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Article
Autonomous Vehicle Adoption in Developing Countries: Futurist Insights

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Abstract: In recent years, research into autonomous vehicles (AVs) has become highly popular in industrialized nations due to their importance in the future success of smart cities. Research on this mobility technology and the critical elements affecting its development in developing countries, however, has been rather limited. This paper aims to shed light on the most influential elements of AV adoption in developing nations. A structural analysis approach is used, based on the primary qualitative data—that was gathered via an expert-opinion poll utilizing the fuzzy Delphi with a snowballing method and engaging 25 experts in the field in two rounds—, in accordance with the tradition of futurist research. The analysis has led to the identification of 11 key factors, from the initial factor pool of 54, affecting AV adoption in the case study context of Iran. The results of the analysis revealed the following conclusions, that fall under the policy and legislation domain, and present the most significant issues impacting AV adoption: (a) Future orientation of government—consistency and of accountability of policies, the long-term vision of the government for developing AVs industry; (b) Managing the international sanctions for foreign investment, and; (c) Funding mega projects to enable AVs. The results indicate that the establishment of legislation and the formulation of government policy regarding the provision of infrastructure, investment, and credit allocation are crucial for the development of AVs in Iran and other developing nations with comparable characteristics.

Keywords: autonomous vehicles; autonomous driving; driverless car; technology adoption; technology acceptance; smart mobility; futurist research; Delphi study; developing countries; Iran

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1. Introduction

The fields of information and communication technology (ICT) have advanced significantly in recent years, resulting in innovations like artificial intelligence (AI), robotics, quantum computing, Internet-of-Things (IoT), and fifth-generation wireless technologies (5G) [1]. As a result of the obvious effects that these technologies will have on urban areas and other facets of human life, the concept of smart cities is gaining popularity [2]. In the field or transportation, autonomous vehicles (AVs) are viewed as an essential component of the transportation system in smart cities and have been a contentious subject in recent years [3]. This is such a critical issue that some governments have incorporated it into their macro plans and produced short-term and long-term strategies. In this respect, several developed countries, including Australia, Canada, the UK, the USA, and Germany, have been investing in research and development (R&D) of AV technology.

There is no doubt that AVs would have a significant impact and vast market in developing countries, even though they are more likely to be adopted in developed countries initially. However, the findings from research conducted in developed countries may not be transferrable to developing countries due to significant differences in urbanization and development levels, cultural norms, and transportation rationales [4]. There are serious drawbacks associated with increasing urbanization in developing nations' large metropolises. The increased demand for transportation brought on by rapid urbanization exacerbates existing infrastructure constraints. Number of factors has contributed to this crisis, including a lack of investment in transportation infrastructure, an inadequate supply of public transit options, ineffective traffic management, and a general lack of technical understanding and expertise [5].

AVs and other forms of cutting-edge technology are being used in metropolitan areas to alleviate the traffic congestion that comes along with rapid urbanization. Here, an AI-based traffic system may govern traffic flow in the city and reduce congestion by collecting and analyzing real-time and historical traffic data from linked traffic systems. Less time spent idling translates to greater fuel economy and a smaller carbon impact for cars powered by fossil fuels. Analyzing data from the infrastructure itself is another use of artificial intelligence and its subsets in traffic efficiency. In addition to improving safety, deep learning algorithms may help cities save money by predicting when and where repair is required on transportation infrastructure [6]. Therefore, progress in technology might be seen as a potential solution to urbanization's challenges. At present, these issues are more pressing in developing nations; yet the adoption of these technologies in these regions is hindered by low-quality infrastructures.

Thus, this research hopes to shed light on the most important elements influencing AV adoption in the context of developing nations. Furthermore, the current study addresses the following key research question: What are the most significant factors to AV use in developing countries, with reference to Iran?

Iran is a nation in West Asia with an economy that the World Bank classifies as lower-middle-income. Services contributed the most to GDP, followed by industry (mining and manufacturing) and agriculture [6]. The population of Iran is above 80 million, and approximately 74.9% of the population lived in urban areas, and the nation is home to eight megacities with populations of a million or more each [7]. These cities' problems stem in part from the high population densities that characterize them, but also from the additional challenges that this phenomenon presents to city governments.

Urban transportation has been plagued by issues that have repercussions for urban residents, including traffic congestion, pollution, noise, mortality from vehicle accidents, rising car ownership rates, and more [8–10]. AV technology appears to be able to help urban management tackle these issues, as it has the potential to drastically cut down on things like pollution, traffic congestion, transportation costs (including vehicle depreciation, energy, and fuel consumption), infrastructure maintenance, wasted parking space, and accidents.

Due to the state of the existing scientific platform and infrastructure pertinent to the area of AV technology, including road infrastructure, communication infrastructure, legal infrastructure, and so on, Iran is still in the early stages of research and development in this industry. The greatest way to plan forwards and aspire for future architecture under these conditions is to make sure you do not get left behind in terms of technological progress. Since Iran is a developing country, learning about the obstacles it faced while trying to implement AV technology might be instructive for similar nations. They have a comparable degree of urbanization and level of development, as well as cultural norms and transportation rationale [11].

Dealing with the future via forecasting and trend analysis has often led to innumerable difficulties in program implementation [12]. These issues arise when people fail to consider how new technology will influence their daily lives, or when they fail to give enough attention to the forces and circumstances that will ultimately facilitate future difficulties or development challenges. If vital forces and drives are ignored throughout development, they will diminish over time, which will harm the system.

The structure of the paper is as follows. Following this introduction first, a review of the theoretical literature on AVs is presented. Then, the techniques for data collection and analysis are detailed. Afterward, the research results are presented in three sections, followed by a discussion and conclusion.

2. Literature Background

2.1. Autonomous Vehicles in a Nutshell

AVs have been defined as systems that can perform all driving activities without the participation of a person. These smart vehicles utilize a combination of artificial intelligence, computers, software, and hardware sensors that can interact with one another [13]. Due to the time of adaptation and acceptance of prior technologies such as automatic transmissions and hybrid vehicles, it is anticipated that by 2040, AVs would account for half of the vehicle sales, 30% of vehicle registrations, and 40% of total automobile journeys [14]. As a result, it is critical to understand the possible concerns and obstacles to assist a country in planning for the usage of AVs in the future. Here below a concise review of the literature highlights the issues and developments in the field in a nutshell.

For instance, according to Manivasakan et al. [15], alternative measures and arrangements may be considered for various locations. Krueger et al. [16] analyzed the influence of AVs on German and American travel behavior and found that the National policy's underlying components impact the acceptability of AVs and the shift in travel demand.

In another study, Faisal et al. [17] using the Scientometrics method showed that educational institutions performed 87.7% of AV research. Europe is the most productive continent in audiovisual research, accounting for 35.9% of all publications, while with 41.1% of citations, North America is the most significant region in AV research. However, AV research in many settings is still in its infancy, and collaboration and transfer of information between academia and business are quite limited [17].

In an empirical study Luke et al. [18], by investigating factors affecting public awareness of AVs in Brisbane, Australia, found that public awareness is positively correlated with age and public transport usage, while increasing the number of household vehicles has a negative correlation with AV acceptance. This is to say AV technology adoption is strongly correlated with technology acceptance [18].

A review study conducted by Golbabaei et al. [19] found that the introduction of dynamic sharing AV (SAV) services may lead to considerable reductions in traffic congestion, travel costs, parking demand, car ownership, and glasshouse gas emissions. Additionally, the good environmental consequences may be reinforced by completely electrifying the SAV fleet by charging with renewable energy. As a smart urban mobility system with dynamic sharing services, SAV integration may enhance sustainability, social fairness, and transportation uptake [19].

Additionally, some AV studies were also carried out in undeveloped nations, with an emphasis on public perception and societal acceptability of AVs. For example, in research from Pakistan, Shafique et al. [20] investigated the adoption of AV technology from the standpoint of Pakistani youth. A questionnaire was issued to 356 students from three Lahore Universities, including Universities of Central Punjab, Engineering and Technology, Management and Technology. The findings indicated that, while AVs have not yet been deployed in Pakistan, most participants are aware of the technology. Furthermore, respondents expressed considerable reservations about going by autonomous public transportation and seeing autonomous trucks on the road, despite admitting most of the benefits associated with AVs. Furthermore, the findings revealed respondents' skepticism about the usage of driverless vehicles by youngsters [20].

Likewise, Ackaah and Osei [21] investigated popular attitudes toward AVs. A poll with 417 participants was undertaken for this aim. According to the findings, most respondents (66.4%) were familiar with AVs. The majority (55.4%) had a favorable attitude toward AVs, and the far majority (78.2%) were eager to test them out. However, respondents still wanted to retain some control over their vehicles if they had prior experience with AVs (Automation Level 3 and below). In addition, respondents voiced anxiety about the safety of their AVs. Finally, the researchers presented several recommendations to the Ghanaian government to secure public acceptance of AVs [21].

Moreover, a study of the development and deployment of AVs in Singapore showed that formalizing safety evaluations and publishing technical standards are among the most consistent and innovative strategies permitted in Singapore for managing unmanned aerial vehicles. In addition, Singapore employs a proactive and responsive adaptive method for AVs. In addition, it reveals the concurrent adoption of two opposing prescriptive-experimentalist approaches to the acceptance of AVs [22]. A summary of the background of the literature is presented in the form of Table 1.

Table 1. A summary of the background literature.

Title	References	Study Field
Infrastructure requirement for autonomous vehicle integration for future urban and suburban roads: current practice and a case study of Melbourne, Australia	[15]	Transport infrastructure
Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour in Germany and the USA	[16]	Travel behavior
Mapping two decades of autonomous vehicle research: a systematic scientometric analysis	[17]	Autonomous driving
Factors influencing public awareness of autonomous vehicles: empirical evidence from Brisbane	[18]	Transport technology acceptance
The role of shared autonomous vehicle systems in delivering smart urban mobility: a systematic review of the literature	[19]	Smart urban mobility
Public perception regarding autonomous vehicles in developing countries: a case study of Pakistan	[20]	Transport technology acceptance
Perception of autonomous vehicles: a Ghanaian perspective	[21]	Transport technology acceptance
Adaptive governance of autonomous vehicles: accelerating the adoption of disruptive technologies in Singapore	[22]	Transport technology adoption

Lastly, the review of the literature on AVs has undercover the key factors affecting the use of AVs in the following areas: (a) Social acceptance; (b) Infrastructure; (c) Policy and legislation, and; (d) Technology and innovation. These areas are elaborated on in detail in the next sections.

2.2. Social Acceptance

The adoption of new technology has always been influenced by how individuals think and act. The public's acceptance of AVs is essential for their rapid and broad adoption [23,24]. In general, specialists and the public have a favorable view of AVs, although they have serious reservations. Because there are no human drivers, certain members of society may be skeptical about the safety of AVs in their early phases of development [25]. However, human mistakes cause at least 90% of all vehicle accidents, therefore the arrival of AVs on the road can remove or diminish the major source of accidents, i.e., human error. In addition, these vehicles are faster in making decisions and conducting driving-related tasks than human drivers. However, the manufacture and sale of AVs will introduce additional safety concerns [13]. The deadly accident involving Tesla's AVs in 2016 demonstrated the lack of safety in AVs as well as the incapacity of technology to avert mishaps in certain conditions [26,27]. On the other hand, packed streets with heavy traffic and the presence of people will provide difficulty for AVs [28]. As a result, public adoption of this technology may be hampered by concerns about collisions between AVs and human-centered vehicles in mixed traffic, as well as pedestrians [29].

Although the safety features of AVs are a priority, the issue of security has received little attention. Indeed, another fear that might dramatically impede AV acceptability is the technology's vulnerability to cyber and privacy threats [30]. According to a 2015 poll of 5000 individuals in 109 countries, AV users with all degrees of autonomy were more concerned about hacking and exploiting vehicle software [31]. The California Consumer Watchdog organization has expressed privacy issues for AV users. This problem poses five data-related concerns: Who should have ownership of or control over vehicle data? What sort of information will be saved? Who will have access to this dataset? How will such information be made available? And how will this information be used? [32].

Another issue with societal acceptance of AVs is "responsibility". There are numerous uncertainties surrounding AVs right now, such as who is accountable in the event of an accident [33]. Because of these uncertainties, people have been hesitant to adopt this new technology. Further explanations on "cyber security", "privacy", and "responsibility" will be provided in Section 2.4 (policy and legislation). In other circumstances, the navigation system of AVs is sensitive to severe weather conditions e.g., fog, rain, snow, etc., and dark regions e.g., the entry or departure of a road tunnel, limiting people's adoption of this technology [34,35]. It is critical to have appropriate knowledge about new technology and the benefits of AVs to enhance the adoption of AVs. The individual and social advantages of utilizing AVs have a beneficial impact on the technology's acceptability. Users are typically attracted to benefits that save them time and money [36], such as shorter travel times, less congestion, and greater fuel economy.

Furthermore, the widespread use of AVs has benefits not only for individuals but for society, such as reducing emissions [37], including lower CO_2 emissions, and reducing energy consumption and reliance on fossil fuels [29], leading to a reduction in environmental footprint as well as improving living conditions [38]. Other benefits include increased independence of vulnerable social groups such as the elderly, children, and the disabled [29], as well as improved safety and more efficient traffic flow [39]. AVs, lower the need for parking space, especially since the introduction of AVs, which allow customers to enter and exit a location without having to search for and pay for parking space [38]. In addition, consumers can avoid the high cost of purchasing, maintaining a vehicle, and paying only the annual fee or payment per use [40]. It is anticipated that the cost per kilometer of shared AVs would be not only less than taxi fares, but also less than the cost of individual vehicle ownership [41]. Shared autonomous public transportation is cited by researchers as a possible replacement for conventional modes of transportation [42]. This is both ecologically friendly and economical for households [43].

In general, the benefits experienced from a personal or societal standpoint have a favorable influence on AV acceptability. A good view of AV technology enhances trust in the technology while decreasing risk perception among potential customers [44].

Trust is the strongest determinant of performance hope and essential to reducing risk perception [41]. Therefore, researchers have suggested trust as a determining factor for the acceptance of AVs [42,43]. Some researchers argue that AVs are not yet commercialized and that most end users are unfamiliar with this technology. As a result, media, and public advertising play an important role in molding end-user perceptions about AVs [45]. Another concern is the degree of individual readiness, which is affected by a variety of characteristics such as adult literacy, digital literacy, the number of Internet users, and the number of active social media users, as indicated in many studies. Residents of major cities are more inclined to adopt this technology since living in big cities is closely tied to access to facilities. As a result, the social acceptability of new technology will grow in these cities [46,47].

2.3. Infrastructure

The first area is to concentrate on the geometric design of roadways and adjust their cross-sectional dimensions in preparation for the introduction of AVs. The reduction in needed lane width is one of the projected changes in road layout with the advent of AVs [48]. This is due to AVs' enhanced lateral control as compared to conventional vehicles; which means that the safe cross-section for AVs can be deemed less than that of conventional vehicles. Based on current regulations, the cross-sectional area of highways is 3.5 m, which is high for the movement of AVs. According to studies, construction plans and standards should be re-evaluated, improved, and updated to guarantee that they can respond to altered loading patterns and higher loads associated with AVs [15]. Regardless of the type of vehicle, an AV can drive at faster speeds than a conventional vehicle. This may result in higher traffic flow and greater pavement loads. As a result of increased traffic loads and vehicle movement at high speeds, the construction, and materials of roads, such as road pavements and bridges, necessitate new requirements [49,50].

The proper operation of AVs necessitates the use of road signs and markers. Clear and consistent markers are required for AVs to prevent misunderstanding and for sensors to interpret road information [51]. As a result, cities should have regular markings and quality road signs that are not readily worn out and can be seen properly [52]. Furthermore, various infrastructure adjustments are suggested, such as the placement of a transmitter on the road surface, which allows for a more effective diagnosis to avoid misinterpretation, for example, the identification of a painted white line and a genuine line. In recent years, a digital alternative known as Vehicle to Everything Technology (V2X) has gained popularity [53]. This technology enables digital mapping to include information such as road signs and lines, road conditions, and traffic [54]. This technology includes communications such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and so on [54].

Facility maintenance is critical to ensuring that road infrastructure remains useable for the duration of its design life. Over time, road markings and pavements deteriorate, resulting in the removal of lines, pits, and vague signs. Any deficiency in road infrastructure can lead to inconsistency. As a result, it may impair AVs' capacity to navigate, perhaps leading to accidents [55]. Parking facilities and road lines that are suitable for AVs should also be created. Furthermore, the provision of specialized places for AV transportation aids in infrastructure preparation because AVs act differently than human drivers, and having dedicated spaces makes them easier to utilize. High-tech roadside amenities are among the other necessary road constructions. Because most AVs are likely to be electric, a considerable number of high-tech roadside amenities, such as electric vehicle charging stations, are necessary [52,56].

The availability of an integrated Internet for the successful transmission of AV-related data is an important part of communication infrastructure readiness. AVs may interact with the infrastructure network by utilizing the coverage of the fifth generation of 5G wireless technologies. They can successfully communicate and receive important safety information to and from a centralized mobile control center thanks to their high-speed Internet connection [52]. The data transfer speed with 5G will be 100 times quicker than with 4G. As a result, because AVs generate and consume a large amount of data, reaction times will be substantially faster [34].

Cities should have local data centers for efficient processing and analysis of such massive amounts of big data. A data center of this type may act as a command-and-control center for all ITS-related operations, as well as aid AVs while driving [52]. The Intelligent Transportation System (ITS) is a network-based system in which the vehicle serves as a router, transmitter, and receiver [57]. As a result, developing an acceptable ITS system in cities, such as putting cones and lights coupled with sensors, is crucial.

2.4. Policy and Legislation

The future orientation of government in each country is defined based on average measures in the fields of policy stability, government accountability for change, adaptability of the legal framework to change, and long-term government perspective [46], which plays a critical and effective role in the maturity of new technologies and government readiness. It demonstrates that national policies have a significant impact on the acceptability of AVs [16], and the efficacy of law is a difficult problem that must be addressed. Indeed, legal difficulties are a key worry for the usage of AVs, since duties should be explicit in the event of a system failure [58]. Responsibility is an important aspect since it is intertwined with insurance. According to some experts, the purpose of such a regulation is to resolve the question of who is liable for the costs of accidents. Is it the victim's fault, the fault of another actor, or the fault of both [59]? The driver oversees the vehicle in most accidents involving regular automobiles.

As a result, he bears primary responsibility for the vehicle's fate, although individuals in an AV no longer have control over the vehicle. As a result, it appears that manufacturers and third parties engaged in the design of AV safety systems may face increased liability in associated cases [13]. As a result, automakers are more at risk of tarnishing their brand because of accidents caused by design and manufacturing flaws in their vehicles [13]. There is currently no legislative structure in place to determine how responsibility for the design and manufacturing of AV systems should be divided among third parties such as the manufacturer, component supplier, software developer, or software user. This makes identifying and distinguishing the many components and circumstances that have caused the vehicle to malfunction challenging [13]. Another unresolved problem is the transfer of liability to the insurer and its impact on insurance premiums [60].

Hackers are drawn to AVs because of their capacity to store and send data. Because the computer controls most of the vehicle, such vehicles are more vulnerable to cyber-attacks than standard automobiles, and the driver has less ability to interfere during the assault. Without adequate security in the communication routes between these vehicles, such vehicles are vulnerable to hacking, which can result in serious collisions. Entering phony messages and tampering with such vehicles' worldwide satellite navigation systems are the most serious risks that AVs may face because tampering with this satellite data might impair the vehicle's vital safety functions [61,62]. Other cyber dangers include the manipulation of vehicle sensors to mislead decision-making systems, the shutdown of cameras, and the creation of radar news to conceal the obstructions in the path of vehicle cameras [63].

The performance of AVs is dependent on cameras, sensors, precise maps, and other equipment that collect data about the vehicle. AI in the vehicle system then optimizes this information to assure the vehicle's performance [63]. However, there are significant worries regarding how to regulate and use this information. Some concerns about information confidentiality remain unresolved. The reasons for collecting such information, the categories of information obtained, third-party access to this information, and the duration permitted to retain the gathered information have not yet been stated. The capacity of AVs to interact with one another allows for the exchange of information acquired by each vehicle for the safe operation of such vehicles. However, it exposes the vehicle's movements and position to detection by external networks, allowing third parties to get access to the user or occupant of the AVs [64]. The use of black boxes to explain the cause of an accident is another source of concern, since this information might be sold to other parties such as insurance companies and used against drivers.

Other concerns associated with information confidentiality include the possibility of exploiting information obtained by the vehicle system to harass AV users via marketing and advertising, stealing users' identities and profile images, and so on [64]. Another problem is the use of camera monitoring in AVs, such as those employed in self-driving taxis. Because the occupants of AVs are not the proprietors, it is unclear if these vehicles are deemed public spaces and whether public monitoring of them can be tolerated [65].

Governments should collaborate with manufacturers and research institutions to welcome this new mobility while ensuring that related regulations are as safe as feasible [66]. To build a legislative framework that provides minimal safety, large-scale AV experiments on public roads must be encouraged. Furthermore, this testing may result in technological advancements and legal laws [67]. Thus, investing in AV infrastructure is a vital aspect of promoting the deployment of driverless vehicles, as technological restrictions now prevent AVs from fully functioning on ordinary roads, requiring them to be driven in specialized infrastructure. This issue necessitates the establishment of specific test facilities for such vehicles, where complete external assistance for their operation may be supplied [52].

Furthermore, because of the specialized and extremely complicated repair, maintenance, and operation, specialist crew training is critical. Thus, encouraging colleges to perform research on AVs and perhaps including this topic in university curricula might be a beneficial step forward. Motor vehicle ownership and use legislation, as well as traffic laws, should be amended including the development of laws and regulations which prioritize the use of AVs [28]. One of these regulations may permit AVs to operate High Occupancy Vehicles (HOV) even if only one person is present. Similarly, roadways in downtown regions are typically congested, and allowing only AVs to access these routes will encourage individuals to utilize such vehicles. Aside from such laws, local administration can provide AVs the ability to park in private spaces, even in congested locations, or offer toll savings in contrast to conventional vehicles [52,68].

2.5. Technology and Innovation

KPMG, one of the world's leading consulting, financial consulting, tax, and auditing organizations, has released statistics on the preparedness of countries to deploy AVs, taking the following technological and innovative factors into account: Industrial relationships between automakers and suppliers of automotive technology. Indeed, the rapid and disruptive nature of AV technology has led to the formation of several partnerships between automakers and technology suppliers. In addition to the number of AV technology companies that are engaged in investing and testing for this new technology. The number of patents associated with AVs, the amount of industrial investment in AVs, the cyber security of infrastructure, the allocation of a portion of the automobile market to electric vehicles, cloud computing, artificial intelligence, and the Internet of Things are being evaluated [46].

Humans have long envisioned "thinking" devices that operate without human assistance. In the late 1950s, the introduction of the first computers amplified this interest and made it possible for the project to focus on the emerging field of artificial intelligence. By developing three-dimensional maps of their environs, AVs gain knowledge from their surroundings. Such maps enable AVs to have a complete understanding of their position in real-time. Using radar and lidar together, three-dimensional pictures are captured. After the photographs have been captured and filtered, it is the responsibility of the computer system to appropriately analyze their meaning and assess the worth of the gathered data. AI arrives at this point [34].

Such vehicles need artificial intelligence to comprehend, learn, and navigate the actual world. Artificial intelligence should get data via many channels and make decisions based on analysis. Consequently, this procedure can be divided into four phases: environmental comprehension, decision-making, route design, control, and navigation. Cloud computing is heavily used in AV decision-making. In addition, they leverage cloud computing on IoT to handle traffic data, meteorological information, maps, and road conditions. This offers a deeper awareness of the situation and the surrounding environment, allowing for more effective decision-making. Due to the complexity and difficulty of urban environments, particular research is needed in the fields of big data, sensor technologies, IoT, cloud computing, and artificial intelligence to build the necessary infrastructure for their administration [69].

2.6. Conceptual Framework

Considering the review, this study formed a conceptual framework for AV adoption with reference to Iran. Based on this conceptual framework, the variables affecting the usage of AV in the four categories of social acceptability, infrastructure, policy and legislation, and technology and innovation have been explored (Figure 1). Each of these constructs contains number of specific components that may be assessed using an expert opinion survey. For instance, five measures are stated as follows for social acceptance: (a) Users' trust; (b) Media and publicity; (c) Cost-effective use of AVs; (d) Individual readiness, and; (e) Social benefits of using AVs.

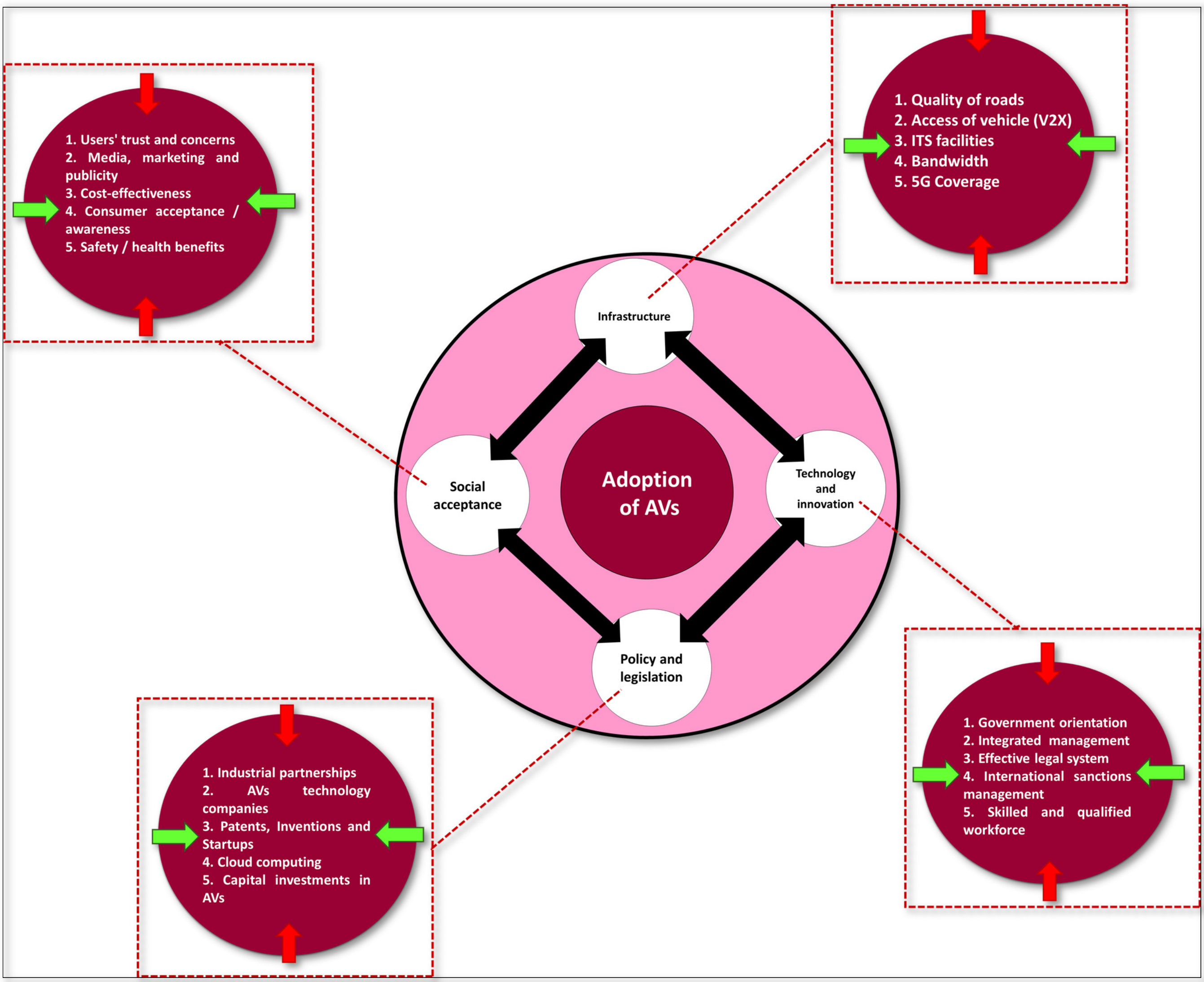

Figure 1. Conceptual framework of AV adoption.

3. Materials and Methods

This research used a mixed methodological strategy involving both quantitative and qualitative analyses. To achieve the study objective, structural analysis was used. There is a network of interrelationships between variables in this system, and their examination is crucial to comprehending the future development of the system. The significant outcome of structural analysis is the discovery of the essential factors that regulate the development of AVs [70]. The structural analysis consists of three steps: creating an inventory matrix of factors, describing the relationships amongst the factors, and then identifying key factors [71].

3.1. Step 1: Identifying Factors

Based on the literature, there are four major categories of societal acceptability, infrastructure (roads and communication), policy and Legislation, and technology and innovation, as well as around 54 long-listed factors. The Fuzzy Delphi approach was then utilized in two phases to find additional factors and assess the initial 54 factors. Delphi methodology is a way of acquiring collective knowledge that has been used for over half a century. Although experts' mental talents and abilities are employed for comparisons in traditional Delphi methods, the quantification of expert judgments cannot fully capture the human way of thinking. Using fuzzy sets is more consistent with human language and often imprecise descriptions, and it facilitates better decision-making in the actual world. Using fuzzy sets, the error rate is minimized [72]. The questionnaire was distributed to all experts at each phase as a combination of closed and open questions. Closed questions use the Likert scale to judge the importance of the long list of factors. Expert-suggested factors are the subject of open questions. The long list of factors that did not score in the first stage of Delphi was deleted for the second stage.

Eight of the first 54 long-listed factors were eliminated during the first round of Delphi, and the first three were recommended by experts. More details of the panel are provided in Appendix C. The second round authorized 49 long-listed factors in four targeted sectors. In this study, 25 experts from different fields of expertise were members of the Delphi panel. All 25 experts have participated in two Delphi rounds. More details of the panel are provided in Appendix A.

To choose appropriate experts, a non-probabilistic snowball sampling method was used. The snowball sampling strategy guides the researcher to additional individuals who may be able to contribute to the study topic until the researcher reaches a point of repetitive responses [73].

3.2. Step 2: Describing Relationships among Factors

A two-dimensional matrix known as the "Structural Analysis Matrix" was utilized in structural analysis to determine the correlations between factors. This matrix should ideally be populated by experts who have already participated in the first stage. The filling of the matrix was a qualitative procedure. The following question was presented for each pair of factors: Is there a direct connection between factors i and j? The factors in the row influence the factors in the column. The degree of association is represented by a number between 0 and 4. Number "zero" denotes "no effect", number "one" denotes "weak effect", number "two" denotes "moderate impact", number "three" denotes "strong effect", and lastly number "four", even if no association exists now, may exist in the future [71].

As a result, if the number of recognized factors is n, an $n \times n$ matrix containing the influence of the factors on each other will be generated. In this work, a matrix having 49×49 dimensions was developed. Only five volunteer experts from the previous phase were employed for scoring due to the high dimension of the matrix, the time needed to fill in the matrix, as well as to simplify the computations. According to Clayton [74], between five and 10 people are enough if a mix of specialists with various expertise is utilized. The degree of filling the matrix was 84.4 percent. Based on statistical indicators, the data had 100 percent usefulness and optimization, showing the questionnaire's excellent dependability (Table 2).

Table 2. Details on the dimensions of the structural analysis matrix.

Indicator	Value
Matrix size	49
Number of iterations	2
Number of twos	637
Number of threes	632
Number of P or four	0
Number of zeros	374
Number of ones	758
Total	2027
Response rate	84.4%

3.3. Step 3: Identification of Key Factors

This stage entails finding and re-ranking the critical factors, i.e., the factors required for the AV's development. The key factors were extracted using MICMAC (Matrix of Crossed Impact Multiplications Applied to a Classification) [71]. The software output includes the

Matrix of Direct Influences (MDI) and its associated graphs, and the Matrix of Indirect Influences (MI) and its related graphs. If the structural analysis matrix reveals possible links between factors, the program generates a Matrix of Potential Direct Influences (MPDI) and a Matrix of Potential Indirect Influences (MPII), as well as accompanying graphics. The amount of the impact and influence of each factor may be displayed in a two-dimensional graph with the x-axis representing influence and the y-axis representing impact (Figure 2). In addition to finding the most influential factors in the system, the different mappings of such factors may be studied [71].

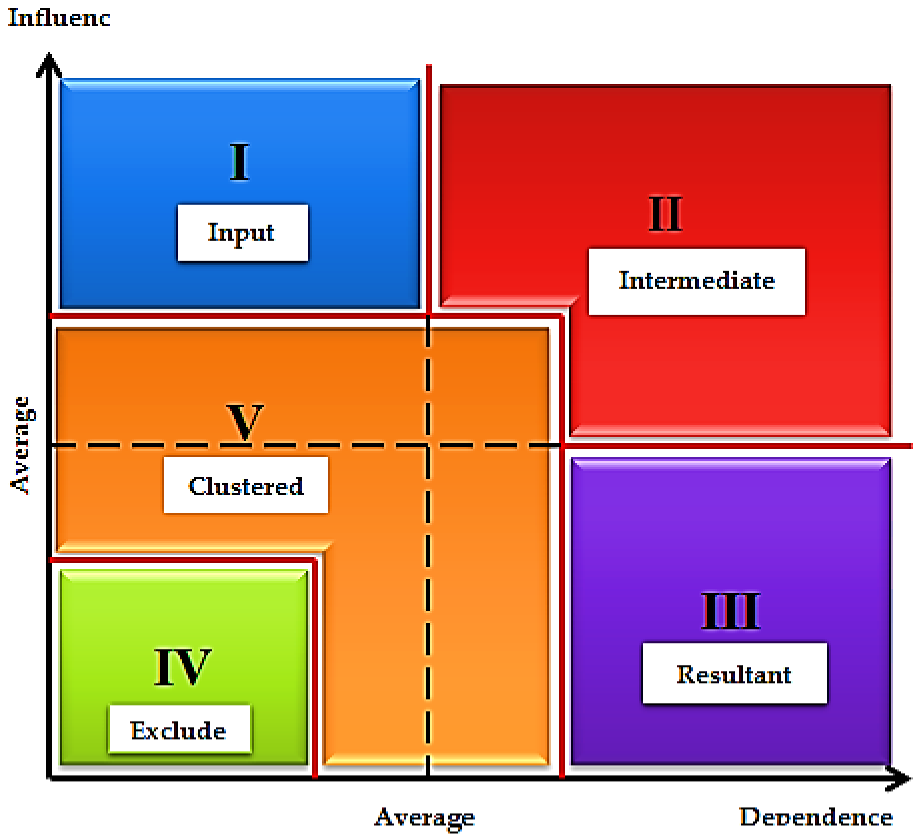

Figure 2. Different types of factors on the matrix with axes of influence and dependence.

Their placements illustrate the various roles performed by system factors (input factors, intermediate factors, resultant factors, excluded factors, and clustered factors). These maps illustrate the current and future participants' perceptions of the system's potentials (factors with high influence and dependency capacity), opportunities (factors with moderate influence and dependence capacity), and constraints (factors that cannot be affected) for change. By creating influence graphs, the networks or loops of connected components are formed [75] (a description is given in Appendix B).

And finally, node connection analysis has been done using Gephi software version 0.9.0 to better display the relationships between factors.

Based on the provided explanations, the research process is presented as follows in Figure 3.

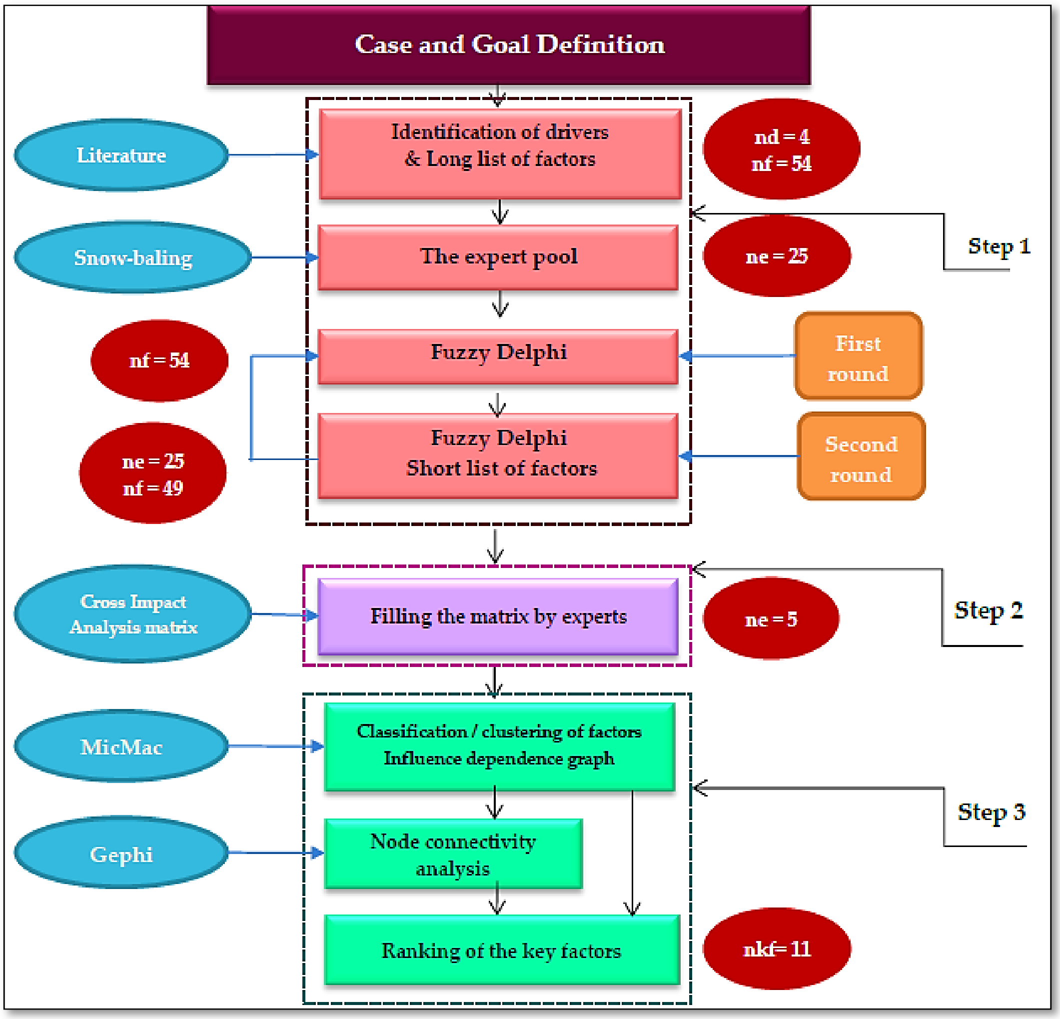

Figure 3. The research process (nd= number of drivers, n e= number of experts, nf= number of factors, nkf= number of key factors).

4. Results

4.1. Step 1: Identifying Factors

This phase entails developing a list of factors that is as complete as feasible. The long list can be divided into four categories: Policy and legislation, Technology and innovation, Infrastructure (communication and roads), and Societal (public) acceptability. A total of 49 factors were discovered (Table 3).

Table 3. Factors affecting the development of AVs, fuzzy Delphi results.

Drivers	Factors	Abbreviation	Delphi Value of Each Factor	Percentage of Consensus	Amount of Weight	Rank
Social acceptance	Sufficient technical knowledge of AV technology	A1	3.438	56.67	0.020	30
	Users' trust in the companies responsible for introducing and selling AVs	A2	3.260	60	0.019	42
	Media and marketing	A3	4.013	70	0.023	6
	Resistance to lifestyle change among potential customers	A4	3.708	53.33	0.021	16
	Residence in larger cities (cosmopolitans)	A5	3.222	53.33	0.018	43

Table 3. *Cont.*

Drivers	Factors	Abbreviation	Delphi Value of Each Factor	Percentage of Consensus	Amount of Weight	Rank
	Concerns related to cybersecurity and endangering privacy and personal information	A6	3.030	63.33	0.017	49
	Concerns about AVs accident with other vehicles (autonomous -ordinary)	A7	3.554	53.33	0.020	24
	Concerns about AVs accidents with pedestrians	A8	3.364	63.33	0.019	36
	Social acceptance of new technologies	A9	3.871	60	0.022	9
	Cost-effectiveness compared to human-driven vehicles	A10	4.250	70	0.024	3
	Individual readiness	A11	3.459	62.07	0.020	27
	Awareness of the environmental benefits of using AVs	A12	3.0634	56.67	0.017	47
	Awareness of the social benefits of using AVs	A13	3.165	51.72	0.018	45
	Legal and technical gaps related to AVs	A14	3.298	56.67	0.019	41
	Feasibility of using AVs in collective and shared modes	A15	3.069	60	0.017	46
Infrastructure	Quality of streets and roads (quality of markings and signs, quality of asphalt, etc.)	B1	3.666	74.19	0.021	17
	Revision in the geometric design of roads	B2	3.413	53.33	0.019	32
	Revision in road paving standards	B3	3.730	51.72	0.021	15
	Revision in the design and standards of bridges	B4	3.0399	51.72	0.017	48
	Revision in the design of parking spaces	B5	3.221	51.72	0.018	44
	Backup equipment, data clouding, and maintenance	B6	3.575	62.07	0.020	21
	Collecting and transmission of online data on road conditions	B7	3.321	60	0.019	40
	Supplying roadside service stations (charging and repair stations)	B8	3.597	63.33	0.020	20
	5G Internet coverage	B9	3.839	58.62	0.022	10
	V2X (passing information from a vehicle to any entity)	B10	3.989	55.17	0.023	7
	Availability of local data centers	B11	3.781	53.33	0.022	13
	ITS facilities	B12	3.624	66.67	0.021	19
	Bandwidth	B13	3.824	56.67	0.022	11
Policy and legislation	Developing transparent supportive laws/regulations for the use of AVs in the field of priority and right of way, insurance, and certification	C1	3.444	58.62	0.020	29
	Developing legislation in the field of criminals, including responsibility for road accidents, privacy, and cyber security	C2	3.555	62.07	0.020	23
	Supporting R&D activities	C3	3.637	68.97	0.021	18
	Funding mega projects on AVs	C4	3.475	63.33	0.020	26
	Providing incentives to attract private sector investment	C5	3.4156	60	0.019	31
	Reduction of tariffs for importing Avs vehicles, systems, and technologies	C6	3.458	53.33	0.020	28
	Encouraging PPT (public and private partnership) in developing Avs systems	C7	3.331	53.33	0.019	39

Table 3. *Cont.*

Drivers	Factors	Abbreviation	Delphi Value of Each Factor	Percentage of Consensus	Amount of Weight	Rank
	Supporting skilled and qualified workforce (in the areas of manufacturing, repair, maintenance, and operation)	C8	3.358	56.67	0.019	37
	Funding support of research/ education activities	C9	3.764	60	0.021	14
	Managing the international sanctions for foreign investment	C10	3.368	63.33	0.019	35
	future orientation of government (stability and accountability of policies, the long-term vision of the government for developing AV industry)	C11	3.568	63.33	0.020	22
	Supporting transparency and accountability in the AV market	C12	3.818	66.67	0.022	12
	Establishing a coordination plan among stakeholders and influential parties	C13	3.983	73.33	0.023	8
	Refining and developing the legal system in addressing the AVs regulations	C14	3.399	53.33	0.0194	33
Technology and innovation	Tendency to mass production and industrial partnerships	D1	4.277	66.67	0.0244	2
	Number of patents, innovations, and products related to AVs	D3	3.340	63.33	0.0194	38
	The volume of investment in AVs	D4	4.143	56.67	0.024	5
	Development of high-level cybersecurity protection	D5	3.487	60	0.020	25
	Development of IoT	D6	4.328	76.67	0.025	1
	Number and quality of research publications/outputs and training/education activities	D7	3.391	65.52	0.019	34

4.2. Step 2: Describing Relationships among Factors

The total of the row values for each factor in the structural analysis matrix reflects the degree of influence, and the column sum of each factor reveals the degree of dependence on other factors. According to the analytical results of this matrix, the influence of "Policy and legislation" and "Social acceptability" among the recommended factors is significantly more than their dependence and has a significant influence on the system. On the contrary, "infrastructure (communication and road network)" and "technology and innovation" are positioned differently from the other two drivers. In other words, their dependence much outweighs their influence. The numerical disparity between the influence and dependence of the "Legal and policy" drivers is more obvious among the other drivers (Table 4).

Table 4. Ranking of long-listed factors based on the degree of influence and dependence.

Drivers	Factors	Influence	Rank	Dependence	Rank
	A1	75	23	65	41
	A2	63	36	110	3
	A3	111	10	91	14
	A4	67	32	105	7
	A5	103	12	4	49
	A6	62	37	81	28
	A7	82	17	97	12
Social acceptance	A8	82	18	96	13
	A9	71	28	110	4

Table 4. *Cont.*

Drivers	Factors	Influence	Rank	Dependence	Rank
	A10	115	8	106	6
	A11	55	42	66	40
	A12	74	24	75	36
	A13	71	29	75	37
	A14	66	35	36	45
	A15	113	9	130	1
Infrastructure	B1	59	40	98	16
	B2	53	43	89	20
	B3	53	44	89	21
	B4	53	45	89	22
	B5	49	48	90	16
	B6	67	33	102	9
	B7	59	41	90	17
	B8	51	47	90	18
	B9	68	31	88	23
	B10	118	6	87	24
	B11	60	39	90	19
	B12	119	4	87	25
	B13	67	34	79	33
Policy and legislation	C1	117	7	80	31
	C2	119	5	83	26
	C3	84	16	79	34
	C4	126	3	78	35
	C5	86	14	80	32
	C6	47	49	74	38
	C7	81	19	81	29
	C8	74	25	82	27
	C9	78	20	81	30
	C10	132	2	7	48
	C11	139	1	42	43
	C12	53	46	37	44
	C13	76	22	32	47
	C14	62	38	33	46
Technology and innovation	D1	77	21	105	8
	D2	85	15	101	10
	D3	72	27	91	15
	D4	87	13	107	5
	D5	70	30	52	42
	D6	104	11	73	39
	D7	73	26	115	2

4.3. Step 3: Identification of Key Factors

The factors distribution reveals the degree of stability or instability of the researched system. In general, there are two sorts of distributions: stable and unstable systems. The distribution of components in stable systems is as L in English; That is, some factors have a high influence, and some have high dependence; However, in unstable systems, the issue is more complicated than in stable ones. The factors in this system are dispersed along the diagonal axis and frequently represent an intermediate state of influence and dependence, making it extremely difficult to evaluate the key factors. However, (Figure 2) is offered to identify key system factors [76]. The map of scattering the factors which affect the development of AVs in Iran showed the instability state of the system (Figure 4). Since the results of direct and indirect influences of the factors were the same, only the results obtained from the matrix of direct influences were presented. Figure 4 presents the distribution map of long-listed factors and their position in the axis of influence dependence.

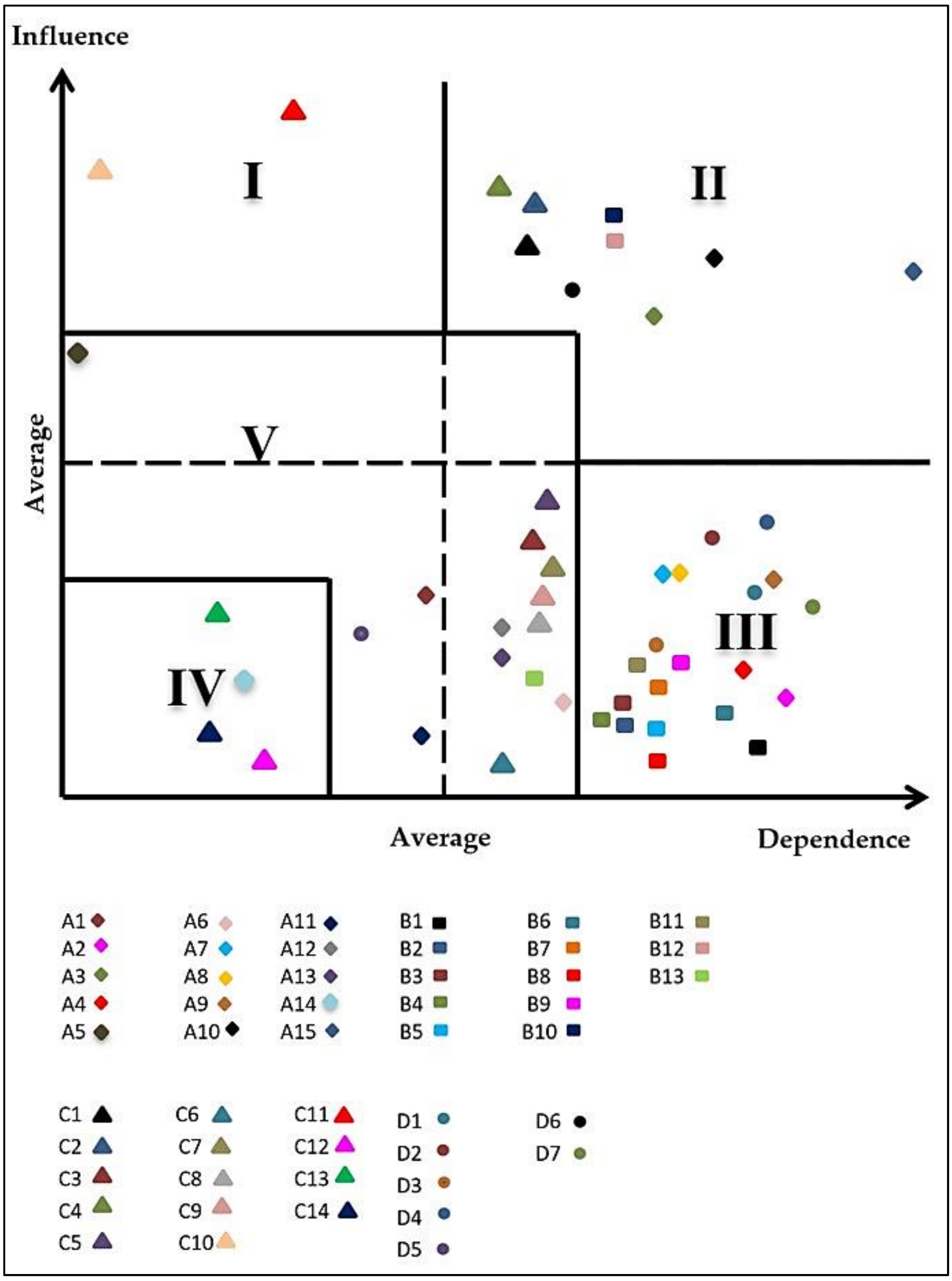

Figure 4. Distribution map of long-listed factors and their position in the axis of influence-dependence.

Gephi software version 0.9.0 has been used to better display the relationships between factors. Figure 5, which is called the "weighted-out-degree" graph, shows the degree of influence of the factors on each other. Nodes that have a larger weighted out-degree value have more influence than other nodes. Weighted out-degree is a measure of the system-wide influence that a node has [77]. Based on Figure 5 and Table 4, the future orientation of government (stability and accountability of policies, the long-term vision of the government for developing AV industry) (C11), Managing the international sanctions for foreign investment (C10), Funding mega projects on AVs (C4) have the highest influence on other factors.

Figure 6, which is called a "weighted-in-degree" graph, shows the dependence of each factor on other factors. Nodes with high in-degree are in the center which can affect others easily. The weighted in-degree is a measure of the system-wide influence that a particular node has [77]. Based on Figure 6 and Table 4, the feasibility of using AVs in collective and shared modes (A15), and the number and quality of research publications/outputs and training/education activities (D7) receive the highest influence from other factors.

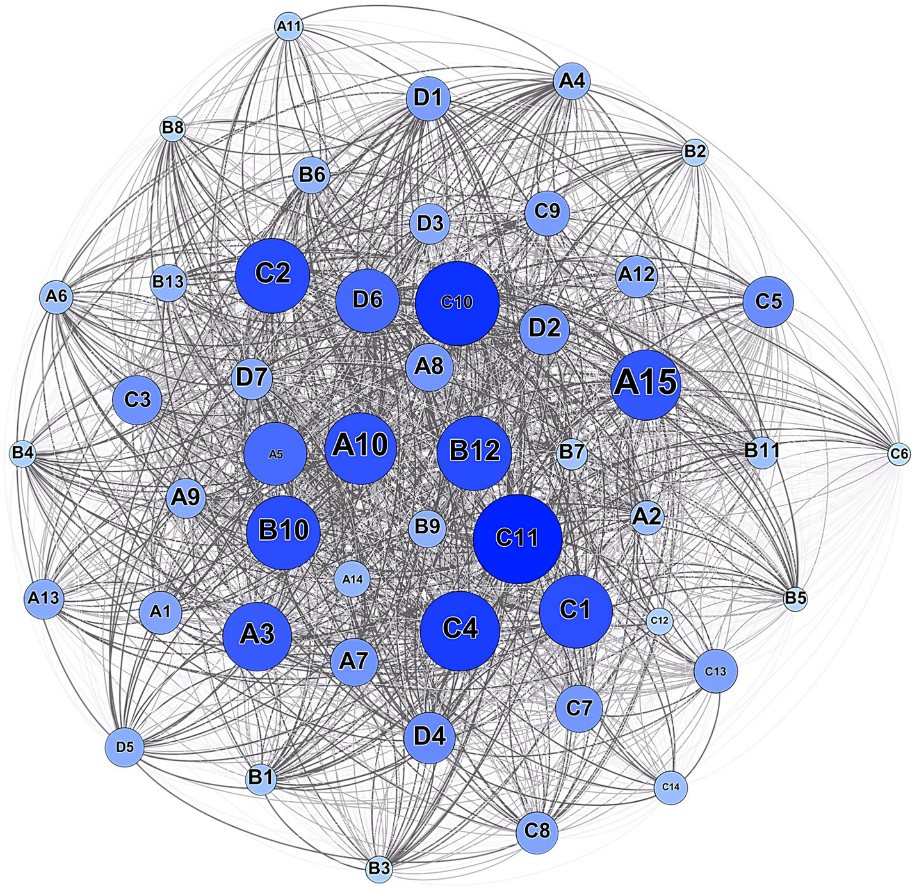

Figure 5. Weighted-out-degree.

Thus, the status of each factor according to their position in Figure 4 can be identified as follows (Table 5).

Table 5. The position of each factor in the influence-dependence map.

Position	Factors
Input factors (1)	C10, C11
Intermediate factors (2)	C1, C2, C4, A3, A10, A15, D6, B10, B12
Resultant factors (3)	D1, D2, D3, D4, D7, B1, B2, B3, B4, B5, B6, B7, B8, B9, B11, A2, A4, A7, A8, A9, C8
Excluded factors (4)	C12, C13, C14, A14
Clustered factors (5)	A1, A5, A6, A11, A12, A13, D5, C3, C5, C6, C7, C9, B13

Based on Table 5 and the explanations provided in the appendix, the influence and rank of the key AV adoption factors are as shown in Figure 7.

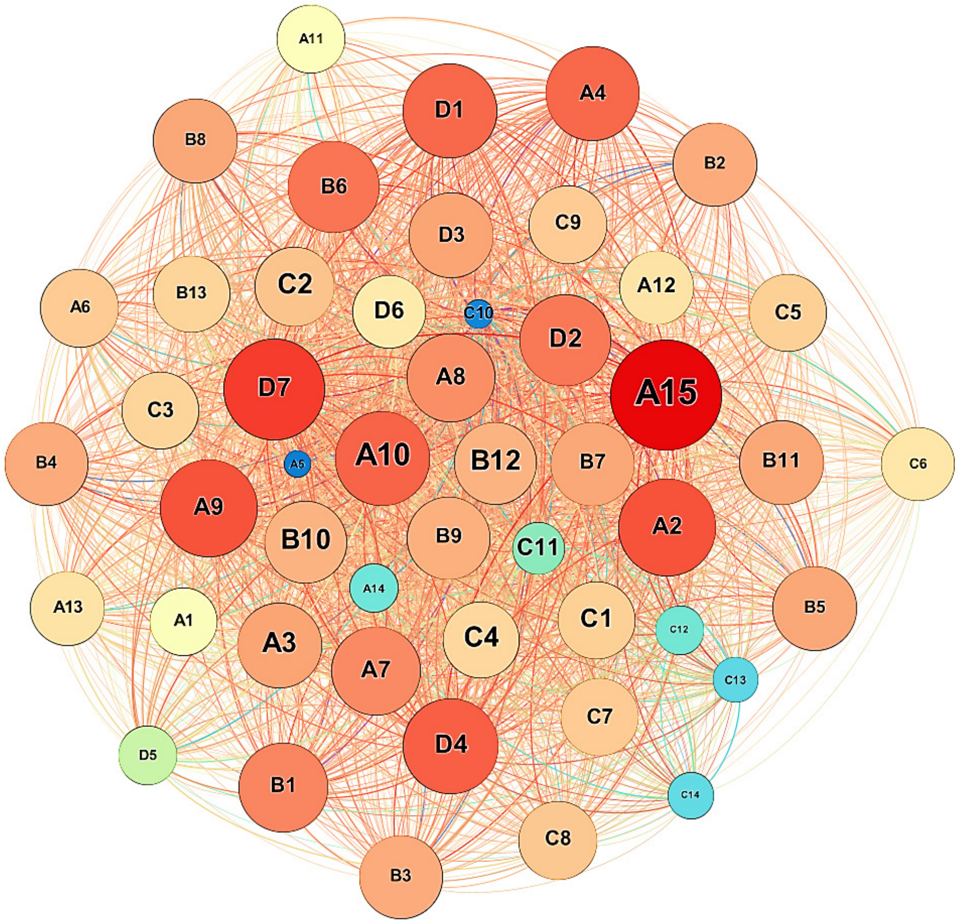

Figure 6. Weighted-in-degree.

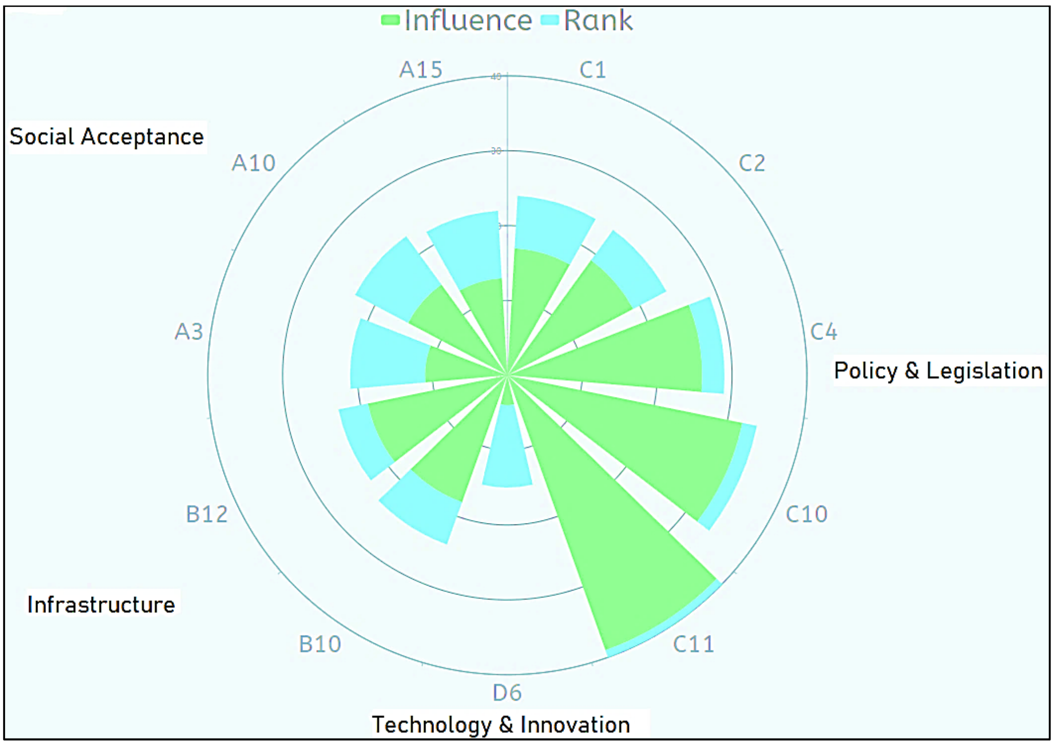

Figure 7. Influence and rank of the key AV adoption factors.

5. Discussion and Conclusions

In this study, the critical factors and barriers impacting the development of AVs in Iran are identified: Societal acceptance, Infrastructure (roads and communication), Policy and legislation, and Technology and innovation. The findings showed that in the field of "Policy and legislation", the factors of "future orientation of government", " Managing the international sanctions for foreign investment", "Funding mega projects on AVs", "Developing legislation in the field of criminals, including responsibility for road accidents, privacy, and cyber security", and "Developing of transparent supportive laws/regulations for the use of AVs in the field of priority and right of way, insurance, and certification", appeared as key factors.

International sanctions imposed on Iran's automotive and manufacturing sectors, along with the departure of multinational manufacturers, have effectively prevented the Iranian car market from receiving cutting-edge technology. This limitation has affected not just ordinary automotive manufacturing but has also caused Iran to lag far behind in the development of emerging technologies such as AVs. Furthermore, due to current uncertainty in the sphere of criminal laws, such as culpability for road accidents, privacy, cyber security, as well as traffic rules, insurance laws, and AV licensing, legislation efficiency is a significant barrier. On the other hand, it may imperil a country's critical infrastructure, disrupt key service delivery, and harm society's general well-being [78]. As a result, a roadmap for collaboration between the public and commercial sectors, as well as research institutes, is necessary to build a clear legislative framework. The elements "Media and marketing", "Cost-effectiveness compared to human-driven cars", and "Feasibility of using AVs in collective and shared modes" emerged as major considerations in the realm of "social acceptance". Based on cultural norms and socio-demographic environment, social acceptability would be closely associated with the client's lifestyle and personal preferences. The public would appreciate it if they were more aware of the genuine benefits, such as reduced travel time and cost savings. Media, advertising, and campaigns have a significant impact on how end-users perceive AVs.

The most important variable in the "technology and innovation" area was determined as the "development of IoT". Because the issue of smart vehicles is entangled with several new technologies such as cloud computing, artificial intelligence, and IoT, a roadmap in communication and information technology connected to intelligent vehicle transportation should be devised (electric vehicles, AVs, passages, smart signs, etc.). In this topic, the country's status in each field is assessed to define investment and research priorities, as well as decision-making intentions towards R & D. In the field of "Infrastructure" the factors of "V2X, passing information from a vehicle to any entity", and "ITS equipment" were proposed as key factors. Modern cities are expected to supply local data centers for efficient processing and analysis of such massive amounts of big data. A data center of this type may act as a command-and-control center for all ITS-related operations, as well as aid AVs while driving. An intelligent transportation system (ITS) is an advanced application that aims to provide innovative services relating to different modes of transport and traffic management and enable users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks. Some of these technologies include calling for emergency services when an accident occurs and using cameras to enforce traffic laws or signs that mark speed limit changes depending on conditions.

This study showed that the important element with the highest effect was "Policymaking and Legislation", demonstrating that the government's intervention would remove a large share of the impediments. Furthermore, the government's investment in developing infrastructure (road and communication) and technology essential for the introduction of AVs into the country is highly effective. All planning and decision-making procedures in Iran are determined by the role and origin of the government. State control and management of economic concerns is a sovereign responsibility enshrined in national legislation.

The study's findings are in line with earlier works reported in the literature. For instance, Talebian and Mishra [79] discovered that the adoption of AVs among American academics (in the case of Memphis University) would be greatly reliant on the social network among individuals, which is afterward impacted by media advertisement and marketing. Likewise, an Australian study discovered that gender would influence whether tertiary students use AVs, even though students are worried about cyber security and the failure of AVs [80]. Similarly, in terms of urban and transport infrastructure development involving advanced technologies, Yigitcanlar and Bulu [81] highlighted various challenges in the context of a developing country, Turkey, that align well with the findings of the study at hand. Additionally, another study revealed, in the context of Brazil, that stimulating technological innovation through government incentives is critical [82].

Although in this research the variables influencing the development of AVs in Iran were examined, the findings may be applied to other emerging nations with similar economic and social situations. As most of the existing study on AVs focuses on the public [80], it is advised that the viability of implementing AVs for passengers with diverse mobility and communication demands be investigated [83]. This is particularly crucial for Iran, a nation with a large proportion of elderly [72] and handicapped citizens who have difficulty using the standard public transportation networks now in place [84]. This research may go further by investigating transport priorities such as safety, capacity, and accessibility of the services, particularly if they are linked with other public transportation systems [85]. One of the main constraints of this study was finding the most pertinent specialists to take part in it because the technology of AVs in Iran is still in the early phases of study and research. This research may potentially be enhanced by recruiting a broader pool of stakeholders and especially conducting focus groups with potential AV clients. Additionally, it is beneficial to go deeper into the technical technique and undertake a cross-impact balance analysis for scenario analysis, as is customary in futurist research.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Profile of Delphi experts.

Items	Details	Number	Percent
Age group	Less than 30 years	9	36
	Over 30 years	16	64
Field of expertise	Transportation planning/traffic engineering	4	16
	Regional planning	1	4
	Urban planning	3	12
	Urban design	1	4
	Automotive engineering	2	8
	Electrical engineering	2	8
	Futures studies	3	12
	Project management	1	4
	Law	3	12
	Applied physics/physics	2	8
	Business management/economics	2	8
	Applied mathematics	1	4
Educational Level	Bachelor	3	12
	Masters	15	60
	PhD/PhD candidate	7	28
Years of experience	Lee than 5 years	9	36
	Between 5 and 10 years	4	16
	Between 10 and 15 years	7	28
	Over 20 years	5	20
Employment sector	Government agencies	12	48
	Consultants	10	40
	Self- employed	3	12
Sum		25	100

Appendix B

Types of factors based on the influence-dependence chart in Figure 2.

Factors	Notes
Input Factors (1)	These factors are highly effective and independent. Such factors describe the studied system and the dynamic conditions of the system. If possible, these factors should be prioritized for strategic operational plans.
Intermediate Factors (2)	These factors are highly effective and dependent. Thus, they are unstable by nature. Any action on these factors will flow into the rest of the system and deeply affect the dynamics of the system.
Resultant Factors (3)	These factors are not effective but are highly dependent. Thus, their status explains the effects of other factors (mainly input and intermediate factors).
Excluded Factors (4)	These factors are neither effective nor dependent. Thus, they have little effect on the studied system. As a result, excluding these factors will have few consequences for system analysis.
Clustered Factors (5)	These factors are not effective or dependent enough to be included in the previous classifications. No definite conclusions can be drawn about these factors and their effect on the system.

Appendix C

The long list of factors.

Drivers	Factors
Social acceptance	Sufficient technical knowledge of AV technology Loss of "freedom" and "pleasure" of driving Loss of driving-based jobs Vulnerability of AVs navigation systems against human and natural threats Users' trust in the companies responsible for introducing and selling AVs Media and marketing Resistance to lifestyle change among potential customers Residence in larger cities (cosmopolitans) Concerns related to cybersecurity and endangering privacy and personal information Concerns about AVs accident with other vehicles (autonomous -ordinary) Concerns about AVs accidents with pedestrians Social acceptance of new technologies Cost-effectiveness compared to human-driven vehicles Individual readiness Awareness of the environmental benefits of using AVs Awareness of the social benefits of using AVs Legal and technical gaps related to AVs Feasibility of using AVs in collective and shared modes
Infrastructure	Quality of streets and roads (quality of markings and signs, quality of asphalt, etc.) Assigning a separate route to the movement of AVs Revision in the geometric design of roads Revision in road paving standards Revision in the design and standards of bridges Revision in the design of parking spaces Backup equipment, data clouding, and maintenance Collecting and transmission of online data on road conditions Supplying roadside service stations (charging and repair stations) 5G Internet coverage V2X (passing information from a vehicle to any entity) Availability of local data centers ITS facilities Bandwidth
Policy and legislation	Developing transparent supportive laws/regulations for the use of AVs in the field of priority and right of way, insurance, and certification Developing legislation in the field of criminals, including responsibility for road accidents, privacy, and cyber security Supporting R&D activities Funding mega projects on AVs Providing incentives to attract private sector investment Reduction of tariffs for importing AVs vehicles, systems, and technologies Encouraging PPT (public and private partnership) in developing AVs systems Supporting skilled and qualified workforce (in the areas of manufacturing, repair, maintenance, and operation) Funding support of research/education activities Managing the international sanctions for foreign investment Establishing a political vision for developing AVs Supporting transparency and accountability in the AV market Establishing a coordination plan among stakeholders and influential parties Refining and developing the legal system in addressing the AVs regulations

Drivers	Factors
Technology and innovation	Tendency to mass production and industrial partnerships Number and reputation of companies delivering and supporting AVs Number of patents, innovations, and products related to AVs The volume of investment in AVs Development of high-level cybersecurity protection Development of IoT Allocation of a share of the car market to electric cars Number and quality of research publications/outputs and training/education activities

References

1. Yigitcanlar, T.; Kankanamge, N.; Regona, M.; Ruiz Maldonado, A.; Rowan, B.; Ryu, A.; Desouza, K.; Corchado, J.; Mehmood, R.; Li, R. Artificial intelligence technologies and related urban planning and development concepts: How are they perceived and utilized in Australia? *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 187. [CrossRef]
2. Manfreda, A.; Ljubi, K.; Groznik, A. Autonomous vehicles in the smart city era: An empirical study of adoption factors important for millennials. *Int. J. Inf. Manag.* **2021**, *58*, 102050. [CrossRef]
3. Chen, F.; Song, M.; Ma, X. A lateral control scheme of autonomous vehicles considering pavement sustainability. *J. Clean. Prod.* **2020**, *256*, 120669. [CrossRef]
4. Moody, J.; Bailey, N.; Zhao, J. Public perceptions of autonomous vehicle safety: An international comparison. *Saf. Sci.* **2020**, *121*, 634–650. [CrossRef]
5. Wang, Z.; Safdar, M.; Zhong, S.; Liu, J.; Xiao, F. Public Preferences of Shared Autonomous Vehicles in Developing Countries: A Cross-National Study of Pakistan and China. *J. Adv. Transp.* **2021**, *2012*, 5141798. [CrossRef]
6. Soltani, A.; Ivaki, Y.E. The influence of urban physical form on trip generation, evidence from metropolitan Shiraz, Iran. *Indian J. Sci. Technol.* **2011**, *4*, 1168–1174. [CrossRef]
7. Statistics Center of Iran. *Statistical Yearbook of the Country*; Statistics Center of Iran: Tehran, Iran, 2019.
8. Soltani, A.; Askari, S. Exploring spatial autocorrelation of traffic crashes based on severity. *Injury* **2017**, *48*, 637–647. [CrossRef]
9. Abdi, M.H.; Soltani, A. Which Fabric/Scale Is Better for Transit-Oriented Urban Design: Case Studies in a Developing Country. *Sustainability* **2022**, *14*, 7338. [CrossRef]
10. Soltani, A. Social and urban form determinants of vehicle ownership; evidence from a developing country. *Transp. Res. Part A Policy Pract.* **2017**, *96*, 90–100. [CrossRef]
11. Villacorta, P.J.; Masegosa, A.D.; Castellanos, D.; Lamata, M.T. A new fuzzy linguistic approach to qualitative Cross Impact Analysis. *Appl. Soft Comput. J.* **2014**, *24*, 19–30. [CrossRef]
12. Puglisi, M.; Marvin, S. Developing urban and regional foresight: Exploring capacities and identifying needs in the North West. *Futures* **2002**, *34*, 761–777. [CrossRef]
13. Collingwood, L. Privacy implications and liability issues of autonomous vehicles. *Inf. Commun. Technol. Law* **2017**, *26*, 32–45. [CrossRef]
14. Litman, T. Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. In Proceedings of the Transportation Research Board (TRB) Annual Meeting. Victoria Transport Policy Institute, Victoria, BC, Canada, 6 November 2022.
15. Manivasakan, H.; Kalra, R.; O'Hern, S.; Fang, Y.; Xi, Y.; Zheng, N. Infrastructure requirement for autonomous vehicle integration for future urban and suburban roads–Current practice and a case study of Melbourne, Australia. *Transp. Res. Part A Policy Pract.* **2021**, *152*, 36–53. [CrossRef]
16. Kröger, L.; Kuhnimhof, T.; Trommer, S. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. *Transp. Res. Part A Policy Pract.* **2019**, *122*, 146–161. [CrossRef]
17. Faisal, A.; Yigitcanlar, T.; Kamruzzaman, M.; Paz, A. Mapping Two Decades of Autonomous Vehicle Research: A Systematic Scientometric Analysis. *J. Urban Technol.* **2021**, *28*, 45–74. [CrossRef]
18. Butler, L.; Yigitcanlar, T.; Paz, A. Factors influencing public awareness of autonomous vehicles: Empirical evidence from Brisbane. *Transp. Res. Part F Traffic Psychol. Behav.* **2021**, *82*, 256–267. [CrossRef]
19. Golbabaei, F.; Yigitcanlar, T.; Bunker, J. The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature. *Int. J. Sustain. Transp.* **2021**, *15*, 731–748. [CrossRef]
20. Shafique, M.A.; Afzal, M.S.; Riaz, N.; Ahmed, A. Public Perception regarding Autonomous Vehicles in Developing Countries: A Case study of Pakistan. *Pak. J. Eng. Appl. Sci.* **2021**, *28*, 1–6.
21. Ackaah, W.; Leslie, V.L.D.; Osei, K.K. Perception of autonomous vehicles—A Ghanaian perspective. *Transp. Res. Interdiscip. Perspect.* **2021**, *11*, 100437. [CrossRef]
22. Tan, S.Y.; Taeihagh, A. Adaptive governance of autonomous vehicles: Accelerating the adoption of disruptive technologies in Singapore. *Gov. Inf. Q.* **2021**, *38*, 101546. [CrossRef]
23. Liljamo, T.; Liimatainen, H.; Pöllänen, M. Attitudes and concerns on automated vehicles. *Transp. Res. Part F Traffic Psychol. Behav.* **2018**, *59*, 24–44. [CrossRef]

24. Faisal, A.; Yigitcanlar, T.; Kamruzzaman, M.; Currie, G. Understanding autonomous vehicles: A systematic literature review on capability, impact, planning and policy. *J. Transp. Land Use* **2019**, *12*, 45–72. [CrossRef]
25. Schoettle, B.; Sivak, M. A survey of public opinion about autonomous and self-driving vehicles in the US, UK and Australia. University of Michigan, Ann Arbor, Transportation Research Institute: Ann Arbor, MI, USA, 2014; pp. 1–38.
26. Coca-Vila, I. Self-driving Cars in Dilemmatic Situations: An Approach Based on the Theory of Justification in Criminal Law. *Crim. Law Philos.* **2018**, *12*, 59–82. [CrossRef]
27. Butler, L.; Yigitcanlar, T.; Paz, A. Smart urban mobility innovations: A comprehensive review and evaluation. *IEEE Access* **2020**, *8*, 196034–196049. [CrossRef]
28. Raza, M. Autonomous Vehicles: Levels, Technologies, Impacts and Concerns. *Int. J. Appl. Eng. Res.* **2018**, *13*, 12710–12714.
29. Nikitas, A.; Njoya, E.T.; Dani, S. Examining the myths of connected and autonomous vehicles: Analysing the pathway to a driverless mobility paradigm. *Int. J. Automot. Technol. Manag.* **2019**, *19*, 10–30. [CrossRef]
30. Parkinson, S.; Ward, P.; Wilson, K.; Miller, J. Cyber Threats Facing Autonomous and Connected Vehicles: Future Challenges. *IEEE Trans. Intell. Transp. Syst.* **2017**, *18*, 2898–2915. [CrossRef]
31. Kyriakidis, M.; Happee, R.; de Winter, J.C.F. Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transp. Res. Part F Traffic Psychol. Behav.* **2015**, *32*, 127–140. [CrossRef]
32. Fagnant, D.J.; Kockelman, K. Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transp. Res. Part A Policy Pract.* **2015**, *77*, 167–181. [CrossRef]
33. Bichiou, Y.; Rakha, H.A. Developing an Optimal Intersection Control System for Automated Connected Vehicles. *IEEE Trans. Intell. Transp. Syst.* **2019**, *20*, 1908–1916. [CrossRef]
34. Chehri, A.; Mouftah, H.T. Autonomous vehicles in the sustainable cities, the beginning of a green adventure. *Sustain. Cities Soc.* **2019**, *51*, 101751. [CrossRef]
35. Golbabaei, F.; Yigitcanlar, T.; Paz, A.; Bunker, J. Individual predictors of autonomous vehicle public acceptance and intention to use: A systematic review of the literature. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 106. [CrossRef]
36. Whittle, C.; Whitmarsh, L.; Hagger, P.; Morgan, P.; Parkhurst, G. User decision-making in transitions to electrified, autonomous, shared or reduced mobility. *Transp. Res. Part D Transp. Environ.* **2019**, *71*, 302–319. [CrossRef]
37. Bansal, P.; Kockelman, K.M.; Singh, A. Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transp. Res. Part C Emerg. Technol.* **2016**, *67*, 1–14. [CrossRef]
38. Millard-Ball, A. The autonomous vehicle parking problem. *Transp. Policy* **2019**, *75*, 99–108. [CrossRef]
39. Papadoulis, A.; Quddus, M.; Imprialou, M. Evaluating the safety impact of connected and autonomous vehicles on motorways. *Accid. Anal. Prev.* **2019**, *124*, 12–22. [CrossRef] [PubMed]
40. Haboucha, C.J.; Ishaq, R.; Shiftan, Y. User preferences regarding autonomous vehicles. *Transp. Res. Part C Emerg. Technol.* **2017**, *78*, 37–49. [CrossRef]
41. Xu, X.; Fan, C.K. Autonomous vehicles, risk perceptions and insurance demand: An individual survey in China. *Transp. Res. Part A Policy Pract.* **2019**, *124*, 549–556. [CrossRef]
42. Ribeiro, M.A.; Gursoy, D.; Chi, O.H. Customer Acceptance of Autonomous Vehicles in Travel and Tourism. *J. Travel Res.* **2022**, *61*, 620–636. [CrossRef]
43. Wang, S.; Zhao, J. Risk preference and adoption of autonomous vehicles. *Transp. Res. Part A Policy Pract.* **2019**, *126*, 215–229. [CrossRef]
44. Kassens-Noor, E.; Wilson, M.; Yigitcanlar, T. Where Are Autonomous Vehicles Taking Us? *J. Urban Technol.* **2021**, *28*, 1–4. [CrossRef]
45. Anania, E.C.; Rice, S.; Walters, N.W.; Pierce, M.; Winter, S.R.; Milner, M.N. The effects of positive and negative information on consumers' willingness to ride in a driverless vehicle. *Transp. Policy* **2018**, *72*, 218–224. [CrossRef]
46. Threlfall, R. *2020 Autonomous Vehicles Readiness Index*; Kpmg: Swiss, 2022; pp. 1–70.
47. Dennis, S.; Paz, A.; Yigitcanlar, T. Perceptions and Attitudes Towards the Deployment of Autonomous and Connected Vehicles: Insights from Las Vegas, Nevada. *J. Urban Technol.* **2021**, *28*, 75–95. [CrossRef]
48. Engholm, A.; Pernestål, A.; Kristoffersson, I. *System-Level Impacts of Self-Driving Vehicles: Terminology, Impact Frameworks and Existing Literature Syntheses*; Swedish National Road and Transport Research Institute (VTI): Linköping, Sweden, 2018.
49. Chen, B.; Sun, D.; Zhou, J.; Wong, W.; Ding, Z. A future intelligent traffic system with mixed autonomous vehicles and human-driven vehicles. *Inf. Sci.* **2020**, *529*, 59–72. [CrossRef]
50. Butler, L.; Yigitcanlar, T.; Paz, A. How can smart mobility innovations alleviate transportation disadvantage? Assembling a conceptual framework through a systematic review. *Appl. Sci.* **2020**, *10*, 6306. [CrossRef]
51. Lee, S.; Jang, K.M.; Kang, N.; Kim, J.; Oh, M.; Kim, Y. Redesigning urban elements and structures considering autonomous vehicles: Preparing design strategies for wide implementation in cities. *Cities* **2022**, *123*, 103595. [CrossRef]
52. Khan, J.A.; Wang, L.; Jacobs, E.; Talebian, A.; Mishra, S.; Santo, C.A.; Golias, M.; Astorne-Figari, C. Smart cities connected and autonomous vehicles readiness index. In Proceedings of the 2nd ACM/EIGSCC Symposium on Smart Cities and Communities, Portland, OR, USA, 10–12 September 2019. [CrossRef]
53. Kuutti, S.; Fallah, S.; Katsaros, K.; Dianati, M.; Mccullough, F.; Mouzakitis, A. A Survey of the State-of-the-Art Localization Techniques and Their Potentials for Autonomous Vehicle Applications. *IEEE Internet Things J.* **2018**, *5*, 829–846. [CrossRef]

54. Rubin, I.; Baiocchi, A.; Sunyoto, Y.; Turcanu, I. Traffic Management and Networking for Autonomous Vehicular Highway Systems. *Ad. Hoc. Networks* **2019**, *83*, 125–148. [CrossRef]
55. Carreras, X.D.A.; Erhart, J.; Ruehrup, S. Road infrastructure support levels for automated driving. In Proceedings of the 25th ITS World Congress, Copenhagen, Denmark, 17–21 September 2018; p. 12.
56. Butler, L.; Yigitcanlar, T.; Paz, A. Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature. *Cities* **2021**, *109*, 103036. [CrossRef]
57. Zeadally, S.; Hunt, R.; Chen, Y.S.; Irwin, A.; Hassan, A. Vehicular ad hoc networks (VANETS): Status, results, and challenges. *Telecommun. Syst.* **2012**, *50*, 217–241. [CrossRef]
58. López-Lambas, M.E. The socioeconomic impact of the intelligent vehicles: Implementation strategies. In *Intelligent Vehicles: Enabling Technologies and Future Developments*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 437–453. [CrossRef]
59. Schellekens, M. Self-driving cars and the chilling effect of liability law. *Comput. Law Secur. Rev.* **2015**, *31*, 506–517. [CrossRef]
60. Hevelke, A.; Nida-Rümelin, J. Responsibility for Crashes of Autonomous Vehicles: An Ethical Analysis. *Sci. Eng. Ethics* **2015**, *21*, 619–630. [CrossRef] [PubMed]
61. Bagloee, S.A.; Tavana, M.; Asadi, M.; Oliver, T. Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies. *J. Mod. Transp.* **2016**, *24*, 284–303. [CrossRef]
62. Butler, L.; Yigitcanlar, T.; Paz, A. How Can Smart Mobility Bridge the First/Last Mile Gap? Empirical Evidence on Public Attitudes from Australia. *SSRN Electron. J.* **2022**, *104*, 103452. [CrossRef]
63. West, D.M. *Moving Forward: Self-Driving Vehicles in China, Europe, Japan, Korea, and the United States*; Brookings: Washington, DC, USA, 2016.
64. Glancy, D.J. Privacy in Autonomous Vehicles. *St. Clara Law Rev.* **2012**, *52*, 1171.
65. Schoonmaker, J. Proactive privacy for a driverless age. *Inf. Commun. Technol. Law* **2016**, *25*, 96–128. [CrossRef]
66. Ruggeri, K.; Kácha, O.; Menezes, I.G.; Kos, M.; Franklin, M.; Parma, L.; Langdon, P.; Matthews, B.; Miles, J. In with the new? Generational differences shape population technology adoption patterns in the age of self-driving vehicles. *J. Eng. Technol. Manag.-JET-M* **2018**, *50*, 39–44. [CrossRef]
67. de Bruyne, J.; Werbrouck, J. Merging self-driving cars with the law. *Comput. Law Secur. Rev.* **2018**, *34*, 1150–1153. [CrossRef]
68. Yigitcanlar, T.; Degirmenci, K.; Butler, L.; Desouza, K. What are the key factors affecting smart city transformation readiness? Evidence from Australian cities. *Cities* **2022**, *120*, 103434. [CrossRef]
69. Villagra, J.; Acosta, L.; Artuñedo, A.; Blanco, R.; Clavijo, M.; Fernández, C.; Godoy, J.; Haber, R.; Jiménez, F.; Martínez, C.; et al. *Automated Driving*; Elsevier Inc.: Amsterdam, The Netherlands, 2017. [CrossRef]
70. Nematpour, M.; Faraji, A. Structural analysis of the tourism impacts in the form of future study in developing countries (case study: Iran). *J. Tour. Futures* **2019**, *5*, 259–282. [CrossRef]
71. Godet, M.; Durance, P.; Gerber, A. Strategic Foresight La Prospective Use and Misuse of Scenario Building. *Circ. Future Entrep.* **2013**, *65*, 421.
72. Soltani, A.; Pojani, D.; Askari, S.; Masoumi, H.E. Socio-demographic and built environment determinants of car use among older adults in Iran. *J. Transp. Geogr.* **2018**, *68*, 109–117. [CrossRef]
73. Handcock, M.S.; Gile, K.J. Comment: On the concept of snowball sampling. *Sociol. Methodol.* **2011**, *41*, 367–371. [CrossRef] [PubMed]
74. Habibi, A.; Jahantigh, F.F.; Sarafrazi, A. Fuzzy Delphi Technique for Forecasting and Screening Items. *Asian J. Econ. Bus. Manag.* **2015**, *5*, 130. [CrossRef]
75. Delgado-Serrano, M.d.; Vanwildemeersch, P.; London, S.; Ortiz-Guerrero, C.E.; Semerena, R.E.; Rojas, M. Adapting prospective structural analysis to strengthen sustainable management and capacity building in community-based natural resource management contexts. *Ecol. Soc.* **2016**, *21*, 36. [CrossRef]
76. Zali, N.; Zamanipoor, M.; Ahmadi, H.; Karami, M. Analysis of key factors influencing air pollution of metropolises in developing countries by year 2025 (case study: Tehran metropolis, Iran). *Anu. Do Inst. De Geocienc.* **2018**, *41*, 548–559. [CrossRef]
77. Hua, J.; Huang, M.L.; Huang, W.; Zhao, C. Applying graph centrality metrics in visual analytics of scientific standard datasets. *Symmetry* **2019**, *11*, 30. [CrossRef]
78. Lim, H.S.M.; Taeihagh, A. Autonomous vehicles for smart and sustainable cities: An in-depth exploration of privacy and cybersecurity implications. *Energies* **2018**, *11*, 1062. [CrossRef]
79. Talebian, A.; Mishra, S. Predicting the adoption of connected autonomous vehicles: A new approach based on the theory of diffusion of innovations. *Transp. Res. Part C Emerg. Technol.* **2018**, *95*, 363–380. [CrossRef]
80. Soltani, A.; Ananda, D.; Rith, M. University students' perspectives on autonomous vehicle adoption: Adelaide case study. *Case Stud. Transp. Policy* **2021**, *9*, 1956–1964. [CrossRef]
81. Yigitcanlar, T.; Bulu, M. Dubaization of Istanbul: Insights from the knowledge-based urban development journey of an emerging local economy. *Environ. Plan. A* **2015**, *47*, 89–107. [CrossRef]
82. Yigitcanlar, T.; Sabatini-Marques, J.; da-Costa, E.; Kamruzzaman, M.; Ioppolo, G. Stimulating technological innovation through incentives: Perceptions of Australian and Brazilian firms. *Technol. Forecast. Soc. Chang.* **2019**, *146*, 403–412. [CrossRef]
83. Etminani-Ghasrodashti, R.; Patel, R.; Kermanshachi, S.; Rosenberger, J.; Weinreich, D.; Foss, A. Integration of shared autonomous vehicles (SAVs) into existing transportation services: A focus group study. *Transp. Res. Interdiscip. Perspect.* **2021**, *12*, 100481. [CrossRef]

84. Panahi, N.; Pourjafar, M.R.; Ranjbar, E.; Soltani, A. Examining older adults' attitudes towards different mobility modes in Iran. *J. Transp. Health* **2022**, *26*, 101413. [CrossRef]
85. Miller, K.; Chng, S.; Cheah, L. Understanding acceptance of shared autonomous vehicles among people with different mobility and communication needs. *Travel Behav. Soc.* **2022**, *29*, 200–210. [CrossRef]