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Review

Towards Green Driving: A Review of Efficient Driving Techniques

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Abstract: The exponential increase in the number of daily traveling vehicles has exacerbated global warming and environmental pollution issues. These problems directly threaten the continuity and quality of life on the planet. Several techniques and technologies have been used and developed to reduce fuel consumption and gas emissions of traveling vehicles over the road network. Here, we investigate some solutions that assist drivers to follow efficient driving tips during their trips. Advanced technologies of communications or vehicle manufacturing have enhanced traffic efficiency over road networks. In addition, several advisory systems have been proposed to recommend to drivers the most efficient speed, route, or other decisions to follow towards their targeted destinations. These recommendations are selected according to the real-time traffic distribution and the context of the road network. In this paper, different high fuel consumption scenarios are investigated over the road networks. Next, the details of efficient driving techniques that were proposed to tackle each case accordingly are reviewed and categorized for downtown and highway driving. Finally, a set of remarks and existing gaps are reported to researchers in this field.

Keywords: green driving; road context; driving assistance; traffic situation

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1. Introduction

For decades, motor vehicles have consumed large amount of fuel and contributed to increasing harmful gas emissions. The exponential increase in the number of traveling vehicles over years has encouraged engineers and designers to develop efficient vehicles. Several advanced technologies have been used to develop traditional engines for vehicles and increase their efficiency. These include: cylinder deactivation, turbochargers, gasoline direct injection, valve timing, and lift technologies [1]. Other technologies have improved the transmission system of vehicles, such as additional gears, continuously variable transmissions, and dual-clutch transmissions [2].

Furthermore, the design of vehicles has been adapted to reduce fuel consumption and gas emissions. Small and light-weight vehicles have been introduced that require less fuel and produce fewer gases [3]. This is because of the lower amount of required power to move them compared to heavy-weight or large vehicles. The technology of low rolling resistance tires has also been developed, aiming to reduce the energy loss from tires rolling under high load [4].

Hybrid vehicles are a recent technology that has added an extra motor that uses electricity as a source of power to vehicles [5]. The traditional motor works more efficiently in terms of fuel consumption on highways, whereas the electric motor is better for downtown local driving. Moreover, stop-start, regenerative braking, larger electric motors, and advanced battery technologies have been used to reduce the fuel consumption, especially in downtown areas where vehicles drive in a stop-and-go fashion [6]. The idea of combining more than one of these design technologies in the same vehicle introduce even more efficient vehicles. This increases the reduction percentage in fuel consumption and gas emissions and enhances the efficiency of the vehicle.

However, the behavior, experience, and skills of drivers also affect the fuel consumption and gas emissions of a vehicle. Training drivers to efficiently drive their vehicles is a difficult mission that requires time and real-time guidance. There are no standards for efficient driving or mechanism to estimate the performance effects of each behavior. General driving tips are recommended to drivers to reduce fuel consumption during their trips. These tips are set mainly based on the specific road scenario and its context (i.e., downtown or highway) [7]. Several recently proposed studies aim to enhance the efficiency of driving trips on road networks. However, there is a lack of review and comparison studies in this field of research.

In this paper, we provide an organized review study of green driving assistance techniques. The efficient driving assistant protocols that have been proposed for downtown and highways are investigated. Next, these protocols are categorized based on their used technology. This study investigates the general/special considered parameters and characteristics of high fuel consumption scenarios over road networks by investigating the input and obtained output of each previous study in this field. The main objective of this work is to highlight the gaps and the required work in this field of research and advise researchers on how to focus their efforts.

The rest of this paper is organized as follows: in Section 2, a summary of some previous surveys and literature reviews that have presented the techniques and considerations of reducing fuel consumption and gas emission of traveling vehicles are presented. Next, in Section 3, several high fuel consumption cases are investigated for downtown and highway driving. An overview of mathematical models and techniques used to estimate and measure fuel consumption is presented in Section 4. The general efficient driving tips that drivers should follow to reduce fuel consumption during their trips are discussed in Section 5. Section 6 summarizes and classifies previous efficient driving assistance protocols. Section 7 discusses the general challenges and gaps in this field. Finally, Section 8 concludes the paper and provides recommendations and remarks for researchers regarding future required work in this field of research.

2. Related Work

In the literature, several review research studies have investigated the fuel consumption and gas emission parameters over the road network. First, Alam and McNabola [8] have introduced a review and assessment study of the eco-driving policy and its claimed benefits. They have also investigated the possible negative impacts of eco-driving that may increase accident risks or CO_2 emissions over the road network. The conclusion of this study was that eco-driving policies have the potential to reduce CO_2 emission and fuel consumption in general driving scenarios. However, the effectiveness of these policies is reduced and becomes unpredictable in highly congested downtown scenarios.

Huang et al. [9] review the major factors, research methods, and implementation of eco-driving technology. First, significant eco-driving factors are summarized as acceleration/deceleration, driving speed, route choice, and idling. Next, this work mainly focused on investigating the effectiveness and benefits of eco-driving training programs. A general decrease in fuel consumption and gas emission has been observed with increased travel time in the investigated scenarios. This study highly encouraged considering the network level and pollution factor. The eco-route or eco-path was investigated and reviewed on the road network. Navas-Anguita et al. [10] investigated some production routes for a wide range of road transportation fuels. Moreover, Kopelias et al. [11] provided a review of the environmental and traffic noise impacts caused by connected, autonomous, and electronic vehicles. They investigated how these vehicles have altered fuel consumption, gas emission, etc., in several driving scenarios.

More importantly, heavy vehicles are a serious issue concerning fuel consumption and gas emission on the road network. Traveling in a platoon fashion can improve fuel economy because of the reduction in aerodynamic drag. A truck platoon was defined here as a set of virtually linked trucks that travel small distances. Zhang et al. [12] presented a review of existing studies that aim to save fuel for truck platooning.

This proposed work aims to investigate the details of efficient driving protocols that have been proposed to reduce the fuel consumption and gas emission parameters over different road network scenarios. It focuses mainly on eco-driving assistant protocols that have provided hints and advice to drivers in connected vehicles.

3. High Fuel Consumption Scenarios

The fuel consumption rate of any vehicle is highly affected by the driving behavior and the context of the traveled road. Extensive experience, training, and practice are required to gain efficient driving skills. Over the road network, some scenarios consume fuel at a relatively high rate due to the required driving operations. For example, sudden changes in the traveling speed of vehicles during their trips increase the fuel consumption. Indeed, hard braking and high acceleration increase fuel consumption and emissions of vehicles [13].

In general, driving in downtown areas consumes more fuel compared to driving on highways. This is mainly explained by the context of downtown areas, which are usually designed in a grid layout with a large number of road intersections and short road segments. This context requires frequent stops and frequent variations in the traveling speed, and thus it leads to an increased rate of fuel consumption. Figure 1 illustrates the special scenarios and common areas where vehicles consume fuel at a higher rate in downtown and highway scenarios.

First, as seen from Figure 1, in downtown areas the main features are road intersections and road segments that connect these intersections. Traffic lights, roundabouts, or stop signs are usually installed at road intersections to control the conflicted traffic flows there. However, some road intersections exist without controllers, and drivers follow the applicable driving rules (i.e., first come first pass, or yield to right). In each case of these controlling mechanisms, the efficiency of vehicles is affected differently by stopping, decreasing speed, or waiting.

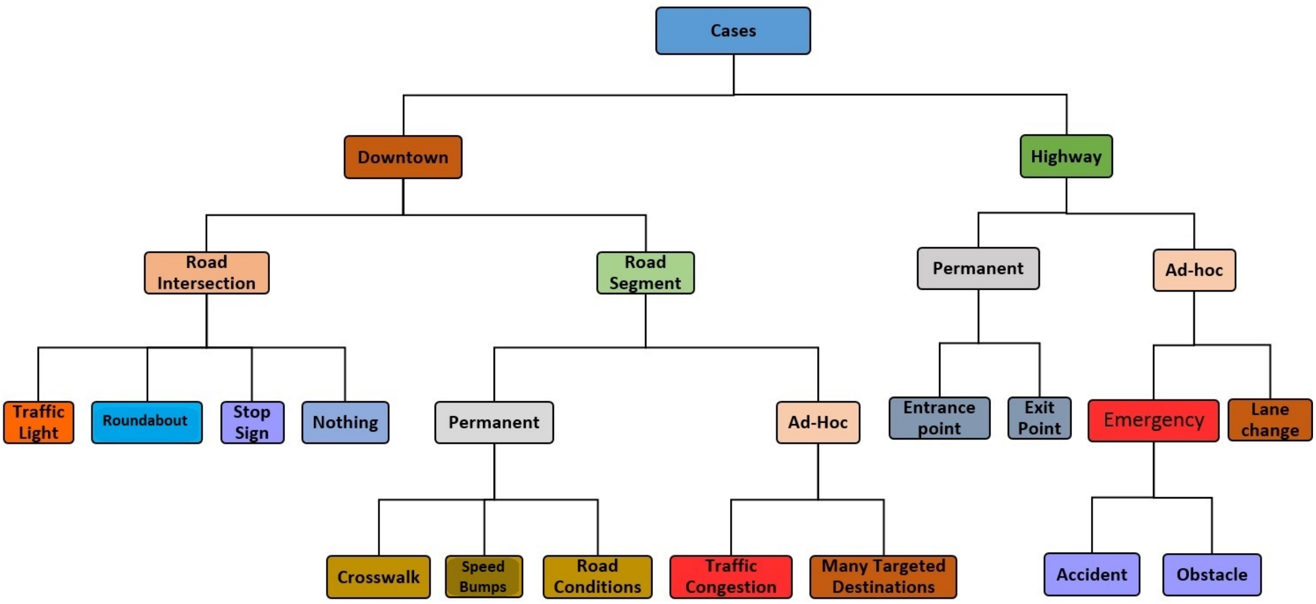

Figure 1. Cases of high fuel consumption on road networks.

On downtown road segments, fuel consumption scenarios are represented by two main categories: permanent and ad-hoc. The permanent cases involve features that are connected to the road, such as crosswalks, speed bumps, and other road conditions. These features are used to help estimate the required fuel consumption to traverse that segment in advance. However, for the ad-hoc cases, features are changed from time to time based on the real-time traffic characteristics and density. They are summarized by traffic congestion level and the number of the targeted destinations at the investigated road segment.

Second, on highways, vehicles are moving straight at an almost steady high speed most of the trip time. Thus, trips over highways are considered relatively more efficient in terms of fuel consumption and gas emission. However, the cases of high fuel consumption over highways are connected mainly to changes in the traveling speed of vehicles or other aggressive driving behavior, such as hard acceleration/deceleration, sudden braking, or high traveling speed. These cases are classified mainly into permanent and ad-hoc categories as well.

The permanent cases are represented by scenarios where the traveling speed should be changed that can be planned in advance. These include taking an exit or getting through an entrance point. In contrast, the ad-hoc cases are mostly unexpected cases that require drivers to react suddenly and quickly. These include changing the traveling lane or reacting to an emergency situation such as an obstacle or accident. Driving around these cases can be smooth and direct for expert drivers. However, new drivers or drivers that are unfamiliar with these areas need more assistance to pass them successfully and efficiently. Assisting drivers to follow efficient driving tips around these cases can achieve targeted green driving and reduce gas emission.

4. Models and Techniques for Estimating Fuel Consumption

The efficiency of traveling vehicles is determined by the rate of fuel consumption and gas emissions. These can be measured using attached sensors and/or equipment in each vehicle. They have also been estimated and mathematically predicted. Several parameters affect the rate of fuel consumption and gas emission of any vehicle during its trip. They may be related to the vehicle, traffic, roadways, drivers, or weather conditions.

Several mathematical models have been introduced to estimate fuel consumption and gas emissions of vehicles based on some measurable parameters [14–16]. These models are classified according to the number of considered parameters and the accuracy of its predictions into three main categories: simple, comprehensive, and instantaneous models. First, simple models are usually dedicated to one type of vehicle, specific mode of driving, or certain design of the roadway. They ignore several effective parameters and focusing on studying the effects of one or more selective parameters in specific, predefined scenarios. In this type of model, the emission factor can be computed as an average of repeated measurements over a particular driving cycle [17].

Second, comprehensive models estimate the fuel consumption of the entire road network based on the average aggregate parameters of the vehicles traveling there. In general, the emission rates are measured for different trips where several average speeds are tested for each trip. These models are usually established aiming mainly to evaluate the environmental performance from different transportation modes. Methodologies for calculating transpiration emissions and energy consumption (MEET) [18] and network for transport and environment (NTM) [19] are popular models of this type that have used a number of regression functions to comprehensively estimate the fuel consumption of traveling vehicles. Moreover, a web application computer program to calculate emissions from road transportation (COPERT) [16] has been widely used by drivers to estimate and compare the vehicle's emission based mainly on that vehicle's engine, type, and speed over the targeted road network [15].

Third, instantaneous models estimate the most accurate fuel consumption of each vehicle based on its real-time parameters at specific periods of time. They consider the instantaneous vehicle kinematic variables: speed, deceleration, acceleration, etc. Bowyer et al. [20] have proposed a strong base for instantaneous fuel consumption models. They investigated several situations and scenarios to estimate fuel consumption. This model has been developed and adapted to several road scenarios. The proposed model (i.e., an instantaneous fuel consumption model (IFCM)) considers the vehicle's mass, energy, efficiency parameters, and drag force. It also uses the fuel consumption components associated with aerodynamic drag and rolling resistance. The idle, cruise, acceleration, and deceleration modes of driving have also been separately investigated. Moreover, Nam and Giannelli [21] designed a physical emission rate estimator model (PERE) that consists of a series of stand-alone spreadsheets that can be run and modified directly by users.

5. Efficient Driving Tips

A vehicle's design and engine directly affect its efficiency [5]. Moreover, driving behaviors and situation-dependent techniques can save the fuel and reduce harmful gases in a dynamic manner. The behavior of users and drivers over the road network affects the rate of fuel consumption and gas emission as much as the manufacturing technologies. For instance, regularly maintaining the vehicle and using the right engine oil help the engine run with maximum capacity. In addition, checking the tire pressure, reducing the loaded weight, and cutting drag by removing roof-racks and boxes reduce the air resistance and the required power to move the vehicle. These habits have significant effects on reducing the fuel consumption and emission [22,23].

Moreover, several environmental protection organizations and car manufacturing companies [13,24] have stated that the differences in fuel consumption and gas emission between good and bad drivers can be 25–40% on average. Some real-time driving tips and recommendations that aim to enhance the fuel consumption and its emissions are summarized here:

1. Accelerate gently: to increase the traveling speed, vehicles should go through gradual acceleration. Increasing the traveling speed requires extra power. The faster the change in the traveling speed, the more the required power. This extra power is generated from burning more fuel. According to the instantaneous fuel consumption rate model introduced by Bowyer et al. [20], the acceleration rate of a vehicle has a direct influence on the fuel consumption rate.
2. Coast to decelerate: gently decelerating the speed of a vehicle reduces the fuel consumption. Hard declaration or sudden braking waste the forward momentum of the traveling vehicle and its associated power. The instantaneous fuel consumption rate is increased by increasing the declaration rate, as well [20].
3. Maintain a steady speed: acceleration and deceleration both have direct influences on increasing the instant fuel consumption rate. Thus, maintaining a steady speed should reduce the extra required power to accelerate and also reduce the wasted power needed for the vehicle to slow down. Efficient driving requires the driver to watch the traveling speed and avoid changing it. Modern vehicles are equipped with cruise control, which helps drivers maintain steady speed whenever possible.
4. Avoid high speeds: the speed limits that are assigned to roads are set according to safety and efficiency conditions. Efficient driving recommends a driver to follow the speed limit of the road. Based on the COPERT model [16], if a certain vehicle drives for 100 km at speed of 100 km/h instead of 80 km/h, it consumes 1.2 liters more fuel. However, the driver would arrive only 15 min earlier.
5. Anticipate traffic: predicting the surrounding traffic and context of the roads helps drivers to react smoothly. Stop signs, cross walks, speed bumps, emergency vehicles, accidents, and other road features require changes in driving behavior and the traveling speed of vehicles. Anticipating the context of the road helps drivers react smoothly and efficiently. Advanced communication technologies and intelligent prediction tech-

niques have been used recently to provide drivers with a good information regarding the surrounding traffic situation.

6. Eco-Driving Assistance Protocols

The behavior of drivers and the applied driving operations affect fuel consumption and gas emissions for each trip. Several protocols have been proposed in the literature aiming to assist drivers and recommend the best operations to enhance the efficiency of driving trips. These protocols can be easily categorized based on the targeted road network: downtown and highways. Moreover, the driving behavior is highly affected by the context and requirements of each scenario. Figure 2 graphically illustrates the main considerations of efficient traffic control protocols in downtown scenarios.

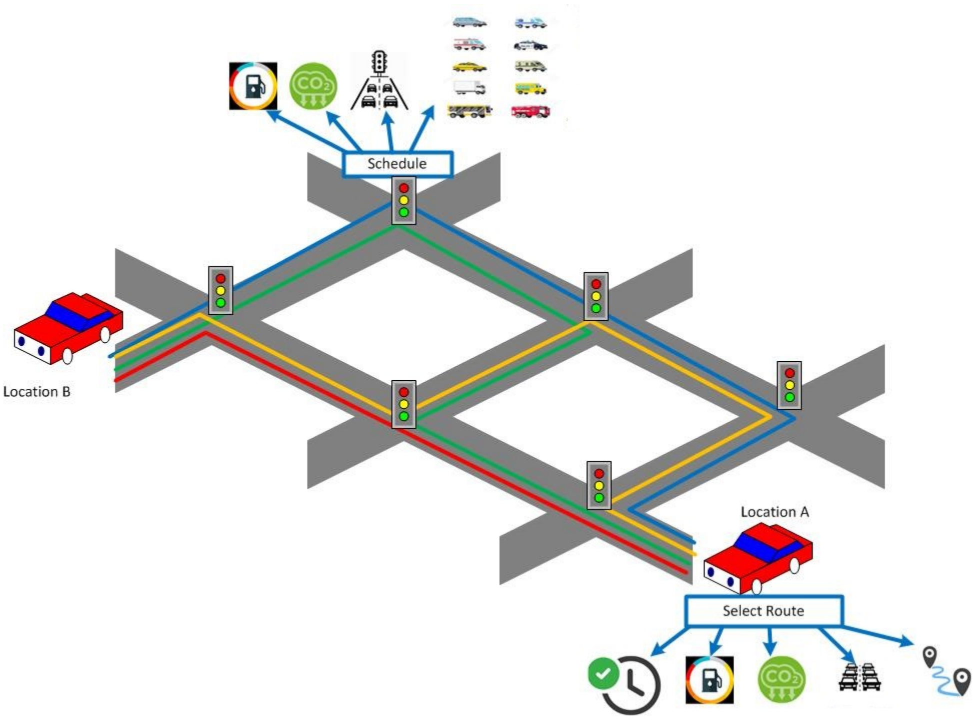

Figure 2. The considerations of efficient traffic control protocols in downtown scenarios.

First, as seen from the figure, finding the efficient path between a source and a destination on a grid-layout downtown road network depends on several real-time traffic characteristics. These include the locations of the source and destination, the estimated travel time of the path chosen, required fuel consumption and gas emissions, and the distribution of traffic and congestion. Second, the located traffic lights must be operating efficiently. This is done by considering the traffic density of the competing traffic flows, their context, and required fuel and gas emissions.

In contrast, Figure 3 illustrates the primary considerations of efficient traffic control protocols on highways. As we can see from the figure, the main considerations of these protocols are the shape of the highway design, the speed of vehicles, traffic congestion, and driving behaviors, including lane changes and exit/entrance points.

In the rest of this section, previous efficient traffic control protocols are investigated and categorized in downtown and highway scenarios.

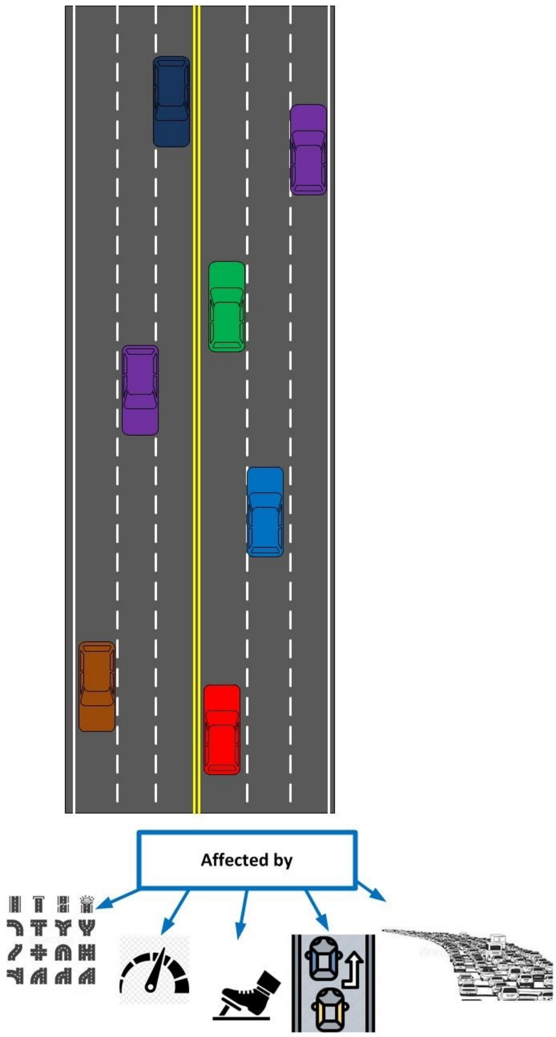

Figure 3. The considerations of efficient traffic control protocols on highways.

6.1. Eco-Path Recommendation Protocols for Downtown Scenarios

First, the grid layout of downtown areas provides several route options that drivers can follow towards their targeted destinations. Selecting the most efficient route that considers the real-time traffic characteristics of the investigated area of interest has been intensively investigated by several studies and projects. Finding the fastest path that leads towards the targeted destination has been developed as essential phase in this field [25,26].

The fuel consumption and gas emission parameters have also been investigated for the selected and candidate routes to recommend the most efficient selection. Mohammad et al. [27] measured the estimated required fuel consumption for the shortest k-routes towards the targeted destination. The estimation process considered the traveling distance and speed of vehicles in addition to other real-time traffic characteristics using the IFC model [20]. The route that was estimated to consume the least amount of fuel is recommended as most efficient route. Xu et al. [28] have applied the same idea, however, they have estimated the fuel consumption for the k-fastest routes instead of the closest one.

Bani Younes and Boukerche [25] introduced a path recommendation protocol that measures the traveling distance and traveling time of each road segment on the grid layout of a downtown road network. A balanced route that considers the traveling time and traveling distance between the source and destination is then selected. No drastic delay or traveled distance is experienced in the selected balanced route towards the targeted destination, and it is constructed based on the characteristics of the linked road segments. Measuring the fuel consumption and gas emission of the balanced route, the fastest route and the shortest route using an instantaneous fuel consumption model is selected [20]. Comparing the fuel and gas emissions of vehicles following these routes, the obtained balanced route can be recommended as the efficient route, as traveling vehicles on this route require the least amount of fuel.

Furthermore, many eco-path protocols have been designed to efficiently control the amount of consumed fuel and produced gases during each vehicle's trip. Kono et al. [29] proposed an ecological path recommendation protocol. This protocol used Dijkstra's algorithm to find the path that requires the least amount of fuel. It depends on a centralized gathering of data for the required fuel to traverse each road segment on the investigated downtown network. Chang et al. [30] developed VANET-based A* route planning algorithm to find the fastest and most efficient route in terms of fuel consumption. This is based on two main real-time traffic sources: traffic data of road segments that the vehicle passes through and traffic information provided by Google Maps.

TraffCon [31], eCo-Move [32], and EcoTrec [33] are smart solutions aimed at enhancing the efficiency of traveling vehicles. TraffCon is an efficient algorithm for vehicle routing that aims to reduce the traveling time of vehicle trips and decrease fuel and gas parameters [31]. It considers three main real-time parameters to recommend a certain route: traveling time, used capacity of the road network, and fuel consumption. The eCo-Move system [32] is constructed based on the assumption that "there is a theoretical minimum energy consumption. That is achieved with the perfect eco-driver travelling through the perfectly eco-managed road network". Thus, a microscopic simulation environment is implemented with installed eCo-Move applications as realistically as possible. This aimed to test and recommend the most efficient behavior and most efficient road management conditions to reduce the fuel consumption of each selected route. EcoTrec [33] is an eco-friendly algorithm that finds the most efficient route considering the fuel consumption parameter. It mainly utilizes the efficiency of selecting individual road segments and considers a number of factors. It balances relevant factors of traffic conditions over the investigated road network such as travel time, road congestion level, and gas emissions. This enhances the fuel consumption and the efficiency for the selected route.

Table 1 summarizes the main considerations and characteristics of some ecological path recommendation protocols and algorithms that have been proposed for efficient traveling over downtown areas. The input and output of each protocol are illustrated in the table.

Table 1. Eco-path recommendation protocols.

Path Recommendation Protocol	Used Technique	Input	Output	Details
Mohammed et al. [27]	Closest k-route	K-shortest route	The route that consumes the least amount of fuel	Measured the estimated required fuel consumption for the k-shortest routes towards the targeted destination. The route that consumes the least amount of fuel is recommended as the most efficient route.
Xu et al. [28]	Fastest k-route	Fastest k-route	The route that consumes the least amount of fuel	Estimated the fuel consumption of the k-fastest route, then selected the most efficient one in terms of fuel consumption.
Bani younes and Boukeche [25]	Balanced route	Travel time and distance of each road segment	Balanced efficient route	A balanced route that considers the traveling time and traveling distance is recommended as the efficient route.

Table 1. *Cont.*

Path Recommendation Protocol	Used Technique	Input	Output	Details
Kono et al. [29]	Dikestra	Fuel consumption of each road segment	The route that consumes the least amount of fuel	Use Dijkstra's algorithm to find the path that requires the least amount of fuel. This is after estimating the required fuel for each existed route.
Chang et al. [30]	A*	Fuel consumption of each road segment	The route that consumes the least amount of fuel	Developed VANET-based A* route planning algorithm to find the fastest and most efficient route.
TraffCon [31]	Eco-route	Real-time traffic characteristics of road network	Less travel time, less fuel path	An efficient algorithm for vehicle routing that considers real time characteristics of the trip.
eCo-Move [32]	Eco-route	Real-time traffic characteristics of road network	Path towards the destination with minimal fuel consumption	Follow the role that perfect eco-driver travelling through the perfectly eco-managed road network.
EcoTrec [33]	Eco-route	Real-time traffic characteristics of road network	Path towards the destination with minimal gas emission	It utilizes the efficiency of selecting individual road segments and considers travel time, road congestion level, and gas emissions.

6.2. *Efficient Road Intersection Controlling Algorithms*

Existing road intersections in a downtown road architecture are shared among several conflicting traffic flows. These intersections are usually controlled by stop signs, roundabouts, or traffic lights aiming to safely schedule competing traffic flows. Few driving assistant protocols have investigated the traffic characteristics and the efficient options that drivers can take around road intersections that are controlled by stop signs and roundabouts [34,35]. However, the fuel consumption and gas emission parameters have not been directly investigated or studied at these intersections.

Traffic lights have been considered as the most sophisticated solution to control conflicting traffic flows at road intersections. Several techniques and technologies have been utilized that aim to provide efficient schedules there [36,37]. These solutions aimed to increase the throughput of the investigated road intersections and decrease the waiting delay time of traveling vehicles. Moreover, many research studies have intelligently considered the parameters of fuel consumption and gas emissions when setting the schedule of each located traffic light [38–40]. A recent infrastructure-less traffic control system that is solely based on vehicle-to-vehicle (V2V) communicationswas proposed by Ferriro et al. [41] for downtown road networks.

Virtual traffic lights are introduced in this system, which aims to control the competing traffic flows at road intersections while considering their real-time traffic characteristics. Ferriro and d'Orey [42] proved the impact of these traffic lights on carbon (CO_2) emissions mitigation. However, Vlasov et al. [43] proposed an adaptive traffic light control algorithm that mainly targets reducing the fuel consumption and gas emissions of traveling vehicles. It considers the dynamic transport demand on the road intersection besides real time traffic characteristics of the competing traffic flows.

Assisting drivers to take the most efficient action and prepare for upcoming conditions help reduce fuel consumption as well. Haritenstien et al. [39] investigated the effects of gear choice and the distance between each vehicle and the traffic light when drivers received the stopping or passing signals on the efficiency of that vehicle in terms of fuel consumption. This assessment has been applied for a large-scale simulation to obtain more accurate and beneficial results. Moreover, Ngo et al. [44] introduced an adaptive traffic light scheduling algorithm and optimal speed advisory method. It recommends the most efficient speed to each driver in order to reduce the total fuel consumption and gas emissions of traffic at the investigated area of interest. The scheduling algorithm can be adapted to solve the yellow-light-dilemma problem. This would extend the yellow signal time for vehicles in a zone, which gives them time to safely stop or pass through the intersection. This increases the smoothness of movement of the vehicle and enhances the efficiency parameters.

Intelligent algorithms have been utilized to set the optimal schedule of traffic lights. These scheduling algorithms also aim to reduce the emission and fuel consumption of the traffic at the investigated area. Alba [40] used particle swarm optimization techniques. Furthermore, Soon et al. [45] developed a pheromone-based green transportation system with three comprehensive phases to tackle all high fuel consumption scenarios in the downtown area. These include: traffic congestion prediction, coordinated traffic light control strategy, and cooperative green vehicle routing. The integration between the traffic light scheduling and the routing phases helps to find the route with the least fuel consumption.

Furthermore, several researchers have considered the context of the traffic while selecting the efficient schedule of the located traffic lights. Younes and Boukerche [46] have considered the existence of emergency vehicles and public transportation. They assigned a higher priority for these vehicles to pass through the signalized intersection quickly and safely. Salin [47] considered public transportation vehicles and assigned them a higher priority to pass through the intersection. Investigating the efficient parameters of these algorithms have shown reduction in the fuel consumption and gas emission parameters. However, Suthaputchakun and Sun [38] considered heavy loaded vehicles with a higher priority to pass through the signalized road intersections. These vehicles consume more fuel compare to normal vehicles due to braking, stopping, and restarting actions. The latter algorithm proved an enhancement in the efficiency of traffic in the investigated area of interest. Table 2 summarizes the details of the main techniques used to efficiently control the traffic light schedule. The input and output of each algorithm have been listed in the table.

Table 2. Eco-traffic light scheduling algorithms.

Traffic Light System	Technique	Input	Output	Consideration Details
Ferriro and d'Orey [42]	Virtual Traffic Light	Traffic characteristics of competing traffic flows	Efficient schedule for the traffic light	Mitigate the carbon (CO_2) emissions.
Vlasov et al. [43]	Adaptive Traffic Light	Traffic characteristics of competing traffic flows	Efficient schedule for the traffic light	Mainly targeted to reduce the fuel consumption and gas emissions of traveling vehicles.
Haritenstien et al. [39]	Advisory System	Distance between vehicle and intersection, gear choice, and traffic light phase	Recommend the gear choice and speed for the vehicle	Investigated the effects of gear choice and distance between each vehicle and the traffic light and when the driver received the stopping or passing signals.

Table 2. *Cont.*

Traffic Light System	Technique	Input	Output	Consideration Details
Ngo et al. [44]	Advisory System	Traffic characteristics of competing traffic flows	Traffic light schedule and speed advisory model	Recommend the efficient speed to each driver and tackle the yellow-light-dilemma problem.
Nieto and Alba [40]	Intelligent Algorithm	Traffic characteristics of competing traffic flows	Efficient traffic light schedule	Used particle swarm optimization technique to schedule the traffic light.
Soon et al. [45]	Intelligent Algorithm	Traffic characteristics of competing traffic flows	Efficient traffic light schedule	Developed pheromone-based green transportation system that utilizes the hierarchical multi-agent algorithm.
Younes and Boukerche [46]	Context-aware Schedule	Traffic characteristics of competing traffic flows	Efficient traffic light schedule	Consider the existence of emergency vehicles.
Sail [47]	Context-aware Schedule	Traffic characteristics of competing traffic flows	Efficient traffic light schedule	Consider the existence of public transportation.
Suthaputch and Sun [38]	Context-aware Schedule	Traffic characteristics of competing traffic flows	Efficient traffic light schedule	Consider the existence of heavy loaded vehicles.

6.3. Sustainable Highway Eco-Driving

The straight, wide, and multiple-lane design of highways is considered an efficient road design. Vehicles consume less fuel to travel on highways compared to the rate of fuel consumption in downtown scenarios. The most common traffic distributions on highways are platooning (i.e., set of platoons where vehicles in each platoon are traveling closely at a steady speed). Each platoon contains several vehicles that follow each other with short gaps and times [48]. However, the comfortable flat design of highways encourages drivers to increase their speed and apply a high acceleration rate. They may also need to apply hard braking in some cases to avoid obstacles or take an exit. These behaviors drastically increase the rate of fuel consumption and gas emissions on highways.

Theoretically, several studies have documented efficient driving tips on highways such as smooth acceleration/deceleration, optimal gear shifting, anticipating traffic, avoid idling, etc. [7,49]. Many environmental organizations have claimed high reduction in the fuel consumption and gas emissions by following some eco-driving techniques compared to the average driving style [13]. Some countries and environmental organizations have introduced eco-driving courses. These courses aim to educate and train drivers for efficient driving [13]. The impact of eco-driving training courses on fuel consumption have been investigated by measuring the historical fuel consumption and gas emissions rates of vehicles during a certain period of training time [50]. The reduction rate in these studies depends mainly on the individual skills of the involved drivers and the design of the tested area.

Furthermore, traffic congestion, accidents, and obstacles cause driving behavior to change on highways. Providing drivers with real-time efficient recommendations such as speed, acceleration rate, or the optimal gear selection should enhance efficient driving behaviors. He and Wu [51] introduced eco-driving advisory strategies that enhance the efficiency of driving on highways, mainly by recommending the optimal speed for each platoon of vehicles. Lee and Son [52] recommend the most efficient depth of the acceleration/deceleration pedal according to the selected gear option. In addition, they correlated the angle of the steering wheel to the fuel consumption rate on highways as an efficient measure of driving.

Additionally, advanced design technologies in vehicles have directly enhanced the efficiency conditions on highways in terms of reducing fuel consumption and gas emissions [53]. For instantce, cruise control equipment has been added to most recent vehicles. Steady speed can be easily maintained on highways using this equipment [54]. Connected vehicles that communicate through vehicular ad-hoc networks have contributed as well to enhancing traffic efficiency. Ploeg et al. [55], Taiebat et al. [56], and Wang et al. [57] have developed different eco-cooperative adaptive cruise control protocols. These protocols have used the connecting technology among traveling vehicles to obtain the most efficient traveling speed according to the real-time traffic distribution and road design. High rates of reduction in the fuel consumption and gas emissions have been reported for utilizing these protocols.

In addition, autonomous and electronic vehicles are foreseen as future development technologies. Several research studies and industrial organizations are working towards them [53]. Autonomous vehicles have several promising features in terms of enhancing the safety conditions on road networks. Moreover, they should enhance the efficiency because the efficient driving conditions are applied automatically without human interference. Several electronic efficiency control systems have been developed to enhance the performance of autonomous and electronic vehicles [55,56,58]. Highways have been the most suitable environment to verify these protocols [59]. Table 3 illustrates the details of main highway eco-driving techniques including the required input for each protocol and its obtained results.

Table 3. Sustainable highway driving.

Highway Eco-Driving	Used Technique	Input	Output	Details
Barla et al. [50]	Eco-driving training	Trained drivers	Lower fuel consumption trips	Following the theoretical efficient driving tips, some training courses have been offered.
He and Wu [51]	Real-time advisory model	Traffic distribution and vehicle's characteristics	Recommend the speed, gear option, and acceleration rate for each vehicle	Recommending the optimal speed for each platoon of vehicles, the most efficient depth of acceleration/deceleration pedal for each gear option and the angle of steering wheel.
Lee and Son [52]	Real-time advisory model	Traffic distribution and vehicle's characteristics	Recommend the speed, gear option, acceleration rate, and angle of steering wheel for each vehicle	Recommending the optimal speed for each platoon of vehicles, the most efficient depth of acceleration/deceleration pedal for each gear option and the angle of steering wheel.
Ploeg et al. [55] Taiebat et al. [56] Wang et al. [57]	Advanced technology	Traffic distribution	Cruise control system	Eco-cooperative adaptive cruise control protocols using VANETs.

Table 3. *Cont.*

Highway Eco-Driving	Used Technique	Input	Output	Details
Taiebat et al. [56] Bengler et al. [53]	Autonomous and electronic vehicles	Real-time traffic distribution	Automated sustainable control system	Efficient driving is applied automatically without human interference, electronic sustainable control systems have been developed to enhance the efficiency of autonomous and electronic vehicles.

7. Discussion and Challenges

In this paper, we have reviewed and categorized green driving techniques that aim to enhance traffic efficiency on road networks. The investigated studies were strongly associated with the traversed road scenario. First, in downtown scenarios, two main challenges have been raised. These are selecting the eco-path towards the targeted destinations and efficiently scheduling the competing traffic flows at road intersections. Several eco-path recommendation protocols have been introduced to assist vehicles in selecting the most efficient path toward their targeted destinations. Advanced mechanisms and intelligent algorithms have been utilized in these protocols. Considering the existing protocols, a good performance in term of reducing fuel consumption and gas emission was obtained. However, the topic of more reduction in these factors is always open for more enhancements and developments. As long as the technologies in manufacturing and producing vehicles are developed, new and better eco-path recommendation protocols can be developed.

For the eco-path recommendation protocols, collecting the real-time traffic characteristics over the investigated area of interest is the first challenge. The correctness and accuracy of the gathered traffic data should be guaranteed in order to obtain correct recommendations. The higher the quality of the gathered data, the more useful they become. The second challenge in this topic is selecting the optimal path in a real-time fashion that predicts and investigates the instantaneous changes in the traffic distribution over the road network. The advanced technologies of machine learning and cloud computing are recommended in this field to predict the traffic changes and compute fast and real-time required computations.

At road intersections, efficient traffic light scheduling algorithms have been considered. Virtual traffic lights, adaptive traffic lights, and advisory systems have been introduced to reduce the total fuel consumption and gas emissions of competing traffic flows. Efficient traffic light scheduling algorithms have used intelligent mechanisms and the context of the competing traffic flows differently. The ability to investigate the real-time traffic characteristics and context of competing traffic flows depends on the used technology (i.e., image processing, connected vehicles, etc.). The accuracy and correctness of the gathered traffic data directly affect the efficiency of the traffic light schedule. Moreover, several priorities could be applied to the traffic light schedule algorithm that should be carefully selected. More importantly, further research studies and investigations are required for the road intersection control scenarios, especially when the intersections are controlled by roundabouts or stop signs.

On highway road scenarios, the efficiency of traffic is mainly affected by driving behavior and the context of the traversed road. Drivers drastically increase their speeds over highways due to the open, wide lanes. Recommending the optimal speed and driving behavior over highways should drastically enhance the efficiency conditions. This is due to the few existing contexts on highways and therefore fewer required changes in driving behavior or speed. Modern vehicles are equipped with technologies and sensors that can help to enhance traffic efficiency in these scenarios. Cruise control, electronic sustainable control systems, and autonomous driving systems all help to enhance fuel consumption and gas emission conditions, especially on highways.

Highways are well known as being generally efficient. Vehicles that travel on them consume less fuel and produce less pollution compared to those traveling in downtown scenarios. However, highways require fast and timely reactions from drivers due to the high travel speed in order to avoid accidents and injuries. Several studies have been proposed in the literature to measure and evaluate the efficient performance of driving behaviors on highways. However, more studies that consider the physical context of the highway (i.e., exit/entrance points, obstacles, accidents, etc.) are required in this regard. The higher the traveling speed on the highway scenario, the faster the required responses. In addition, the more common the context in the investigated scenario, the more the obtained benefits in investigating the efficiency parameters and the efficient driving recommendations.

8. Conclusions and Remarks

Efficient driving assistance protocols have been reviewed and categorized in this work for downtown and highway driving scenarios. The requirements, challenges, and suggestions to enhance each protocol have been investigated. In downtown scenarios, eco-paths and efficient traffic light scheduling algorithms have been deeply investigated and developed for individual vehicles and/or platoons of vehicles in the literature. However, these protocols are open to enhancement mainly by utilizing the advanced technology of machine learning and cloud computing to accurately predict the future traffic distributions in the investigated downtown scenario. Real-time and fast processing and computations are applied to find the optimal recommendations for paths towards the targeted destinations and/or traffic light schedules. More work to recommend efficient driving operations around road intersections that are controlled by stop signs or roundabouts is required in this field. For highway road networks, efficient driving protocols have been developed to assist drivers around unexpected traffic congestion, obstacles, and accidents. Moreover, efficient recommendations about driving on highways have been derived in a real-time fashion according to the traffic characteristics of the investigated road scenario. The efficient options and recommendations for drivers over highways require more study and investigation. This is done by investigating the context of the road and its effects on driving behavior. The fast speed of vehicles on highways introduces a real challenge for eco-driving assistant protocols to provide fast processing and recommendations for each scenario. The delay in obtaining the recommendations for each vehicle on the highway is open for reduction. This can mainly benefit from the new technologies of communication first to gather the traffic data quickly and accurately and then to deliver the recommendations to each vehicle in the investigated scenario.

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