec. 2022, doi: 10.1016/j.jsr.2022.09.002.
- [37] D. Kanthavel, S. K. B. Sangeetha, and K. P. Keerthana, "An empirical study of vehicle to infrastructure communications - An intense learning of smart infrastructure for safety and mobility," *International Journal of Intelligent Networks*, vol. 2, pp. 77–82, 2021, doi: 10.1016/j.ijin.2021.06.003.
- [38] Y.-Y. Tseng, P.-M. Hsu, J.-J. Chen, and Y.-C. Tseng, "Computer Vision-Assisted Instant Alerts in 5G," in *2020 29th International Conference on Computer Communications and Networks (ICCCN)*, IEEE, Aug. 2020, pp. 1–9. doi: 10.1109/ICCCN49398.2020.9209751.
- [39] M. Emara, M. C. Filippou, and D. Sabella, "MEC-Assisted End-to-End Latency Evaluations for C-V2X Communications," in *2018 European Conference on Networks and Communications (EuCNC)*, IEEE, Jun. 2018, pp. 1–9. doi: 10.1109/EuCNC.2018.8442825.
- [40] Q.-H. Nguyen, M. Morold, K. David, and F. Dressler, "Car-to-Pedestrian communication with MEC-support for adaptive safety of Vulnerable Road Users," *Computer Communications*, vol. 150, pp. 83–93, Jan. 2020, doi: 10.1016/j.comcom.2019.10.033.
- [41] Q. Guo, L. Li, and X. (Jeff) Ban, "Urban traffic signal control with connected and automated vehicles: A survey," *Transportation Research Part C: Emerging Technologies*, vol. 101, pp. 313–334, Apr. 2019, doi: 10.1016/j.trc.2019.01.026.
- [42] B. Liu *et al.*, "A Novel V2V-Based Temporary Warning Network for Safety Message Dissemination in Urban Environments," *IEEE Internet of Things Journal*, vol. 9, no. 24, pp. 25136–25149, Dec. 2022, doi: 10.1109/JIOT.2022.3195655.
- [43] R. S. Sandesh and K. V Santhosh, "Scenario-2: Platooning Vehicles will Not Pass the Intersection, Relative Position and Timing Analysis," in *2024 International Conference on Vehicular Technology and Transportation Systems (ICVTTS)*, IEEE, Sep. 2024, pp. 1–6. doi: 10.1109/ICVTTS62812.2024.10763934.
- [44] G. Abdelkader, K. Elgazzar, and A. Khamis, "Connected Vehicles: Technology Review, State of the Art, Challenges and Opportunities," *Sensors*, vol. 21, no. 22, p. 7712, Nov. 2021, doi: 10.3390/s21227712.
- [45] M. Li, X. (Michael) Chen, X. Lin, D. Xu, and Y. Wang, "Connected vehicle-based red-light running prediction for adaptive signalized intersections," *Journal of Intelligent Transportation Systems*, vol. 22, no. 3, pp. 229–243, May 2018, doi: 10.1080/15472450.2016.1215921.
- [46] X. (Michael) Chen, L. Zhou, and L. Li, "Bayesian network for red-light-running prediction at signalized intersections," *Journal of Intelligent Transportation Systems*, vol. 23, no. 2, pp. 120–132, Mar. 2019, doi: 10.1080/15472450.2018.1486192.
- [47] M. Tajalli, S. M. A. Bin Al Islam, G. F. List, and A. Hajbabaie, "Testing Connected

- Vehicle-Based Accident Mitigation for Red-Light Violation Using Simulation Strategies," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2676, no. 6, pp. 583–600, Jun. 2022, doi: 10.1177/03611981221075630.
- [48] O. Dokur and S. Katkoori, "Vehicle-to-Infrastructure based Algorithms for Traffic Light Detection, Red Light Violation, and Wrong-Way Entry Applications," in *2022 IEEE International Symposium on Smart Electronic Systems (iSES)*, IEEE, Dec. 2022, pp. 25–30. doi: 10.1109/iSES54909.2022.00158.
- [49] C.-S. Wang, D.-Y. Liu, and K.-S. Hsu, "Simulation and application of cooperative driving sense systems using prescan software," *Microsystem Technologies*, vol. 27, no. 4, pp. 1201–1210, Apr. 2021, doi: 10.1007/s00542-018-4164-z.
- [50] R. F. Benekohal and J. Treiterer, "CARSIM: Car-following model for simulation of traffic in normal and stop-and-go conditions," *Transportation Research Record*, vol. 1194, pp. 99–111, 1988.
- [51] D. Krajzewicz, J. Erdmann, M. Behrisch, and L. Bieker, "Recent development and applications of SUMO-Simulation of Urban MObility," *International Journal on Advances in Systems and Measurements*, vol. 5, no. 3, pp. 128–138, 2012.
- [52] M. Qin, T. Tang, S. Wen, and X. Yuan, "Risk analysis of pedestrian crosswalks in airport drop-off zones based on integrated VISSIM–SSAM model," *Accident Analysis & Prevention*, vol. 224, p. 108279, Jan. 2026, doi: 10.1016/j.aap.2025.108279.
- [53] G. M. Baumgardner, R. K. Boyapati, and A. V. Kamaraj, "Effective Advanced Warning for Connected Safety Applications - Supplementing Automated Driving Systems for Improved Vehicle Reaction," in *Advances in Road Infrastructure and Mobility*, 2022, pp. 269–284. doi: 10.1007/978-3-030-79801-7_19.
- [54] S. Banerjee, M. Jeihani, N. K. Khadem, and M. M. Kabir, "Influence of red-light violation warning systems on driver behavior – a driving simulator study," *Traffic Injury Prevention*, vol. 21, no. 4, pp. 265–271, May 2020, doi: 10.1080/15389588.2020.1744135.
- [55] S. Y. Gelbal *et al.*, "Hardware-in-the-Loop and Road Testing of RLVW and GLOSA Connected Vehicle Applications," in *SAE Technical Paper*, Apr. 2020. doi: 10.4271/2020-01-1379.
- [56] M. Arafat, E. Sadeghvaziri, and R. Javid, "Performance evaluation of red-light violation warning application with traffic signal actuation and coordination," *Digital Transportation and Safety*, vol. 4, no. 2, pp. 108–117, 2025, doi: 10.48130/dts-0025-0007.
- [57] M. Arafat, M. Hadi, T. Hunsanon, and T. Wang, "Hardware-in-the-Loop Simulation for Assessing Red-Light Violation Warning Application With Semi-Actuated Signal Control in a Connected Vehicle Environment," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2677, no. 5, pp. 1085–1099, May 2023, doi: 10.1177/03611981221140371.
- [58] M. Hadi, K. Amine, T. Hunsanon, and M. Arafat, "Evaluating the Benefits of Red-Light Violation Warning System in a Connected Vehicle Simulation Environment," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2675, no. 11, pp. 1372–1381, Nov. 2021, doi: 10.1177/03611981211026662.
- [59] Y.-J. Moon, J. Lee, and Y. Park, "System Integration and Field Tests for Developing In-Vehicle Dilemma Zone Warning System," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1826, no. 1, pp. 53–59, Jan. 2003, doi: 10.3141/1826-08.
- [60] J. A. Jang, H. S. Kim, and H. B. Cho, "Smart Roadside System for Driver Assistance and Safety Warnings: Framework and Applications," *Sensors*, vol. 11, no. 8, pp. 7420–7436, Jul. 2011, doi: 10.3390/s110807420.
- [61] G. Parikh, M. Duhn, and J. Hourdos, "How locals need to prepare for the future of v2v/v2i connected vehicles," 2019.
- [62] E. Mintsis, E. I. Vlahogianni, and E. Mitsakis, "Dynamic Eco-Driving near Signalized Intersections: Systematic Review and Future Research Directions," *Journal of*

- Transportation Engineering, Part A: Systems*, vol. 146, no. 4, Apr. 2020, doi: 10.1061/JTEPBS.0000318.
- [63] T. Tielert, M. Killat, H. Hartenstein, R. Luz, S. Hausberger, and T. Benz, "The impact of traffic-light-to-vehicle communication on fuel consumption and emissions," in *2010 Internet of Things (IOT)*, IEEE, Nov. 2010, pp. 1–8. doi: 10.1109/IOT.2010.5678454.
 - [64] H. Xia *et al.*, "Field operational testing of ECO-approach technology at a fixed-time signalized intersection," in *2012 15th International IEEE Conference on Intelligent Transportation Systems*, IEEE, Sep. 2012, pp. 188–193. doi: 10.1109/ITSC.2012.6338888.
 - [65] A. Sarker *et al.*, "A Review of Sensing and Communication, Human Factors, and Controller Aspects for Information-Aware Connected and Automated Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, no. 1, pp. 7–29, Jan. 2020, doi: 10.1109/TITS.2019.2892399.
 - [66] S. Mandava, K. Boriboonsomsin, and M. Barth, "Arterial velocity planning based on traffic signal information under light traffic conditions," in *2009 12th International IEEE Conference on Intelligent Transportation Systems*, IEEE, Oct. 2009, pp. 1–6. doi: 10.1109/ITSC.2009.5309519.
 - [67] K. Katsaros, R. Kernchen, M. Dianati, and D. Rieck, "Performance study of a Green Light Optimized Speed Advisory (GLOSA) application using an integrated cooperative ITS simulation platform," in *2011 7th International Wireless Communications and Mobile Computing Conference*, IEEE, Jul. 2011, pp. 918–923. doi: 10.1109/IWCMC.2011.5982524.
 - [68] Krajzewicz, Bieker, Erdmann, and 2012, "Preparing simulative evaluation of the glosa application," in *Proceedings CD ROM 19th ITS World Congress 2012*, 2012.
 - [69] R. K. Kamalanathsharma and H. A. Rakha, "Multi-stage dynamic programming algorithm for eco-speed control at traffic signalized intersections," in *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, IEEE, Oct. 2013, pp. 2094–2099. doi: 10.1109/ITSC.2013.6728538.
 - [70] D. Eckhoff, B. Halmos, and R. German, "Potentials and limitations of Green Light Optimal Speed Advisory systems," in *2013 IEEE Vehicular Networking Conference*, IEEE, Dec. 2013, pp. 103–110. doi: 10.1109/VNC.2013.6737596.
 - [71] A. Stevanovic, J. Stevanovic, and C. Kergaye, "Green Light Optimized Speed Advisory Systems," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2390, no. 1, pp. 53–59, Jan. 2013, doi: 10.3141/2390-06.
 - [72] M. Seredynski, W. Mazurczyk, and D. Khadraoui, "Multi-segment Green Light Optimal Speed Advisory," in *2013 IEEE International Symposium on Parallel & Distributed Processing, Workshops and Phd Forum*, IEEE, May 2013, pp. 459–465. doi: 10.1109/IPDPSW.2013.157.
 - [73] J. Li, M. Dridi, and A. El-Moudni, "Multi-vehicles green light optimal speed advisory based on the augmented lagrangian genetic algorithm," in *17th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, IEEE, Oct. 2014, pp. 2434–2439. doi: 10.1109/ITSC.2014.6958080.
 - [74] M. Staubach, N. Schebitz, F. Köster, and D. Kuck, "Evaluation of an eco-driving support system," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 27, pp. 11–21, Nov. 2014, doi: 10.1016/j.trf.2014.09.006.
 - [75] R. T. van Katwijk and S. Gabriel, "Optimising a vehicle's approach towards an adaptively controlled intersection," *IET Intelligent Transport Systems*, vol. 9, no. 5, pp. 479–487, Jun. 2015, doi: 10.1049/iet-its.2014.0155.
 - [76] Stebbins, Kim, Hickman, H.L, and 2016, "Combining model predictive intersection control with green light optimal speed advisory in a connected vehicle environment," in *ATRF 2016 - Australasian Transport Research Forum 2016*, 2016.
 - [77] N. Wan, A. Vahidi, and A. Luckow, "Optimal speed advisory for connected vehicles in arterial roads and the impact on mixed traffic," *Transportation Research Part C: Emerging Technologies*, vol. 69, pp. 548–563, Aug. 2016, doi:

- 10.1016/j.trc.2016.01.011.
- [78] G. De Nunzio, C. Canudas de Wit, P. Moulin, and D. Di Domenico, "Eco-driving in urban traffic networks using traffic signal information," in *52nd IEEE Conference on Decision and Control*, IEEE, Dec. 2013, pp. 892–898. doi: 10.1109/CDC.2013.6759995.
 - [79] S. Stebbins, M. Hickman, J. Kim, and H. L. Vu, "Characterising Green Light Optimal Speed Advisory trajectories for platoon-based optimisation," *Transportation Research Part C: Emerging Technologies*, vol. 82, pp. 43–62, Sep. 2017, doi: 10.1016/j.trc.2017.06.014.
 - [80] G. Njobelo, T. Sando, S. Sajjadi, E. Mtoi, M. A. Dulebenets, and J. Sobanjo, "Enhancing The Green Light Optimized Speed Advisory System to Incorporate Queue Formation," in *Transportation Research Board 97th Annual Meeting*, 2018.
 - [81] H. Suzuki and Y. Marumo, "A New Approach to Green Light Optimal Speed Advisory (GLOSA) Systems and Its Limitations in Traffic Flows," in *International Conference on Human Systems Engineering and Design: Future Trends and Applications*, 2019, pp. 776–782. doi: 10.1007/978-3-030-02053-8_118.
 - [82] H. Suzuki and Y. Marumo, "Evaluating Green Light Optimum Speed Advisory (GLOSA) System in Traffic Flow with Information Distance Variations," in *International Conference on Human Interaction and Emerging Technologies*, 2020, pp. 502–508. doi: 10.1007/978-3-030-25629-6_78.
 - [83] M. Kloeppel, J. Grimm, S. Strobl, and R. Auerswald, "Performance Evaluation of GLOSA-Algorithms Under Realistic Traffic Conditions Using C2I-Communication," in *The 4th Conference on Sustainable Urban Mobility*, Springer, 2019, pp. 44–52. doi: 10.1007/978-3-030-02305-8_6.
 - [84] K. McConky and V. Rungta, "Don't pass the automated vehicles!," *Transportation Research Part C: Emerging Technologies*, vol. 100, pp. 289–305, Mar. 2019, doi: 10.1016/j.trc.2019.01.024.
 - [85] C. Guardiola, B. Pla, V. Pandey, and R. Burke, "On the potential of traffic light information availability for reducing fuel consumption and NO_x emissions of a diesel light-duty vehicle," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 234, no. 4, pp. 981–991, Mar. 2020, doi: 10.1177/0954407019867167.
 - [86] C. B. Masera, M.-I. Imprialou, and C. Morton, "Estimating the traffic impacts of green light optimal speed advisory systems using microsimulation," *International Journal of Transport and Vehicle Engineering*, vol. 13, no. 1, 2019.
 - [87] L. Simchon and R. Rabinovici, "Real-Time Implementation of Green Light Optimal Speed Advisory for Electric Vehicles," *Vehicles*, vol. 2, no. 1, pp. 35–54, Jan. 2020, doi: 10.3390/vehicles2010003.
 - [88] Z. Zhang, Y. Zou, X. Zhang, and T. Zhang, "Green Light Optimal Speed Advisory System Designed for Electric Vehicles Considering Queuing Effect and Driver's Speed Tracking Error," *IEEE Access*, vol. 8, pp. 208796–208808, 2020, doi: 10.1109/ACCESS.2020.3037105.
 - [89] A. Coppola, L. Di Costanzo, L. Pariota, S. Santini, and G. N. Bifulco, "An Integrated Simulation Environment to test the effectiveness of GLOSA services under different working conditions," *Transportation Research Part C: Emerging Technologies*, vol. 134, p. 103455, Jan. 2022, doi: 10.1016/j.trc.2021.103455.
 - [90] M. Karoui, G. Chalhoub, and A. Freitas, "An efficient path planning <scp>GLOSA</scp>-based approach over large scale and realistic traffic scenario," *Internet Technology Letters*, vol. 4, no. 4, Jul. 2021, doi: 10.1002/itl2.194.
 - [91] T. Otto, M. Klöppel-Gersdorf, and I. Partzsch, "A Framework for Urban C-ITS GLOSA Evaluation," in *Conference on Sustainable Urban Mobility*, 2023, pp. 382–392. doi: 10.1007/978-3-031-23721-8_33.
 - [92] M. Klöppel-Gersdorf and J. Grimm, "Evaluating Suitable Glosa-Algorithms by Simulation Considering Realistic Traffic Conditions and V2X-Communication," *Transport and Telecommunication Journal*, vol. 21, no. 4, pp. 303–310, Dec. 2020, doi: 10.2478/ttj-2020-0025.

- [93] A. Chaudhry *et al.*, "Examining road safety impacts of Green Light Optimal Speed Advisory (GLOSA) system," *Accident Analysis & Prevention*, vol. 200, p. 107534, Jun. 2024, doi: 10.1016/j.aap.2024.107534.
- [94] Wieteska, O. Cairns, and P. Warren, "Modelling GLOSA Benefits in the Context of the ITS Whole System Approach," in *15th ITS European Congress*, 2023, pp. 1–10.
- [95] H. H. Karabag *et al.*, "Estimating the impact of green light optimized speed advisory (Glosa) on exhaust emissions through the integration of vissim and moves," *Advances in Transportation Studies*, vol. 52, pp. 5–22, 2020.
- [96] Warren, Paul, and M. Wieteska, "Modelling HGV emissions for GLOSA connected vehicle services," WSP. [Online]. Available: <https://www.wsp.com/en-id/insights/modelling-hgv-emissions-for-glosa-connected-vehicle-services>
- [97] R. Yang, J. Zhou, Q. Wang, J. Liang, and K. Yang, "Platoon-Centric Green Light Optimal Speed Advisory Using Safe Reinforcement Learning," *IEEE Transactions on Vehicular Technology*, vol. 75, no. 3, pp. 3711–3724, Mar. 2026, doi: 10.1109/TVT.2025.3610106.
- [98] H. Chen, H. A. Rakha, A. Loulizi, I. El-Shawarby, and M. H. Almannaa, "Development and Preliminary Field Testing of an In-Vehicle Eco-Speed Control System in the Vicinity of Signalized Intersections," *IFAC-PapersOnLine*, vol. 49, no. 3, pp. 249–254, 2016, doi: 10.1016/j.ifacol.2016.07.042.
- [99] P. Hao, G. Wu, K. Boriboonsomsin, and M. J. Barth, "Eco-Approach and Departure (EAD) Application for Actuated Signals in Real-World Traffic," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 1, pp. 30–40, Jan. 2019, doi: 10.1109/TITS.2018.2794509.
- [100] I. Iglesias, L. Isasi, M. Larburu, V. Martinez, and B. Molinete, "I2V Communication Driving Assistance System: On-Board Traffic Light Assistant," in *2008 IEEE 68th Vehicular Technology Conference*, IEEE, Sep. 2008, pp. 1–5. doi: 10.1109/VETECF.2008.437.
- [101] Bernais, Benedikt, A. Lotz, and H. Pu, "Design and implementation of a traffic light assistance system based on C2X and TSI messages," in *AmE 2016 - Automotive meets Electronics; 7th GMM-Symposium*, 2016, pp. 1–6.
- [102] R. Braun *et al.*, "TRAVOLUTION-netzweite optimierung derlichtsignalsteuerung und lsa-fahrzeug-kommunikation," *Straßenverkehrstechnik*, vol. 6, p. 365, 2009.
- [103] M. Zweck and M. Schuch, "Traffic light assistant: Applying cooperative ITS in European cities and vehicles," in *2013 International Conference on Connected Vehicles and Expo (ICCVE)*, IEEE, Dec. 2013, pp. 509–513. doi: 10.1109/ICCVE.2013.6799846.
- [104] M. Nour, M. Nour, and M. H. Zaki, "Integrating Vehicle-to-Infrastructure Communication for Safer Lane Changes in Smart Work Zones," *World Electric Vehicle Journal*, vol. 16, no. 4, p. 215, Apr. 2025, doi: 10.3390/wevj16040215.
- [105] R. Stahlmann, M. Moller, A. Brauer, R. German, and D. Eckhoff, "Technical evaluation of GLOSA systems and results from the field," in *2016 IEEE Vehicular Networking Conference (VNC)*, IEEE, Dec. 2016, pp. 1–8. doi: 10.1109/VNC.2016.7835967.
- [106] R. Stahlmann, M. Möller, A. Brauer, R. German, and D. Eckhoff, "Exploring GLOSA systems in the field: Technical evaluation and results," *Computer Communications*, vol. 120, pp. 112–124, May 2018, doi: 10.1016/j.comcom.2017.12.006.
- [107] R. Stahlmann, A. Tornatis, R. German, and D. Eckhoff, "Multi-hop for GLOSA systems: Evaluation and results from a field experiment," in *2017 IEEE Vehicular Networking Conference (VNC)*, IEEE, Nov. 2017, pp. 175–178. doi: 10.1109/VNC.2017.8275617.
- [108] T. Wágner, T. Ormándi, T. Tettamanti, and I. Varga, "SPaT/MAP V2X communication between traffic light and vehicles and a realization with digital twin," *Computers and Electrical Engineering*, vol. 106, p. 108560, Mar. 2023, doi: 10.1016/j.compeleceng.2022.108560.
- [109] Sumner, Roy, B. Eisenhart, and J. Baker,

- "SAE J2735 standard: applying the systems engineering process," 2013.
- [110] J. Mathew, H. Li, and D. M. Bullock, "Using Stochastic Variation of Cyclic Green Distributions to Populate SAE J2735 Message Confidence Values along a Signalized Corridor," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2674, no. 9, pp. 426–437, Sep. 2020, doi: 10.1177/0361198120929337.
- [111] A. Gholamhosseinian and J. Seitz, "Empirical Estimation of ETSI ITS-G5 Performance Over an IPv6-based Platform," in 2022 *IEEE International Performance, Computing, and Communications Conference (IPCCC)*, IEEE, Nov. 2022, pp. 185–193. doi: 10.1109/IPCCC55026.2022.9894344.
- [112] A. Lalaguna, P. Townend, B. Ojaghi, and C. Vázquez, "Cooperative and Connected Mobility Services in the Cloud-Edge Continuum with Function As A Service Technology and AI-enabled Orchestration," in 2024 *Mediterranean Smart Cities Conference (MSCC)*, IEEE, May 2024, pp. 1–6. doi: 10.1109/MSCC62288.2024.10697004.