INNOVATIONS IMPACTING THE FUTURE OF TRANSPORTATION: AN OVERVIEW OF CONNECTED, AUTOMATED, SHARED, AND ELECTRIC TECHNOLOGIES

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Abstract

To anticipate the future transportation system in the Year 2050, this paper overviews emerging technology development by emphasizing Connected, Automated, Shared, and Electric (CASE) technologies. Literature on 14 CASE technologies is synthesized, with an outlook toward practical use cases, predictions, and policies. This paper adds to the literature by consolidating important predictions of CASE-related technologies, services, and policies. The development trend argues that connected and automated technologies are still not mature and there remain many gaps in the abilities of the technology; shared mobility will have a large market share; and electric technologies will finally replace internal combustion engines.

Keywords: Transportation Futures, Connected, Automated, Shared, Electric, Predictions, Year 2050

INTRODUCTION

Innovations in vehicle, battery, and information technologies are making transportation systems more efficient and reliable. Emerging options, like shared rides using shared autonomous vehicles (SAVs) and drone deliveries, can improve safety and convenience for travelers and shippers while reducing costs, congestion, and emissions across regions. New transport policies (like credit-based congestion pricing) and infrastructure changes (like an increase in high-occupancy lanes and access to electric vehicle charging stations) can support these innovations. But impacts are uncertain, and will not always be positive without smart management. For example, ride-hailing can be very convenience, but often increases congestion, (Todd, 2019). Predicting the future technologies' impacts is important in the evolution of local, regional, and interregional operations.

Many experts anticipate a driverless and zero (tailpipe) emissions future. Hancock et al. (2019) claimed that fully automated or "autonomous" vehicles (AVs) will evenutally become indispensable. To promote smooth AV driving, vehicle connectivity and communication technologies are needed (Dai Nguyen and Zoltán, 2019; Sumalee and Ho, 2018). They ensure the real-time and precise transfer of information between vehicles, infrastructure, and people, while enabling tighter following distances, and thus higher lane (and intersection) capacities. In terms of energy and greenhouse gas emissions, Jung and Koo (2017) predicted that Korea's road-based CO_2 emissions will fall to 36% (to 655,773 tons per year) if about half the nation's fuel stations became electric vehicle (EV) charging stations (and drivetrain adoption followed suit). Shared travel is another, nearer-term way to reduce emissions. Martin and Shaheen (2016) estimated that carsharing lowered households' car-based greenhouse has emissions by 20% or more in five US cities. However, how these and other transportation-related innovations will impact future transportation systems is uncertain.

In terms of city form, 80% of the US population now resides in urban areas, and that share is the prediction for year 2050 globally (Hannah and Max, 2019). Many cities may become self-sustainable, in terms of food, water, and energy (Kiss et al., 2015), while climate changes will make regions warmer and storms and droughts more severe (Irfan et al., 2019). Many travelers and businesses will have new ways of meeting their transportation and consumption needs, hopefully in more cost-effective and sustainable ways.

This paper takes a close look at of 14 CASE-based transport technologies (as shown in Figure 1), with most still under design and pilot testing. Based on this review, 19 year-2050 predictions for US cities are divided into technologies vs. services and policies.

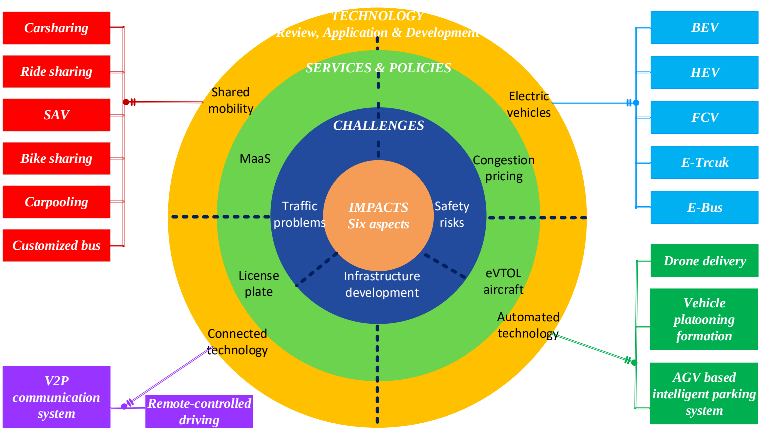


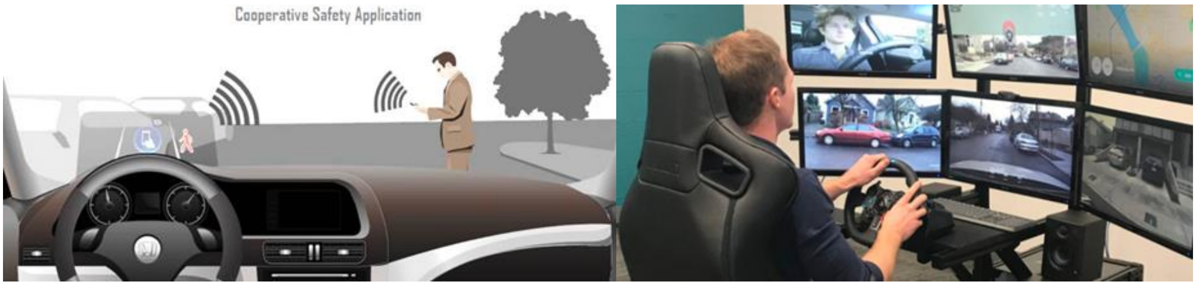
Figure 1 Research summary of this paper

The remainder of this paper is organized as follows: in Section 2, new technologies under development and research directions are introduced; Section 3 proposes predictions on the development of transportation systems in the future; finally, conclusions and future research directions are provided.

REVIEW OF CASE-RELATED TECHNOLOGIES

This section reviews 14 new technologies across four aspects: connected, automated, shared, and electric technologies. For each of them, the state-of-the-art research is described along with a brief background.

Connected Technologies



(a) V2P communication system[1]　　　(b) Remote-controlled driving[2]

Figure 2 Connected technologies

V2P Communication System

While vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems are more commonly discussed to ensure safe vehicle operation, V2P communication systems offer real-time traffic conditions and warnings to non-motorized road users (Rahimian et al., 2018; Rouchitsas and Alm, 2019). Pedestrians and bicyclists receive safety alerts via wearable devices, such as smartphones for adults, tags for children, seniors and physically disadvantaged persons, and special helmets for cyclists (Sewalkar and Seitz, 2019).

Current studies focus mainly on information-communication technologies and communication notification. Wi-Fi and dedicated short-range communication are the two main technologies currently being used. Anaya et al. (2014) suggest that a Wi-Fi system can meet the basic requirements to fulfill the V2P data exchange. However, Wi-Fi has low stabilization since other devices can easily interfere with the WiFi communication link. Tahmasbi-Sarvestani et al. (2017) and He et al. (2017) found that dedicated short-range communication has better performance, and real-time communication can be carried out between fast-moving vehicles and pedestrians.

[1] *https://smartamerica.org/teams/smart-vehicle-communication/*

[2] *https://www.traffictechnologytoday.com/news/autonomous-vehicles/remote-safety-net-for-texas-am-autonomous-shuttles.html*

Remote-controlled Driving
Under complex traffic conditions, caused either by weather, malfunction, or contradiction in sensory inputs (Kang et al., 2018), vehicles can be remotely controlled by drivers using teleoperation. Such a technology plays an important role in the progression to fully automated driving without driver intervention.

Network delay is a key problem that should be handled with regard to remote-controlled driving. A one second, or even shorter, delay in communication would bring great improvements in driving performance. Davis et al. (2010) found that real-time driving cannot be ensured if the network time delay is greater than one second. The driver reaction time is another factor. Human activities and responses to remote driving can easily increase reaction time. For example, visual-motion coupling delays always exist in a driving simulator (Frank et al., 1988). Related studies are typically conducted using a simulation experiment (Chen et al., 2007). Another notorious delay is caused by the information communication speed in the network. Liu et al. (2017) analyzed the response delay in the long-term evolution network. Results show that delay variability plays a bigger role than the magnitude. A series of methods are proposed to address such a problem. Gohar and Lee (2020) proposed a method in which multiple people are driving the car remotely, from different locations. This allows each driver to drive a different segment of the trip, reducing the physical distance between vehicles and drivers. The current information technology contributes to the reduction of network delay. As claimed by Huawei (2017), the faster 5G network can avoid the limitations of long-term evolution when used.

Automated Technologies

(a) AGV based parking[3] (b) Vehicle platooning[4] (c) Drone delivery[5]

Figure 3 Automated technologies

AGV-based Intelligent Parking Systems
Intelligent parking systems can largely reduce parking time, which includes time spent waiting and searching for parking spaces. Using AGVs is an innovative method that allows vehicles to be carried by AGVs to an empty parking space or be moved out of a parking structure. In the future, this technology might be widely used to assist human-driven vehicle parking.

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[3] *http://www.automatedroboticparking.com/parking-equipment-types/agv/*
[4] *https://people.kth.se/~kallej/papers/vehicle_ieeetits16formation.pdf*
[5] *https://www.suasnews.com/2019/05/dhl-launches-its-first-regular-fully-automated-&-intelligent-urban-drone-delivery-service/*

Most of the existing studies focus on AGV schedule and route optimization in parking stations. Sun et al. (2018) proposed a Dijkstra algorithm to optimize the AGV parking schedule, which considers the operation of multiple vehicles and multiple routes. Results show that the various conflicts and deadlock problems can be solved quickly. Moreover, Liao et al. (2019) combined both the K-shortest path and time windows. Compared with the study by Sun et al. (2018), the K-shortest path provides more alternative solutions when AGVs meet the time-window conflict. Even though route optimization is a traditional problem, the intelligent parking AGV operation brings more breakthroughs. Shi et al. (2018) collaboratively optimized the parking space layout and route design. A multi-objective model is established and then solved using simulation to maximize the utilization rate of parking spaces and minimize drivers' waiting times. Furthermore, they used an ant colony algorithm to solve the multi-objective model (Wang et al., 2020a). Results show that high-quality solutions and high solution speed are obtained in the latter study.

Vehicle Platooning Formation

Vehicle platooning formation is normally used in truck fleets. Platooning is achieved when vehicles in one fleet move at the same speed and maintain a safe constant distance from surrounding vehicles. The leader vehicle decides the speed and direction of the fleet, and the follower vehicles respond to the leader vehicle. It can be remotely operated or automatically decided. The main benefits are fulfilling fuel efficiency and traffic congestion reduction (Axelsson, 2016; Soni and Hu, 2018; Zhang et al., 2020). Platooning may be adopted by groups of vehicles for personal use when traveling to a common destination. Although research is limited on this topic, there may be benefits observable if adopted by intra-city buses.

Vehicle platooning formation operation depends on a complex formation control that can be separated into three categories: leader-follower approach, behavior-based approach, and virtual structure approach (Chunyu et al., 2009; Lawton et al., 2013; Ren and Beard, 2004; Soni and Hu, 2018). A few studies explore performance of the different control approaches. Wang et al. (2020b) analyzed the platooning formation operation reflecting real-time demand by using an agent-based model. Results reveal that the widely used leader-follower approach can largely reduce the hold-on time, which is the time difference between the leading vehicle and the whole vehicle platoon starting to move.

Drone Delivery

Drone delivery is proposed to solve the last-mile delivery problem (Brunner et al., 2019). A drone can drop off parcels with a short travel distance by flying in the air or driving on the road. It is predicted that drone delivery has a large potential market share and that the maximum share may reach up to 30% in European cities (Aurambout et al., 2019).

The existing studies mainly focus on the drone delivery route and schedule optimization problem. Dorling et al. (2016) built two mathematical models to explore the vehicle routing problem (VRP) of drones: minimizing the total operation cost and total travel time. It is found that an inverse exponential relationship exists between the operational cost and delivery time.

Alwateer and Loke (2019) considered the cooperation framework of multiple stations and multiple drones. They show the drone delivery system can ensure a high service rate and few delays.

Shared Technologies

(a) Carsharing[6] (b) Ridesharing[7] (c) SAV[8]

(d) Bike-sharing[9] (e) Carpooling[10] (f) Customized bus[11]

Figure 4 Shared technologies

Carsharing

Carsharing was first proposed in the 1940s when a travel service system called Sefage in Zurich was built to allow neighboring users to share a vehicle (Shaheen and Cohen, 2014). Carsharing can be divided into two categories according to its service operation: round-trip and one-way carsharing. The former asks users to return vehicles to pick-up stations, while the latter allows vehicles to be dropped off at any pre-approved spaces. Considering its station type, one-way carsharing can be divided into a station-based model with fixed parking stations and a free-floating mode with social parking spaces.

The existing studies of carsharing systems focus on two aspects: upper-level strategic planning and lower-level operational decisions (Huang et al., 2018a). The strategic planning decides station location, capacity, and fleet size that belongs to the long-term planning based on the month's or year's travel choice. The lower level optimizes the real-time carsharing operations including vehicle relocations, vehicle movements and personnel movements. When adopting a

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[6] *https://www.automoblog.net/2019/08/04/best-car-sharing-services/*
[7] *https://getcell411.com/2016/10/27/decentralized-ride-sharing-is-here-no-driver-fees-any-payment-method/*
[8] *https://www.sharedmobility.news/cities/*
[9] *https://www.economist.com/the-economist-explains/2017/10/03/how-bike-sharing-works*
[10] *https://www.irishtimes.com/business/car-sharing-start-up-is-the-talk-of-europe-1.1855715*
[11] *https://www.intelligenttransport.com/transport-news/78232/demand-responsive-bus-service-expansion-oxford/*

carsharing system in a city, both levels should be considered together (Brandstätter et al., 2017; Huang et al., 2020b; Xu et al., 2018).

Ridesharing

Ridesharing, also called ride-pooling, can reduce waiting time and travel fees for its users by matching travelers with common origins and destinations, or those that have overlapping routes. Researchers have found that ridesharing can save over 20% vehicle-miles traveled (VMT) and demand (Wang et al., 2018). Another study using a computational experiment indicates that around 66% of taxi demand can be satisfied with limited vehicles if ridesharing is an option (Lin et al., 2012). Besides, ridesharing brings higher profits for the operator (either the driver or a central dispatching agency). Since drivers have no desired origins and destinations, providing ridesharing services can reduce redundant trips (Lyu et al., 2018).

Ridesharing is attracting attention from researchers, who normally divide ridesharing into two sub-problems: matching strategy and fare pricing.

The rideshare matching strategy considers the passengers' matching and route choice simultaneously. These are the primary aspects of both static and dynamic ridesharing. In the former, ridesharing demand over a long period is needed to ascertain how passengers' matching and route choice will be conducted. This is a strategic tool but cannot be implemented for daily operations. Many earlier studies use the static modeling method by introducing daily commute trip data (Hong et al., 2017; Dong et al., 2018). For example, Bimpikis et al. (2019) used the available origin-destination preferences to optimize ridesharing for passengers and matching for drivers. With the rapid development of emerging IT techniques, many mobile Apps allow users to publish ride sharing demand. Other studies focus on dynamic modeling with real-time demand (Lokhandwala and Cai, 2018; Gurumurthy and Kockelman, 2018). Ma et al. (2014) proposed a spatial-temporal index-based searching algorithm to deal with real-time taxi requests. Operational vehicles must pick up other passengers waiting on the roadside. Wang et al. (2018) explored the ridesharing route and schedule design before vehicles departed. Drivers and passengers get the fixed route and pick-up time information and no new passengers will be able to join after the start of the trip. Liu et al. (2019) established a dynamic method to optimize rideshare matching and routing at railway stations. Based on static taxi demand data, the authors randomly generated passengers' destinations and rolled optimization once a new demand is proposed.

Shared Autonomous Vehicles (SAVs)

A fleet of centrally-operated shared AVs, called SAVs, can also be offered with or without ridesharing. They can largely reduce labor costs because no driver-related operation costs are generated during the vehicle relocations and empty movements. Moreover, SAVs have a higher vehicle utilization rate than private cars, which can further help reduce parking demand and vehicle ownership (Fagnant and Kockelman, 2014; Yan et al., 2020). Although AV technology has not matured yet, SAVs have been predicted as one of the main future travel modes, with a comparable disruption to present-day ride-sourcing companies.

Without real data on SAV operations, an agent-based simulation model is established to track vehicle movements. By using the collected demand and network data, the SAV operation environment has been thoroughly tested (Fagnant et al., 2015; Segal and Kockelman, 2016; Levin et al., 2018). A general framework was established that includes the demand inputs, vehicle arrangements, and traffic flow simulations. Using EVs can further reduce operating costs. However, EV-based SAVs bring more difficulties due to the additional charging behavior. Chen et al. (2016), Loeb et al. (2016), and Loeb and Kockelman (2019) used EVs to provide SAV service by setting different scenarios, which include the vehicle fixed costs and charging infrastructure costs. They found that EV-based SAVs bring higher profits and environmental benefits. Moreover, with the rapid development of IT, real-time responses to ridesharing propose more challenges. Gurumurthy and Kockelman (2018) predicted that a very high sharing rate can be achieved if a slightly longer waiting time is allowed.

Bike-sharing

Bike-sharing can address the first-mile and last-mile (FMLM) problem when using public transport. Traditionally, shared bikes are located in fixed stations, called bikeshare stations. Even so, users have to walk a short distance to the bikeshare station and many users may be unwilling to do so. Hence, state-of-the-art dockless bike-sharing systems were developed as a result (Gu et al., 2020). The fixed parking stations are unnecessary because bikes can be parked on most public property, such as roadsides and public parks.

Most studies focus on the factor analysis of bike-sharing services and users' mode choice preferences. For demand generation, Eren and Uz (2020) established a complete research framework to predict bike-sharing demand, which considers weather, temporal and spatial factors, socio-demographic attributes, and safety. Moreover, Gu et al. (2019a) explored how evolving transportation facilities affect bike-sharing demand. A before-and-after survey of bike-sharing choice is conducted when a new mass transit system is made available. Results show that the metro can largely encourage bike-sharing trips. However, for dockless bike-sharing, Gu et al. (2019b) showed that the high demand is due to supply driven by operators rather than user demand because trip allowance promotes market development. Research reveals that dockless bikes provide convenient service for users, but can create bike-parking (pile-up) problems across narrow sidewalks and at popular destinations (Li et al., 2018b; Chen et al., 2020). Dockless bikes are still a controversial topic in many cities like Beijing, Amsterdam, and Singapore (Gu et al., 2019b).

Carpooling as a Business

Carpooling with colleagues, family members, and neighbors was proposed in the last century with the advantages of easing congestion, lowering travel costs and sometimes delivering preferential parking spaces (Li et al., 2018a). Considering the convenient service and low travel fee, sharing vehicles with strangers, called carpooling as a business, can be a bridge between private cars and taxis or on-demand services.

Travel behavior analysis of carpooling has attracted the attention of researchers. A series of revealed preference (RP) surveys were conducted to identify the motivations of carpooling choice. Shaheen et al. (2016) carried out face-to-face and in-vehicle interview surveys to collect mode choice data. It is found that saving time, reducing travel fees, and providing convenient service are the main factors contributing to the carpool decision. When considering unknown carpooling scenarios, the stated preference (SP) survey is proposed. Huang et al. (2019) found that travel time, travel cost, and safety are the main factors deciding users' carpooling choice via an SP survey for about 150 residents of Huaian City, China. IT technology promotes the online survey. Delhomme and Gheorghiu (2016) and Malodia and Singla (2016) deployed web-based surveys for France and India, respectively, with both studies verifying that saving travel time and travel cost play important roles, as expected.

Demand-responsive Customized Bus

To meet the demand-responsive transit service, a customized bus is proposed to bridge taxis or on-demand services and buses. The customized bus has the benefits of a flexible route, dynamic schedule, and high capacity. Passengers can submit the demand as late as hours before departure or as early as a day before departure and propose real-time requests. After receiving a real-time confirmation, the customized bus can take a detour to pick up waiting passengers who are at neighboring stations. In addition, based on the total demand by the booking system, the operator can dynamically arrange vehicles with different occupancies to save operational costs.

The existing studies mainly focus on route optimization. Considering origin and destination stations, the customized bus route can be divided into many-to-one and many-to-many modes. Zhou et al. (2018) defined the former as a single origin and multiple destination service system, normally used in commute buses. The complex situation with multiple origins and destinations of users results in the many-to-many service system (Huang et al., 2020c). VRP always exists in the route optimization of the customized bus, regardless of the route type. Guo et al. (2018) built a mixed integer programming model to address the static route planning based on the given demand. Huang et al. (2020a) explored the demand-responsive route optimization by conducting real-time vehicle searching, in which vehicles have to take a short-distance detour to pick up or drop off new passengers.

Electric Technologies

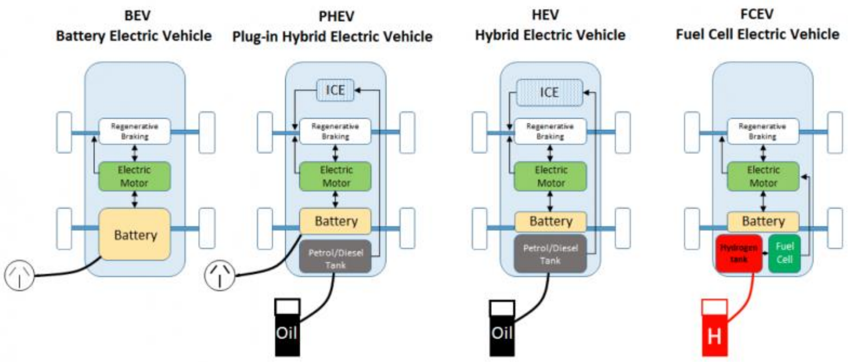

Figure 5 Electric vehicles[12]

Electric Vehicles

Faced with the energy and climate crises, the widespread adoption of electric vehicles is of paramount importance. There are several categories of electric vehicles, including battery-electric vehicles, hybrid-electric vehicles, and fuel-cell-based electric vehicles (Khaligh et al., 2010). Battery electric vehicles (BEVs) use a battery to store energy. Plug-in hybrid-electric vehicles (PHEVs) uses both gasoline (or diesel) energy and electric power. They can be charged externally and harvest power from vehicle operation. But, their electric-only range is typically only 10-30 miles. Hybrid electric vehicles (HEVs) are more fuel-efficient than internal combustion engine vehicles (ICEVs) due to the optimization of the engine operation and recovery of kinetic energy during braking. Fuel cell vehicles (FCVs) use hydrogen as the fuel to produce electricity and are emission-free.

Saving resources and reducing emissions are two main reasons to develop cost-effective EVs that can replace ICEVs. However, the high initial cost as of the current state of technology, short driving range, long charging (refueling) time, and reduced passenger and cargo space have proven to be a limitation of battery-powered EVs (Chan, 2007). Two comparative analyses of the full life-cycle energy consumption and emissions between ICEVs and FCVs were applied in Canada and China. The study conducted in Canada (Zamel and Li, 2005) shows that the energy consumption of FCVs is 87% lower than that of ICEVs and the total emissions of FCVs are 49% lower than that of ICEVs. However, the study in China gave more insightful findings (Wang et al., 2013), with the ratio of energy consumption between ICEVs and FCVs at 1.62 (FCV hydrogen from electrolysis of water powered by Chinese electricity grids), 1.90 (FCV hydrogen from the electrolysis of water powered by coal-fired energy), 0.72 (FCV hydrogen from NG reforming in central power plants), 0.80 (FCV hydrogen from NG reforming in refueling stations), and 0.53 (FCV hydrogen from electrolysis of water powered by nuclear energy). The ratio of emission between ICEVs and FCVs under five scenarios are 2.18, 2.66, 0.61, 0.68 and 0.17. The FCV performs better than the ICEV in most cases.

E-Truck

Electric-powered trucks (E-Trucks) can be used to deliver cargo while saving operation and emissions costs of freight travel. A survey shows that the global market share of E-Trucks is now 10 times larger than it was 7 years ago (Navigant Consulting Inc., 2014). Considering the benefit of low energy use and emissions, E-Trucks are encouraged by the government and society. For users, the incentive for purchasing E-Trucks is the low operation cost (Gallo, 2016).

Only a few studies have been conducted on E-Trucks, with most focusing on battery efficiency and on reducing emissions. Sen et al. (2017) found that the electric heavy-duty truck has better performance than traditional trucks in life-cycle emissions. Furthermore, by considering energy consumption, Qi et al. (2019) optimized the truck path problem, which is finally solved using

[12] *https://www.omazaki.co.id/en/types-of-electric-cars-and-working-principles/*

the classic genetic algorithm. Baek et al. (2020) analyzed battery size during the E-Truck long-term operation considering battery aging and replacement, charging costs, and delivery revenue in the simulation model. Those existing studies attempt to clearly distinguish the advantages of using E-Trucks.

E-Buses

Electric buses (E-Buses) have the benefits of reducing air pollution and saving operational costs. An increasing number of public transport operators are using E-Buses to replace traditional diesel or gasoline-powered buses (Quarles and Kockelman, 2020). A survey conducted by Chediak (2016) shows that E-Buses will take over about 50% of the world's total city bus fleet in 2025.

Most research focuses on fleet size and optimizing the charging station location. In terms of the limited battery capacity, buses need to be recharged on time for their next schedule. Furthermore, to ensure service quality, there must be enough buses to offer services on the road. Hence, the density of charging stations and fleet size will directly affect operators' earnings and bus service quality (Leou and Hung, 2017). Rogge et al. (2018) optimized both aspects and their results reveal that energy consumption costs can be reduced significantly by using E-Buses. However, the total revenue is not increased even with low energy consumption costs. The main reason is the large charging station building costs that should be accounted for. He et al. (2019) studied the fast charger application and found that it brings about better E-Bus performance. Moreover, to analyze the long-term operations, An Kun (2020) considered the uncertain demand of bus users. The vehicle allocation and charging station locations are decided by the day-to-day dynamic demand. This paper suggests adopting fast chargers at peak hours and in high-demand areas to ensure high profits to operators.

DEVELOPMENT TRENDS

As many as 127 articles of CASE-related technologies are cited in above section, with several more published in specific topics. Figure 1 represents the many CASE technologies in the literature in the past 10 years. There is an obvious growing trend of studies related to CASE innovations in recent years, especially in 2018, 2019, and 2020.

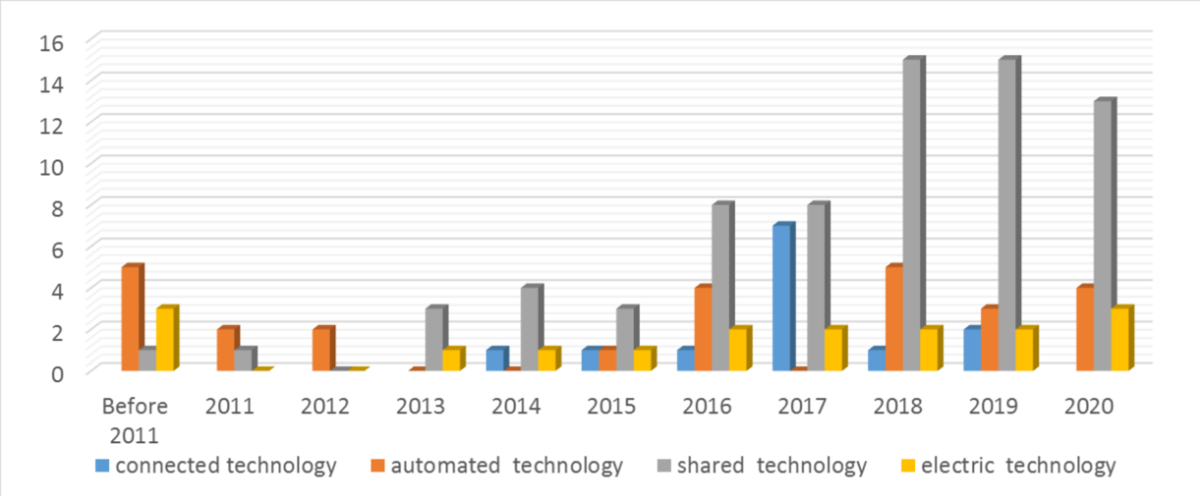

Figure 1 Number of cited publications in CASE technologies

Based on the overview of CASE-related technologies, the future development directions of CASE related technologies are discussed below:

- V2P communication systems have been used in some vehicles, but applications on the pedestrian side are rare. Developing message-receiving devices and providing safety alerts for on-road travelers may be an important focus for the future.
- Remote-controlled driving is an alternative technology to fulfill driverless operation until AVs have gained the trust of the public. For special environments, remote-controlled driving technology can be useful. For example, remote-controlled fire-fighting robots can enter fire sites even if firemen cannot access such locations.
- AGV-based intelligent parking systems are likely to be more popular in large parking stations.
- Truck platooning formation would be adopted in large motorcades. It will provide relief for the truck driver during long-distance trips on the freeway.
- Drone delivery is likely to have a large market share in the future. However, noise and flying risk may block air-based drone delivery development, at least in the near-term. Ground-based drone delivery will be adopted sooner.
- SAVs are a bold innovation, but they are not likely to enter the market soon because AV technology is still not mature. However, they are likely to replace human-driven ridesharing, carsharing, and carpooling services.
- Dockless bike-sharing is losing popularity because it causes some traffic chaos in urban areas, and has therefore been prohibited in many cities. The future of bike-sharing is controversial and not clear.
- Demand-responsive customized bus has a low fare and flexible route, so it can be a significant part of MaaS.
- EVs are predicted to replace ICEVs in the near future. Battery electric and hybrid electric technologies are currently being used by manufacturers. The fuel-cell electric vehicles are limited in quantity but may have a larger market share due to the advantage of zero-emission.

- E-Trucks can save energy resources and protect the environment, and they may become an important transportation tool in the future. However, the limited battery capacity may restrict E-Truck development.
- E-Buses can save energy consumption costs but carry large capital costs for charging station building. Operators have to weigh revenues and costs. However, the E-Bus is likely to eventually hold a larger market share due to the benefits of being environmentally friendly and having a low resource use rate, and, consequently, operating cost.

CONCLUSIONS

This paper explores the technologies impacting the future of transportation by providing an overview of existing and proposed technologies, as well as recommending expected changes in the area. Four main aspects of technologies impacting transportation futures are discussed: connected, automated, shared, and electric technologies. An outline is provided of their development and current research directions. Finally, a thorough discussion is provided, with a set of predictions for CASE technologies.

The review of technology, service, and policy innovations shows that many of these technologies are in the testing phase, although some are actively in use. Vehicle sharing and electrification provide a transition pathway towards CASE. Advancements in battery technology and co-development of grid decarbonization provide support for vehicle electricification being a highly probable pathway. Remote-controlled driving and parking provide controlled environment examples of the path towards vehicle automation.

Predictions show that connected and automated technologies will be developed further in the near-term. Shared mobility will have a large market share: shared autonomous vehicles will offer self-driving carsharing, ridesharing, and carpooling services, and these along with customized buses will be an important part of MaaS. The future trajectory of dockless bike-sharing is unclear. Fuel-cell electric vehicles, electric trucks, and electric buses will be widely adopted.

Many emerging technologies are outlined in this paper. However, there are still many more for which development is in its infancy or the probability of adoption was deemed low (at least in the next 30-50 years). A survey will be developed based on this review to delve deeper into traveler preferences and reservations about the transportation technologies, services, and policies described herein. While the timeline for widescale adoption of these technologies remains uncertain, it is important to anticipate and prepare for their impacts on the transportation system.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm the contribution to the paper as follows: study conception and design: Kai Huang: Conceptualization, Optimziation, Writing. Kara Kockelman: Supervision, Reviewing. Krishna Murthy Gurumurthy:Reviewing. All authors reviewed the results and approved the final version of the manuscript.

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