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Article

Autonomous vehicles impacts on quality of urban life: A review

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ABSTRACT

Developing technology and changing lifestyles also change the expectations of the citizens from the quality of urban life (QOUL). However, today, the automobile-oriented transportation system causes a decrease in the QOUL, especially in crowded cities, due to some reasons such as traffic congestion, high individual vehicle ownership, lack of parking lots, number of accidents, loss of time in traffic, and air and noise pollution. Transportation is one of the indicators that directly and indirectly affect the QOUL. Transportation, which is sensitive to technology, can also directly affect urban space and affect mobility and accessibility in the city. In this context, new technologies such as autonomous vehicles (AV) can lead to significant changes in urban space, human behavior, and QOUL. Once these vehicles are launched, they can affect our lives in many ways: transportation, environment, urbanization, social, economic, and legal. This makes AVs a part of the social debate. Although there are many studies in the literature examining how AVs will affect the fields of transportation, environment, economy, and law, there are very limited studies on how AVs will affect the QOUL. Based on a literature review of the relationship between AVs and QOUL, this study aims to predict how AVs will affect QOUL. According to the findings, it has been observed that AVs will positively affect the QOUL life when they are operated with car sharing/ride-sharing, using electricity, and when they are integrated with public transportation. However, AVs can lead to congested and polluted complex urban centers, suburbanization, extrainfrastructure investment, and cyber threats. According to the study findings, the effects of these vehicles on the QOUL vary depending on the policies applied, the social acceptability of the vehicles, the preparation of the infrastructure, and the market share. With the right policies, know-how, and appropriate infrastructure, AVs can be an opportunity to improve the causes that reduce the QOUL in today's cities.

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INTRODUCTION

Developing technology and changing lifestyles have led to an increase in the expectations regarding the quality of urban life (QOUL) of individuals living in cities. In recent years, QOUL has remarked widespread in different fields such as sociology, economy, psychology, politics, and marketing. In addition, when considering QOUL, the elements that constitute the QOUL should also be evaluated in terms of spatial and local social (Bilgili, 2017). Transportation is also one of the factors affecting the city in terms of spatial and other fields. Transportation, which is sensitive to technological developments, directly and indirectly affects the QOUL. The change in transportation, which has had a great impact on the urban form throughout history, is one of the most basic tools that guide spatial development based on accessibility and mobility. The increase in the use of automobiles in the 1950s was the beginning of the wave of suburbanization, and today, the automobile-oriented transportation system causes a decrease in the QOUL, especially in crowded cities, due to some reasons such as traffic congestion, high individual vehicle ownership, lack of parking lots, number of accidents, loss of time in traffic, and air and noise pollution. With the developments in the automotive industry, the dream of driverless vehicles has become a reality and it is predicted that they can be a solution to today's transportation-related problems. Autonomous vehicles (AVs), which are planned to be launched soon, are expected to affect our cities not only in the field of transportation but also in many areas such as the environment, urbanization, social, economic, and legal regulations. Thus, they can affect the QOUL as well. This makes AVs part of a public debate.

In the construction of livable cities, it is important to predict the future to determine the appropriate policies. Although many studies have been conducted on the effects of AVs on traffic, transportation, and daily habits, very limited studies have been conducted on how AVs will affect the QOUL. This study aims to predict how urban transportation, which can directly or indirectly affect the spatial functions of the city, can be affected by AVs and how its projection to the urban space can affect QOUL. Within the scope of this study, QOUL criteria suggested in previous studies are evaluated with the content analysis method from the literature, together with the possible effects of AVs. In the study, the features of AVs, their effects, and spatial results are evaluated within the framework of QOUL indicators, and it is tried to predict how they would affect the QOUL as a result.

QOUL INDICATORS AND TRANSPORTATION

Simultaneously with the progress in communication and technology, physical and social transformations have been experienced in cities, especially in the past century. These transformations have also affected the way cities are handled, new methods and approaches have been adopted in urban planning and transportation. According to Wey and Huang (2018), urban planning and the development of transportation have a significant and positive effect on the construction of livable and sustainable cities. At the same time, this situation is related to the QOUL (Taki, et al., 2017; Wey, 2015; Wey and Chiu, 2013; Wey et al., 2016). QOUL is a complex concept as it includes variables and multidimensional aspects related to the urban built environment (Wey and Wei, 2016). Although there are many studies on the definition and measurability of QOUL, there is no common definition and standard indicators (Sarı and Kındap, 2018). QOUL concept means that each individual can benefit from the opportunities offered by the city in an equal, balanced, and proportionate manner and also has the opportunity to participate in educational, social, political activities, and processes (Yakin Inan and Ozdemir Sönmez, 2019). This concept is also explained as the ratio between the supply and demand of the city's need for urban services (Görün and Kara, 2010; Turgut, 2007; UN-HABITAT, 1996). The concept of QOUL, which first emerged with the Social Indicators Movement in the 1960s, includes both the natural and built environment, but is more concerned with urban equipment and comfort, and may vary from person to person.

Different indicators/categories have been suggested in studies to measure the QOUL of urban residents. For instance, in the study of Psatha et al. (2011), they suggested 12 general categories to determine the QOUL in European cities. These are economic environment, social environment, natural environment, built environment, urban and suburban green spaces, public spaces and public buildings, culture and leisure, demographic data, education, healthcare, democratic institutions, and traffic and transportation. In the study of Yakın Inan and Ozdemir Sönmez (2019), based on UN, OECD, and EU indicators, they proposed nine indicators to measure the QOUL, namely housing, education, environment, health, safety, transportation, information and communication, infrastructure, and culture, sports, and recreation. Vlasov et al. (2021) stated in their study that there are four indicators of QOUL and discussed them with the titles of urban transport, urban economy, urban social, and urban environment. In the studies, it was defined as the components of the transportation indicator such as traffic situation, parking area, access and effectiveness of public transportation, access to regions, time spent in traffic, transportation infrastructure, rate of business trips according to modes, smart transportation systems, Information and Communication Technology (ICT) support for transportation, and it was supported that these components would affect the QOUL (Psatha et al., 2011; Vlasov et al., 2021; Yakın Inan and Ozdemir Sonmez, 2019). Furthermore, some studies show that transportation will affect the QOUL in many ways (Bonaiuto et al., 2006; Forkenbrock, 2004; Michalos and Zumbo 1999; Senlier et al., 2009; Shafer et al., 2000; Turksever and Atalik, 2001). For example, Schneider's (2013) study for the state of Minnesota revealed that transportation will directly and indirectly affect the QOUL in the categories of safety, maintenance, infrastructure, accessibility, mobility, environment, energy, design, and transparency. In this context, it can be said that the transportation system affected by the changing technology can change with AVs, and this will affect the QOUL. Similarly, it has been claimed in the previous studies that AVs will increase QOUL (Hawes, 2017; Russell, 2015). From this point of view, in this study, how AVs will affect that urban life has been examined under 5 generalized indicators, and then how it will affect that the QOUL has been evaluated.

AVs AS A TYPE OF TRANSPORTATION

In the early 1900s, with the replacement of horse-drawn transportation by motor vehicles, it was seen how cities transformed the way cities functioned and human movements, and it was thought that innovative technologies could revolutionize the way we think, plan, and design cities (Duarte and Ratti, 2018). Today, city planners are working on many trends that will increase accessibility and mobility, such as 20-Min Cities and smart mobility (Calafiore et al., 2022; Toan, 2022). While AVs have been experimentally limited to traffic, transportation planners and urban planners agree that they can redefine urban mobility soon.

Although different from today's AVs applications, the first AV idea became reality with the Fantom-Autos moving with radio frequencies in the 1920s, followed by the vehicles moving with the automation placed in the infrastructure of General Motors in the 1950s (Duarte and Ratti, 2018). Today, it is seen that this science fiction element has become reality with the organization of Defense Advanced Research Projects Agency, where AVs are tested in the urban area (Buehler et al., 2009). With the knowledge of technology, it is observed that the production in the vehicle market has shifted to AVs. In other words, the auto industry is constantly incorporating algorithms and devices required by AVs into regular vehicles. Society of Automobile Engineers defined six different levels of autonomous driving: Zero, when drivers have full control of the car; one, when certain functions, such as steering and acceleration, are performed automatically; two, when some functions respond using information about the driving environment, but the driver must be ready to take control; three, when cars are fully autonomous under certain traffic conditions; four, they can operate in any driving scenario, when the cars perform all safety-critical driving functions within a certain number of driving scenarios; and five, when the vehicles are fully autonomous (Duarte and Ratti, 2018; SAE On-Road Automated Vehicle Standards Committee, 2014).

Conventional vehicles need a driver because they are incapable of sensing and controlling. However, the Advanced Driver Assistance System (ADAS) has long been widely used to improve the driving experience (Yan et al., 2016). They provide dynamic driving control with the data that they receive from the sensors of the AVs for driving control and, therefore, require almost no human intervention. The ADAS has many features that reduce the driving responsibility, such as parking assistance, traffic sign recognition, lane tracking system, blind spot monitoring, and emergency braking system (Kotori, 2018; Schwarz et al., 2013). The developing technology enables vehicles to perceive and make sense of the environment with sensors and cameras. Recently, AVs mostly use LIDAR (laser beams for object identification), Sonar (ultrasonic sound waves for obstacle identification), Radar (radio frequencies for measurement of relative distance, obstacle avoidance, and movement of vehicles on roads), and cameras; finally, the data are interpreted with artificial intelligence (Yan et al., 2016). For AVs to perform at their best, they must not only detect but also communicate with other devices and infrastructure (Duarte and Ratti, 2018). Therefore, AVs communicate with Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-pedestrian (V2P), Vehicle-to-Network (V2N), and all devices that allow wireless connectivity. These communications are generalized as Vehicle to Everything (V2X). Moreover, it is possible to determine the location of the vehicle with GPS and access to simultaneous maps (Kumar et al., 2012).

According to researches on who will own and share AVs when they are released, these vehicles can be used both privately (individually owned and used within the family) and commercially shared (car-sharing/ride-sharing) (Collingwood, 2017; Heinrichs, 2016; Silva et al., 2021). In addition, AVs can be used for commercial taxis or public transport (PT) (Fagnant and Kockelman, 2014; Krueger et al., 2016). Passenger behavior, attitude, social norms, trust, perceived ease of use, perceived risk, compatibility, perceived usefulness, price/performance ratio, mobility, and value of time relative to the person can be influential in the acceptance of AVs (Jing et al., 2020). The study by Moavenzadeh and Lang (2018) found that the acceptance rate of AVs in fast-growing megacities such as Mumbai and Beijing is higher than those in developed markets such as Osaka and Amsterdam. This is because heavy traffic and its consequences affect consumer preferences. It is estimated that the acceptability of AVs will increase as environmental concerns increase and the education level and income level increase in the young population

(Jacyna, 1998; Jacyna and Merkisz, 2014; Koul and Eydgahi, 2018; Silva et al., 2021). How AVs will affect our cities and transportation as they become part of daily life and the benefits/harms will undoubtedly depend on market penetration. It can be said that the first of the variables affecting this situation is social acceptability, how the vehicles will be used, and whether the urban infrastructure is ready for this.

POSSIBLE EFFECTS OF AVs ON THE CITY AND EVALUATION

From the historical perspective, the change observed in the development of urban settlements shaped based on transportation can also be experienced with AVs. AVs will impact urban space and urban life, and therefore on QOUL, as well as on the development and macro form of cities. The possible effects of these vehicles on cities will have many dimensions. Considering the previous QOUL studies, it is possible to collect the possible effects on cities under five indicators: transportation, urbanization, infrastructure, environment, and security.

Transportation

Transportation, and especially urban transportation, has a very wide expansion. Urban transportation is defined as all private or community, personal or public, and commercial or non-commercial transportation activities that occur in a city, and the infrastructure, superstructure, and organization (coordination, management, governance) elements used in fulfillment of these activities (Şenbil, 2012). It is estimated that AVs will have direct or indirect effects on many components of transportation, such as traffic, road capacity, travel demand, travel time, pedestrian-vehicle safety, vehicle ownership, parking needs, and PT.

The main effect of AVs is on traffic. Factors such as different headways, different gap acceptance values, different acceleration values, and different driver behavior (more aggressive or softer) can change the characteristics of the traffic flow and change the existing can cause serious changes in road capacity. In some of the previous studies, it is predicted that AVs will move with lower headways, which will increase road capacity (Friedrich, 2015; Tientrakool et al., 2011) or that lower headways will increase road capacity as AV penetration increases (Li et al., 2020; Mena-Oreja et al., 2018; Talebpour and Mahmassani, 2016). However, Ploeg et al. (2011) stated that headways <2.0 s cause imbalances in traffic flow when V2V and V2I communications are not available. In other studies, it has been claimed that V2V communication provides a safe following distance and stable traffic flow, and they can move on narrower roads due to both less lane use and sharing opposite directions, but this can trigger demand (Millard-Ball, 2018; Naus et al., 2010; Olia et al., 2018; Schlossberg et al., 2018; Swaroop et al., 1994; Swaroop and Rajagopal, 2001).

While it may seem unusual to share a personal vehicle with a stranger, ride-sharing practices have reduced the number of cars on the roads in various countries. In the study of Fagnant and Kockelman (2014), it is argued that each shared autonomous vehicles (SAVs) can replace ten conventional vehicles. Bischoff and Maciejewski (2016) showed that each SAV can replace 11 conventional vehicles, with 100% market penetration. Although using SAVs provides more equal mobility and lower costs, it is predicted that the increase in travel time by ghost trips, the use of different AVs by people sharing the same vehicle, and the demand created by low prices will increase VMT/VKT (vehicle miles /kilometers traveled) (Bahamonde-Birke et al., 2018; Bischoff and Maciejewski, 2016; Fagnant and Kockelman, 2014; Heilig et al., 2017; Levinson and Krizek, 2015; Lokhandwala and Cai, 2018; Martinez and Crist, 2015; Medina-Tapia and Robusté, 2019; Milakis et al., 2017; Moavenzadeh and Lang, 2018; Moreno et al., 2018; Pakusch et al., 2018; Plumer, 2013; Sivak and Schoettle, 2015; Smith, 2012; Spieser et al., 2014; Vosooghi et al., 2019; Zhang et al., 2015). Studies on the effect of SAVs on traffic congestion usually have two opposite views. On the one hand, it is believed that ride-sharing systems can cause an increase in congestion (Zhao and Kockelman, 2018); on the other hand, these systems will reduce congestion (Alazzawi et al., 2018; Martinez and Viegas, 2017). Narayanan et al. (2020) suggest that the positive effect of ride-sharing depends on various factors, such as average vehicle density, demand density, pattern, network topology, vehicle assignment, and location algorithms.

Salazar et al. (2018) suggest that SAVs and PT integration could reduce traffic, while Moavenzadeh and Lang (2018) claim that SAVs could replace individual vehicles and PT. While Stanford (2015) predicts that AVs will cause traffic congestion if they replace PT, Duarte and Ratti (2018) suggest that AVs can be used as a feeder mode for PT stations and corridors. Both Moavenzadeh and Lang (2018) and Litman (2018) stated that while the increase in the possibility of car sharing due to high demand density in the city causes a decrease in traffic, it will increase in the suburbs. In the study of Alessandrini et al. (2015), it is assumed that when people who are currently unable to drive (old, disabled, young, etc.) use AV, urban mobility will increase, in addition, the elimination of driving obligation and ease of use will trigger demand.

Vehicles spend most of their time in parks, and parking lots occupy large areas in the city center (Economist, 2015). In the studies on the parking needs of AVs, it is claimed that the need for parking of AVs will decrease, and AVs can park in cheaper areas far from the city center as they can park without a driver (Bruun and Givoni, 2015; Keeney, 2017; Martinez and Crist, 2015; Yigitcanlar et al., 2019; Zhang et al., 2015; Zhang and Guhathakurta, 2017). In this way, urban centers can become more dynamic, but this can lead to denser urban centers. However, there are also studies showing that AVs will increase the need for parking (Duarte and Ratti, 2018; Grush et al. 2016; Stead and Vaddadi 2019; Zhang et al., 2015).

The greatest impact of AVs will undoubtedly be on transportation. It can lead to great spatial and mobility differences in the urban area, both by changing passenger/driver behavior and by changing road uses. Especially (even if there are opposing opinions, according to general belief), it can lead to more stable traffic flow and more effective use of the road network with its sensors, communication, and artificial intelligence. In this way, when applied correctly, they can solve traffic congestion, one of the greatest problems in cities.

Urbanization

The transportation networks, which cover the largest area use in urban areas (between 25 and 35%), are the main land use in cities (Yigitcanlar et al., 2019). It is believed that AVs will change their traveling behavior (including pedestrians), and thus, our cities will also change (Millard-Ball, 2018). Even if fully AVs are not noticed when they come out, the consequences for urban mobility and urban design can be enormous (Duarte and Ratti, 2018). It is predicted that accessibility and location selection, which may change depending on the change in travels in cities, may also lead to land use and street structure.

In some of the studies examining the effects of AVs on urbanization, it is predicted that the reorganization and redensification of city centers can lead to greener land use and increase the quality of the built environment, which can provide more pedestrian-friendly city centers (Duarte and Ratti 2018; Stead and Vaddadi, 2019). Programming AVs according to traffic rules and speed limits can make cities safer, and it is expected that with the elimination of man-made accidents, fatal accidents will decrease, but not completely due to machine failures (Duarte and Ratti, 2018; Fagnant and Kockelman, 2015; Keeney, 2017; Teoh and Kidd, 2017). According to Beraldi and Thomas (2007), it would be reasonable to allow only AVs to navigate in old settlements, areas with chronic traffic congestion, and narrow and difficult-to-navigate areas. With the platooning technology of AVs, it can create empty spaces for city planners using highways more effectively. It can offer better quality roads for both vehicles and pedestrians, more suitable for urban life (Yigitcanlar et al., 2017; Yigitcanlar et al., 2019). In their study, Zhang et al. (2018) simulated housing location selection with SAVs and concluded that SAVs will not cause urban unfretted sprawl, older people will move closer to the city center and the younger generation will move away from the city center in a limited way.

On the other hand, it is argued that the built environment can be reshaped in line with the needs of AVs and users, urban sprawl will increase due to comfortable trips and suburbanization will increase (Anderson et al., 2014; Meyer et al., 2017; Stead and Vaddadi, 2019). According to Guerra (2016) and Litman (2017), while AVs offer high comfort and road capacity when offered at low prices; it is predicted that they will increase accessibility, cause urban sprawl, and make PT unnecessary. Moreover, the minimum waiting time of SAVs in parking lots will not only reduce the need for parking in the city center but also increase urban density and increase real estate prices in remote settlements (Bagloee et al., 2016; Heinrichs, 2016; Levine et al., 2017; Rubin, 2016; Snyder, 2016).

Many conflicting results can be obtained from studies evaluating the possible effects of AVs on the city. It can reduce driving; it can offer greener, pedestrian-friendly, more accessible cities, offer higher built environment quality, and less traffic congestion, in other respects, it can increase urban sprawl and suburbanization by increasing passengers, increasing real estate prices, additional infrastructure costs, decrease in PT use, densely populated, and cities with increased air/water pollution and decreased livability can also present. While it causes denser urbanization in urban centers, it may lead to dispersed and low-density settlements in urban peripheries and suburbs.

Infrastructure

Urban infrastructure means the needs and tools necessary for fulfillment functions in a city. For the solution to urban problems, the city and urban infrastructure should be approached holistically (Şahin, 2018). The requirements and impacts of AVs, it is expected to change urban infrastructure in numerous ways after they are released.

In his studies examining the transportation effects of AVs, Litman (2017) predicts that AVs need special lanes for positive effects such as automation at intersections and reduction of traffic congestion and this will cause fairness and cost discussions. Glancy (2015) similarly claims that on roads, where automation and collaborative movement increase, additional infrastructure, such as antennas and roadside processing units will be demanded. Tachet et al. (2017) argue that AVs do not need traffic signaling. In addition, it is estimated that gas/petrol stations will be unnecessary, and charging stations will be needed in parking lots (Nunes et al., 2016).

When the studies are examined, it is seen that the urban infrastructure needs to be renewed/improved to run AVs in the most beneficial way for the city. However, although the requirements such as antennas, charging stations, data collectors, and distributors are expected to improve the traffic flow, how to meet the cost, ownership, and financing continues to be discussed.

Environment

Environmental problems, which are one of the biggest problems of big cities today, are increasing due to the increasing population, traffic congestion, and production activities. In particular, air pollution caused by production, transportation, and traffic reaches a level that threatens life in some countries. There is a widespread perception that AVs will be less harmful to the environment due to the expectation that they will reduce traffic and be electrified.

Studies on the environmental effects of AVs are expected to reduce emissions, especially when they are used electrically (Fagnant and Kockelman, 2014; Greenblatt and Saxena, 2015; Lokhandwala and Cai, 2018; Martinez and Viegas, 2017; Martínez-Díaz and Soriguera, 2018; Pakusch et al., 2018; Salazar et al., 2018; Vleugel and Bal, 2018). In addition, it is predicted that autonomous driving, smart steering/motion control, and V2V and V2I communication will provide fuel savings (Anderson et al., 2014; Bullis, 2017; Snyder, 2016; Walker and Crofton, 2014). Moreover, it is expected that AVs will cause less air pollution with low greenhouse gas emissions, and they will be able to find parking spaces in smart cities in a shorter time (Medina-Tapia and Robusté, 2019; Moreno et al., 2018).

Integrating electric vehicles (EVs) and SAVs systems can significantly reduce energy consumption (Fagnant and Kockelman, 2014; Zhang et al., 2015). Integrating SAVs and PT can cause reduced emissions, less traffic congestion traffic, and a decrease in transportation costs (Salazar et al., 2018). In addition, reducing human safety measures to save more fuel, as traffic accidents will likely decrease; therefore, with a reduction in vehicle weight (for example, no longer using bumpers), passive measures may no longer be necessary (Capp and Litkouhi, 2014).

Being electric, being shared, and being able to make simultaneous route planning, AVs can both save fuel and reduce emissions. However, it should be noted that this technology, which seems to be environmentally friendly, can become waste that is harmful to nature when used in batteries of electric cars when they reach the end of their life. Furthermore, AVs can trigger traffic demand and contribute to pollution by increasing urban sprawl. In general, urban sprawl tends to have negative environmental impacts by increasing energy use and reducing water and air quality (Wilson and Chakraborty, 2013). Considering the possibility that the advantages offered by AVs may cause urban sprawl, it shows that AVs are far from being environmentally friendly if the right transportation/management policies are not applied.

Security

Promising safer traffic flow, AVs can radically change our perception of security in our transportation system today. Today, many vehicle manufacturers add features that increase automation to vehicles (Morando et al., 2018). Many studies examining the safety effects of AVs predict that accidents will decrease after the human intervention is eliminated (Fagnant and Kockelman, 2015; Sivak and Schoettle, 2015). Kockelman et al. (2016) suggest that because AVs are less aggressive than human drivers, they will increase road and intersection capacity in the long term, choose shorter routes, and take fewer risks. However, Koopman and Wagner (2016) and Morando et al. (2018) argue that AVs must have a high market share for the benefits of increased automation to be fully realized. It is also assumed that the platooning, communication, brake assist system, and sensors of AVs will reduce accidents (Hannawald and Kauer, 2004; Gavrila et al., 2003; Rosén et al., 2010; Rosén and Sander, 2009; Tian et al., 2016; Zhou et al., 2017).

In addition to the positive studies that all these AVs will increase driving safety, studies have been published that argue that they may require human intervention in case of failure (Dixit et al., 2016), cause security problems due to their communication may be a target of privacy sharing/malicious attacks, and the GPS data received/sent by the vehicle can be manipulated (Koopman and Wagner, 2017; Petit and Shlafover, 2014; Taeihagh and Lim, 2019).

AVs are expected to offer a safer driving experience with their technology, artificial intelligence, sensors, and communication features. However, at this point, discussions continue about who will be responsible for the accident, emergency behavior, how to communicate with the immediate environment, and data security. According to the studies, it can be said that AVs can reduce fatal/injury accident rates with high market share, appropriate infrastructure, and communication. However, especially the discussions on cyber security remain up to date.

Evaluation of the Impacts of AVs on Urban Space and Quality of Urban Life

Knowing the factors that can affect the QOUL of the citizens gains great importance in determining the policies to be followed in the city administration and the existence of livable cities. In this context, transportation connections that directly affect the urban space should be considered together with the changing technology. AVs may also deeply affect both urban transportation and urban space. It has been mentioned above that use of AVs, there may be a wide variety of effects on the QOUL within the framework of transportation, urbanization, infrastructure, environment, and security. The relationship and impact of these effects on urban space and QOUL are evaluated in Table 1.

According to Table 1, when the transportation indicator is considered, AVs can positively affect the QOUL for each sub-title. It is seen that especially self-parking will improve the QOUL. However, not requiring responsibility, having no age and license restrictions, easy to use/access, and being an alternative to PT may negatively affect QOUL. The use of lower headways has the potential to both improve and deteriorate traffic. In addition, ride-sharing/car-sharing can reduce QOUL by increasing empty trips and travel demand, while reducing the number of vehicles in circulation can improve QOUL. When the urbanization indicator is analyzed, AVs can improve QOUL due to the lack of human intervention in terms of traffic safety, accessibility and land use, advanced sensing, and platooning, but they can also have the opposite effect due to low prices and automated mobility. They may also lead to a decrease in QOUL as there is no need for driver responsibility in the urban form and land value subtitles. In the infrastructure indicator, AVs cause the QOUL of citizens to decrease due to the need for new infrastructure investments, while making some infrastructure elements unnecessary can increase the QOUL by gaining space in the city. When the environmental indicator is examined, it is predicted that AVs can increase QOUL with advanced control strategies, integration with PT, working with electricity, and design in the sub-titles of air pollution and fuel consumption, but it will decrease QOUL in the built environment due to urban sprawl. Considering the safety indicator, it can be expected to adversely affect QOUL, especially in cyber security, and increase the QOUL by providing safer driving with ADAS and communication features in the pedestrian and traffic subtitles. However, it should be considered that in case of malfunction, it may decrease the QOUL in terms of pedestrian and traffic safety. As a result, it is seen that the widespread use of these vehicles in cities may lead to changes in travel and road infrastructure and sections in terms of transportation. At this point, it is thought that it may change some land use and density decisions at the urban scale and may affect the urban development and some site selection decisions at the regional scale.

CONCLUSION

It has been seen throughout history that transportation has had a great impact on the urban form. The increment of the automobile in the 1950s marked the beginning of the wave of suburbanization and innovations in transportation continued. It is expected that AVs, which are planned to be launched soon, will cause fundamental changes in human travel behavior, which will affect the social structure and urban form, and thus the QOUL. AVs can facilitate car-sharing/ridesharing, increasing limited accessibility and reliance on sharing systems.

Although AVs impact the city and citizens in various areas, it can be said that the greatest change in space can be seen in using roads and parking lots, as they use the urban infrastructure more effectively. For instance, if roadside parking areas are converted for cultural activities, commercial uses, and vendors, or used for different street improvements, and public space activities, it can contribute to the development of the local economy and overall QOUL of the area. Similarly, when the areas gained by the more effective use of infrastructure are used as green areas, it can serve the citizens and contribute to reducing air pollution caused by traffic.

However, besides all these positive possibilities, AVs may cause a tendency to develop in suburban areas. In this case, construction pressure may occur in natural areas and the protection-utilization balance may be endangered. They can cause urban centers to become more polluted, with high land prices, dense, and complex. In addition, rising demand may cause an increase in transportation-related problems today. Moreover, the need for infrastructure investments may arise. All of these can reduce the QOUL of citizens. When AVs are put into use, it is important to take human-oriented policies, prepare the appropriate infrastructure, make the necessary preparations, and take measures in order not to reduce the QOUL of the citizens.

As a result, all spatial effects that may affect the QOUL of AVs after they are put on the market may vary depending on the policies implemented by the management, the acceptability of these vehicles by the citizens, how well the infrastructure is arranged, and their market penetration rate. With the right policy, information, and infrastructure, AVs can turn into an opportunity by reversing the negative conditions that reduce the QOUL in big cities today. In addition, predicting the effects of AVs on space and QOUL will contribute to the urban planning discipline, which has an important role in space organization, in producing new solutions in the field of planning and design.

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Table 1. Possible effects of autonomous vehicles on urban space and quality of urban life

Quality of urban life ındicator	Subtitle	Autonomous vehicle features	References	Possible effects	Spatial results	Impacts on quality of Urban life
Transportation	Traffic	Communication	Naus et al., 2010; Swaroop et al., 1994; Swaroop and Rajagopal, 2001	More stable traffic flow	Cities with less traffic congestion	Positive
			Olia et al., 2018	Increase in road capacity		
		Lower Headways	Nowakowski et al., 2016; Schlossberg et al., 2018; Tientrakool et al., 2011			
			Nowakowski et al., 2016	Fuel Saving	Less air pollution	
			Millard-Ball, 2018	Increasing travel demand	Traffic jam Increased travel time	Negative
	Public Transport	Alternative to Public Transport	Stanford, 2015; Moavenzadeh and Lang, 2018	Reducing public transport use		
			Salazar et al., 2018	Decrease Traffic	Less traffic and air pollution	Positive
		Feeder to Public Transport	Duarte and Ratti, 2018	Increasing accessibility to areas without access to public transport lines	Higher accessible cities	
	Travel Demand, Travel Time	No age and license restrictions	Alessandrini et al., 2015	Transportation for the elderly, children, and the disabled	More urban mobility	
		No need for driver's liability	Duarte and Ratti, 2018	Increasing road use	Increased traffic congestion and time spent in traffic	Negative
		Easy access/use to vehicles	Alazzawi et al., 2018; Martinez and Viegas, 2017; Zhao and Kockelman, 2018	Increase congestion		
			Lokhandwala and Cai, 2018	Replacing the existing taxi system		
			Pakusch et al., 2018	Decrease congestion	Increase travel demand	Negative
		Ride-Sharing/Car Sharing	Bischoff and Maciejewski, 2016; Fagnant and Kockelman, 2014; Levinson and Krizek, 2015; Milakis et al., 2017; Ratti and Biderman, 2017; Spieser et al., 2014; Vosooghi et al., 2019	Decreased number of cars in circulation	Less traffic jam Reduction in air pollution Decreased time spent in traffic Reduction in individual travel fees	Positive

Table 1. CONT.

Quality of urban life indicator	Subtitle	Autonomous vehicle features	References	Possible effects	Spatial results	Impacts on quality of Urban life
			Plumer, 2013; Sivak and Schoettle, 2015	Reduction in individual vehicle ownership		
			Medina-Tapia and Robusté, 2019	Decreased distance per vehicle		
			Bahamonde-Birke et al., 2018; Bischoff and Maciejewski, 2016; Fagnant and Kockelman, 2014; Martinez and Crist, 2015; Moavenzadeh and Lang, 2018; Moreno et al., 2018; Pakusch et al., 2018	Increase in VMT/VKT due to empty trips	Increased congestion Increase in the number of vehicles in circulation Increased emissions and environmental pollution With less space dedicated to vehicles (roadways and parking)	Negative
			Bahamonde-Birke et al., 2018	Increase in travel demand		
	Parking	Self-parking	Keeney, 2017; Martinez and Crist, 2015; Zhang et al., 2015; Zhang and Guhathakurta, 2017	Decreased parking space requirement	Gaining public space in the city center Cities with more compact uses	Positive
			Zhang et al., 2015	Making roadside parking redundant		
			Yigitcanlar et al., 2019	Finding cheaper parking spaces		
Urbanization	Traffic safety	No human intervention	Keeney, 2017	Fewer accidents	Safer and livable cities	Positive
		Perceiving the environment with artificial intelligence and sensors	Duarte and Ratti, 2018; Fagnant and Kockelman, 2015	Following the traffic regulations		
	Accessibility		Beraldi and Thomas, 2007	Less lane use and maneuvering space	Improving transportation in old settlements, narrow and difficult-to-navigate areas	
		Lower prices	Guerra, 2016; Litman, 2017	Improved accessibility	Urban Sprawl	Negative
	Land Use	Automated mobility	Grush et al., 2016	Increase in demand	Increase in the need for parking	
			Stead and Vaddad, 2019		Need for drop-off points	

Table 1. CONT.

Quality of urban life indicator	Subtitle	Autonomous vehicle features	References	Possible effects	Spatial results	Impacts on quality of Urban life
		Platooning	Stead and Vaddadi, 2019; Yigitcanlar et al., 2017, 2019	Empty spaces in urban areas	Quality of the built environment will increase with the recentralization or reorganization of inner areas, re-densification, land use change to new green area	Positive
		No need for vehicle driving responsibility.	Duarte and Ratti, 2018	Decrease in trips	Pedestrian-friendly central business areas	
	Urban form		Anderson et al., 2014; Duarte and Ratti, 2018; Stead and Vaddadi, 2019	Site selection from suburban areas	Urban sprawl	Negative
			Wilson and Chakraborty, 2013		Increasing energy use, reducing water and air quality Increasing infrastructure investments and costs	
	Land value		Bagloee et al., 2016; Heinrichs, 2016; Rubin, 2016; Snyder, 2016		Rising real estate prices in the suburbs	
Infrastructure	Traffic signalization	Communication	Tachet et al., 2017	No need for traffic signaling	Extra urban area gain	Positive
	Highway operators	Automatic transitions	Glancy, 2015	Antennas and roadside processingunits' requirement	Requires additional investments	Negative
			Litman, 2017	Special lane requirement		
	Energy	Working with electricity	Nunes et al., 2016	Charging stations requirement		
Environment	Build Environment	Integration with infrastructure	Wilson and Chakraborty, 2013	Urban Sprawl	Expansion of infrastructure due to urban sprawl and its negative effects on the environment	
	Air Pollution	Soft acceleration/declarations, optimal control strategies, and energy management	Bahamonde-Birke et al., 2018; Martínez-Díaz and Soriguera, 2018; Pakusch et al., 2018; Wadud, 2017	Compact and mixed-use land use	Decrease in environmental pollution Lower emissions	Positive

Table 1. CONT.

Quality of urban life indicator	Subtitle	Autonomous vehicle features	References	Possible effects	Spatial results	Impacts on quality of Urban life
		Communication	Fagnant and Kockelman, 2014	Platooning		
	Fuel Consumption		Anderson et al., 2014	Fuel-saving		
			Medina-Tapia and Robusté, 2019	Finding a parking area in a shorter time		
		Integration of Public Transport and SAVs	Salazar et al., 2018	Reduced emissions Reducing traffic congestion		
		Intelligent steering and movement	Walker and Crofton, 2014			
		Integration of EV and SAVs	Fagnant and Kockelman, 2014; Greenblatt and Saxena, 2015; Lokhandwala and Cai, 2018; Martinez and Viegas, 2017; Salazar et al., 2018; Vleugel and Bal, 2018; Zhang et al., 2015	Less fuel consumption		
		Design	Capp and Litkouhi, 2014	Reduction in vehicle weight		
Security	Pedestrian and Traffic Security	No human intervention	Dixit et al., 2016	Require human intervention in some malfunction situations.	The dangerous urban environment created by careless users	Negative
			Morando et al., 2018; Fagnant and Kockelman, 2015	Reduction of human-induced accidents	Reduction in fatal and severe injury accidents	Positive
		ADAS	Rosén et al., 2010; Sivak and Schoettle, 2015	Reduce collision severity		
			Gavrila et al., 2003; Hannawald and Kauer, 2004; Rosén and Sander, 2009;		Safer driving in cities	
		Communication	Tian et al., 2016	Platooning	Reduction of chain accident risk and accident severity	
	Cyber Security		Koopman and Wagner, 2017	Cyber-attack risk	Keeping vehicles in communication can cause major problems for cyber-attacks	Negative
		Storage and transfer of data	Taeihagh and Lim, 2019	Privacy sharing and malicious attack risks		
		Connection to Network	Petit and Shladover, 2014	Misleading and fake messages	Irregular and incorrect maneuvers due to the manipulation of maps and vehicle positions	

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